STRUCTURAL RELATIONS BETWEEN THE SHUSWAP AND "CACHE CREEK" COMPLEXES NEAR KALAMALKA LAKE, SOUTHERN BRITISH COLUMBIA

by

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ABSTRACT

Five phases of deformation are recognized in Shuswap metamorphics south of Vernon, British Columbia. Phase 1 and 2 deformations are isoclinal gently dipping folds which trend N and ESE respectively. Some thermal activity may have occurred prior to phase 2 deformation but metamorphism culminated in the amphibolite facies during and following phase 2. Metamorphism waned prior to the development of NE trending phase 3, folds of which are angular and moderately tight with one steep and one shallowly dipping limb. Phase 4 and 5 deformations trend NE and N respectively, and comprise open upright buckle folds and fractures which are contemporaneous with abundant hydrothermal alteration. The 42 $\pm$ 10 m.y. B.P. Sr/Rb whole rock age date secured from a phase 2 sill probably represents thermal upgrading.

Low metamorphic grade "Cache Creek" metasediments west of Vernon have undergone 4 recognized deformational phases. Phase 1 folds are tight, steeply dipping, and trend WNW. Phase 2 comprises E trending, angular mesoscopic folds. Phase 3 and 4 comprise NE and N trending fracture sets. A large amphibolite sill defines the "Cache Creek" albite-epidote-amphibolite facies metamorphic culmination. Metamorphic hornblendes from the amphibolite yield a 178 $\pm$ 6 m.y. B.P. age date, using the K/Ar method. Hydrothermal activity occurred in association with phase 3 and 4 deformations.

The final four phases of Shuswap deformation appear to correlate with respective "Cache Creek" phases, based on structural similarities. This suggests that the two complexes may be, at least in part, structural equivalents.

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1. INTRODUCTION

General Introduction

The Shuswap Metamorphic Complex, which comprises the southern core of the Eastern Cordillera Fold Belt (Campbell, 1973) consists of schists, gneisses, and associated intrusives which have undergone a complex deformational history (figure 1-1). Highly deformed rocks of the Kootenay Arc border the Shuswap Terrain to the east. Highly deformed although generally much lower grade metasediments and volcanics of the Intermontane Zone border the Shuswap Terrain to the west. Numerous workers have mapped both the Shuswap Complex and the Intermontane Zone on a variety of scales. Although still incomplete, a unified structural history across the Shuswap Complex is being synthesized from detailed studies at several locations. The structural history of the Intermontane Zone remains less clear and major stratigraphic revisions have recently been introduced (Okulitch and Cameron, 1976; Monger, 1975). The important question of the structural relationships between the Shuswap and bordering Intermontone rocks remains unsolved. A brief outline of previous work in these areas serves to illustrate the possibilities and complexities involved.

Dawson (1898) first mapped the rocks in the Vernon area, south of Shuswap Lake, introduced the name "Shuswap Series" for the deformed metamorphics, and assigned them a Precambrian age. Daly (1912, p.168) accepted the use of Dawson's terminology and the probability of an ancient origin of the Shuswap metamorphics. He felt that Shuswap rocks had undergone "static load metamorphism" due to very deep burial. Work by Brock (1934) on Shuswap gneisses near Okanagan Lake, however, indicated that plutonic intrusions caused doming and attendant mineral lineations

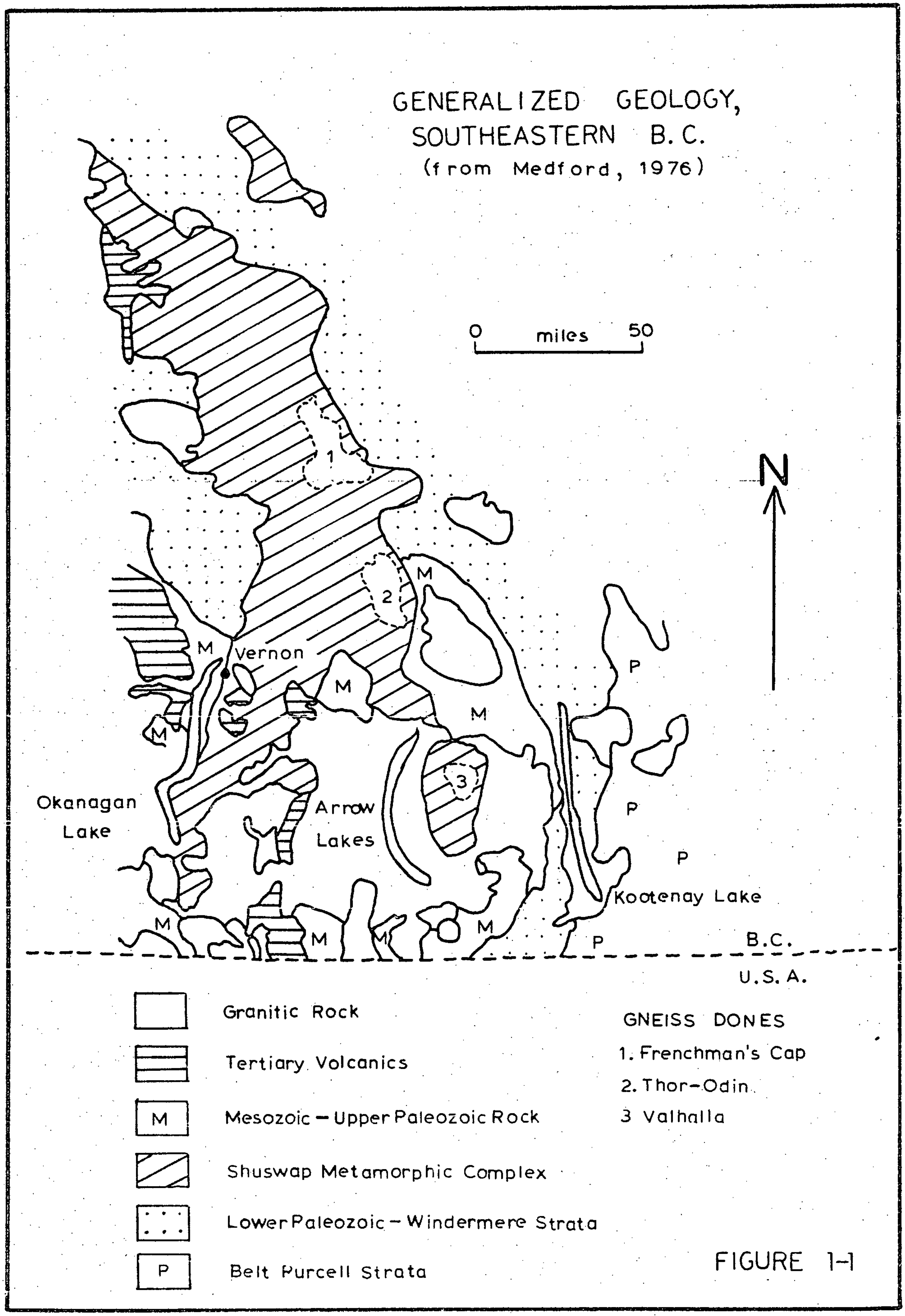

GENERALIZED GEOLOGY,
SOUTHEASTERN B.C.
(from Medford, 1976)
0 miles 50
N
1
2
3
M
Vernon
Okanagan Lake
Arrow Lakes
Kootenay Lake
P
B.C.
U.S.A.
Granitic Rock
Tertiary Volcanics
Mesozoic – Upper Paleozoic Rock
Shuswap Metamorphic Complex
Lower Paleozoic – Windermere Strata
Belt Purcell Strata
GNEISS DONES
1. Frenchman's Cap
2. Thor-Odin
3 Valhalla

FIGURE 1-1

of the gneisses and related sills. He thus interpreted Shuswap metamorphism as dynamic rather than static in nature. Gilluly (1934) further substantiated this dynamic metomorphic hypothesis by petrofabric analysis of Daly's deformed samples. Following extensive more recent detailed work it is now generally accepted that Shuswap rocks have undergone several episodes of regional dynamo-thermal metamorphism and deformation (Christie, 1973; Ross, 1973; Ryan, 1973; Medford, 1976).

Cairnes (1939) felt the Shuswap Complex to be rocks of several ages ranging from Precambrian to Triassic which all experienced common thermal metamorphism due to extensive Mesozoic plutonism. Cairnes also noted that meta-sediments and volcanics of the Cache Creek Complex (Dawson, op.cit.) appeared to be similarly deformed and metamorphosed though at a lower grade and that Shuswap - Cache Creek contacts were generally gradational on a small scale. The controvery between Dawson's Precambrian and Cairnes multiple age of Shuswap sediments hypotheses has yet to be completely resolved.

Continuing work begun in 1945 by Rice; Jones (1959) compiled the definitive summary of geology of the Vernon area on a scale of one inch to four miles in the Geological Survey of Canada Memoir 296 and accompanying map sheet. Jones considered Shuswap rocks to be possibly of Precambrian age and separable into three major stratigraphic groups: The Monashee Group, 50,000 feet thickness, of dominantly high grade schists and gneisses; overlain by the Mount Ida Group, 60,000 feet thickness, composed of low grade meta-sediments and volcanics; capped by the Chapperon Group, about 5,000 feet thickness, of low grade argillites, schists, limestones and quartzites. He noted marked stratigraphic similarities between the Mount Ida and Chapperon Groups. Jones (1959) believed the Shuswap Complex to be unconformably overlain by Permian Cache Creek rocks which consist of argillites, greenstone and limestone. He indicated five possible localities where the upper Shuswap unconformity with overlying Cache Creek rocks is observable. Preto (1964) mapped three of the suggested unconformities at Salmon River, Keefer Gulch and B.X. Creek. He concluded that although the Keefer Gulch and B.X. Creek contacts were probably along faults, there was strong evidence for an angular unconformity at Salmon River. The structural relations between the two lithologies, however, have not been clearly established.

Preto (1967) later correlated Late Precambrian - Early Paleozoic rocks to the east with Shuswap metamorphics, concluding that Shuswap rocks had undergone deformation and attendant metamorphism in Jurrasic time. Other attempts have been made at correlating high grade Shuswap Rocks with surrounding and included lower grade metasediments. Hyndman (1968) attempted to correlate structures between Triassic Slocan Group rocks east of the Shuswap Terrains and higher grade Shuswap rocks. He contended that all major deformation occurred in Tertiary time. Ross (1968, 1970) suggested correlating early phases of deformation in Shuswap rocks with deformation in low grade metasediments near Revelstoke, concluding that some Shuswap deformation occurred during the Paleozoic.

After studying the Thor-Odin gneiss dome which comprises one of the structural culminations of the Omenica Geanticline, Reesor (1970, p.73) concludes:

"...the locus of the gneiss domes is not determined by superposed large scale folds." and "Deformation and metamorphism...is post Mississippian and possibly post Triassic".

Although regional styles and absolute ages of deformation in the Shuswap Complex remain in contention, it is now clear that activity occurred in pre-Mesozoic time. Correlation of structural and metamorphic events in high grade Shuswap rocks has been greatly improved recently due to the combined efforts of several detailed studies: Ross and Christie (1969), Christie (1973), Ross (1973), and Ryan (1973).

Similarly deformed low grade metasediments in northern Washington were mapped by Waters and Krauskopf (1941) and Little (1961). Termed the Anarchist Group after Daly (1912), they were tentatively assigned a Permian age from fossil correlation. Another group of low grade metasediments, termed the Kobau Group by Bostock (1940), was investigated by Okulitch (1970) and assigned a pre-Cretaceous, likely post-Devonian age. Barnes and Ross (1975), however, suggest tectonic emplacement at a later time. In later papers Okulitch (1973) and Okulitch and Cameron (1976) discuss correlation of the Kobau Group with the Anarchist Group, the Chapperon Group west of Vernon, the Mount Ida Group, the Nicola Group, and the Cache Creek Group. These eugeosynclinal, low grade metasedimentary and volcanic assemblages, show important stratigraphic and structural relationships and in a review paper Monger (1975) suggests a unifying classification. He separates the Cache Creek Group into two fundamentally different rock types: The Cache Creek of the Atlin, Terrace, Stuart Lake and Type localities, and the rock type near Kamloops, which correlates stratigraphically with Chapperon, Anarchist, Kobau and Chilliwack metasediments. The former group is characterized by basaltic to rhyolitic volcanics, abundant pyroclastics and volcanic sandstone, carbonate and pelite. The latter group comprises banded chert, pelite, carbonate, basic volcanic rocks and associated gabbro and alpine type ultramafics.

General Geology

Medium to high grade rocks of the Shuswap Complex have undergone a complex sequence of polyphase deformation and metamorphic events. At least the relative sequence and in some instances the absolute ages of these events have been established. Surrounding and included low grade metasediments and volcanics of the Cache Creek Group have also undergone a complex deformational history. The structural and metamorphic relationships between these high and low grade rocks has not been established. The author has mapped an area of approximately twenty square miles near Vernon, British Columbia, on a scale of four inches to one mile, in an endeavour to establish structural relations between these two complexes.

Northerly trending Kalamalka Lake separates the two major rock types (figure 1-2, plate A). To the east medium to high grade metamorphosed sediments have undergone five recognizable phases of deformation. Gneisses, quartzites and schists comprise the four mapable layered units, which contain numerous early granitic dikes and sills. A late discordant diabase dike intrudes the layered rocks and the area is capped in places with Tertiary volcanics and associated volcanic conglomerates.

West and north of Kalamalka Lake siltstones, sandstones, limestone pods and minor chert of the Cache Creek Group have undergone low grade metamorphism, have been involved in three or possibly four deformational phases, and contain a large concordant amphibolite intrusion. Intruding Cache Creek sediments to the south are massive, highly weathered, monzonitic to granitic intrusives. Tertiary andesitic volcanics cap the other units at various places.

The map area location, illustrated in figure 1-3, is on the eastern flank of the south-central Okanagan Valley, about 320 miles east of

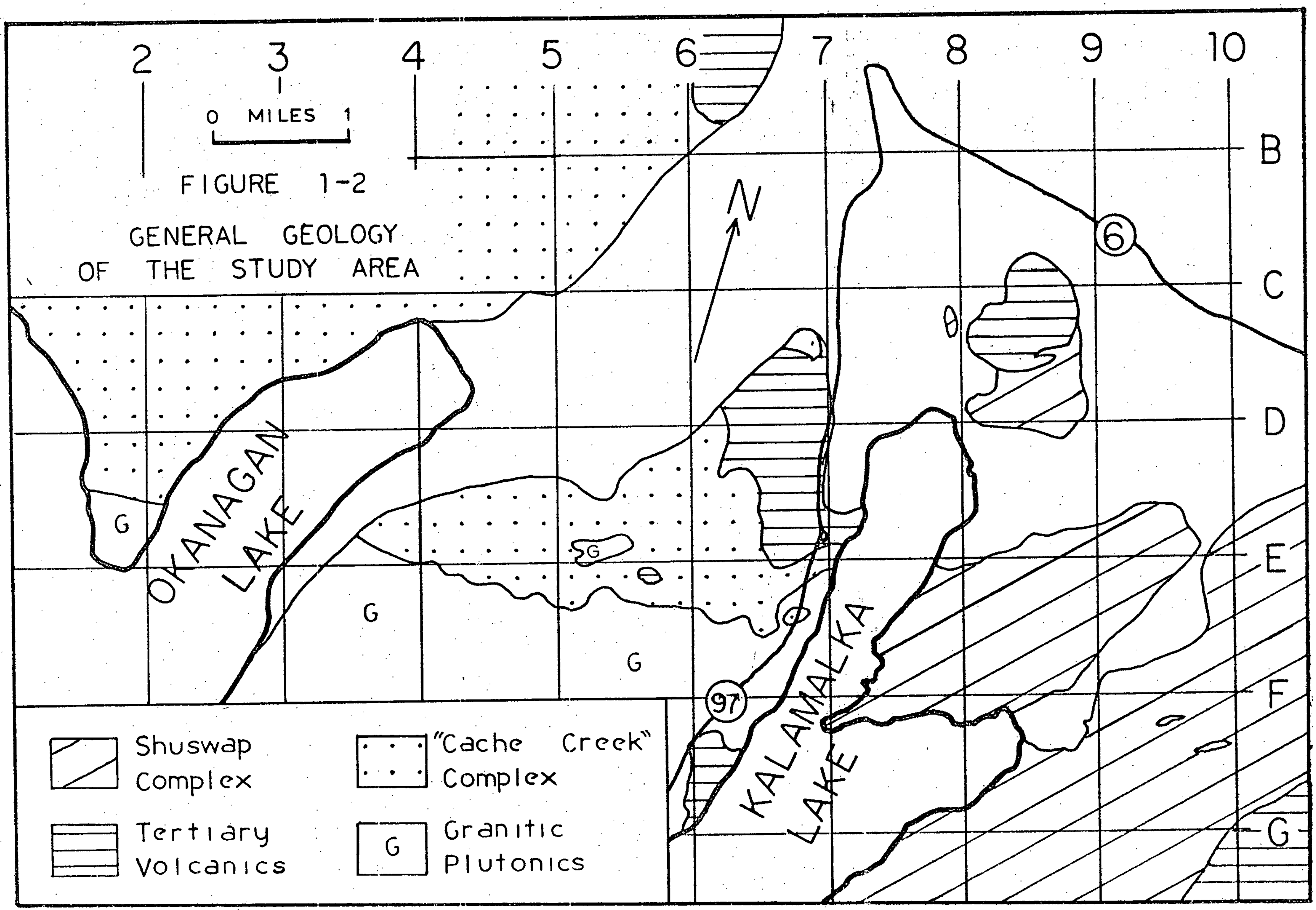


FIGURE 1-2
GENERAL GEOLOGY OF THE STUDY AREA
0 MILES 1
N
2
3
4
5
6
7
8
9
10
B
C
D
E
F
G
OKANAGAN LAKE
KALAMALKA LAKE
6
97
G
Shuswap Complex
"Cache Creek" Complex
Tertiary Volcanics
Granitic Plutonics

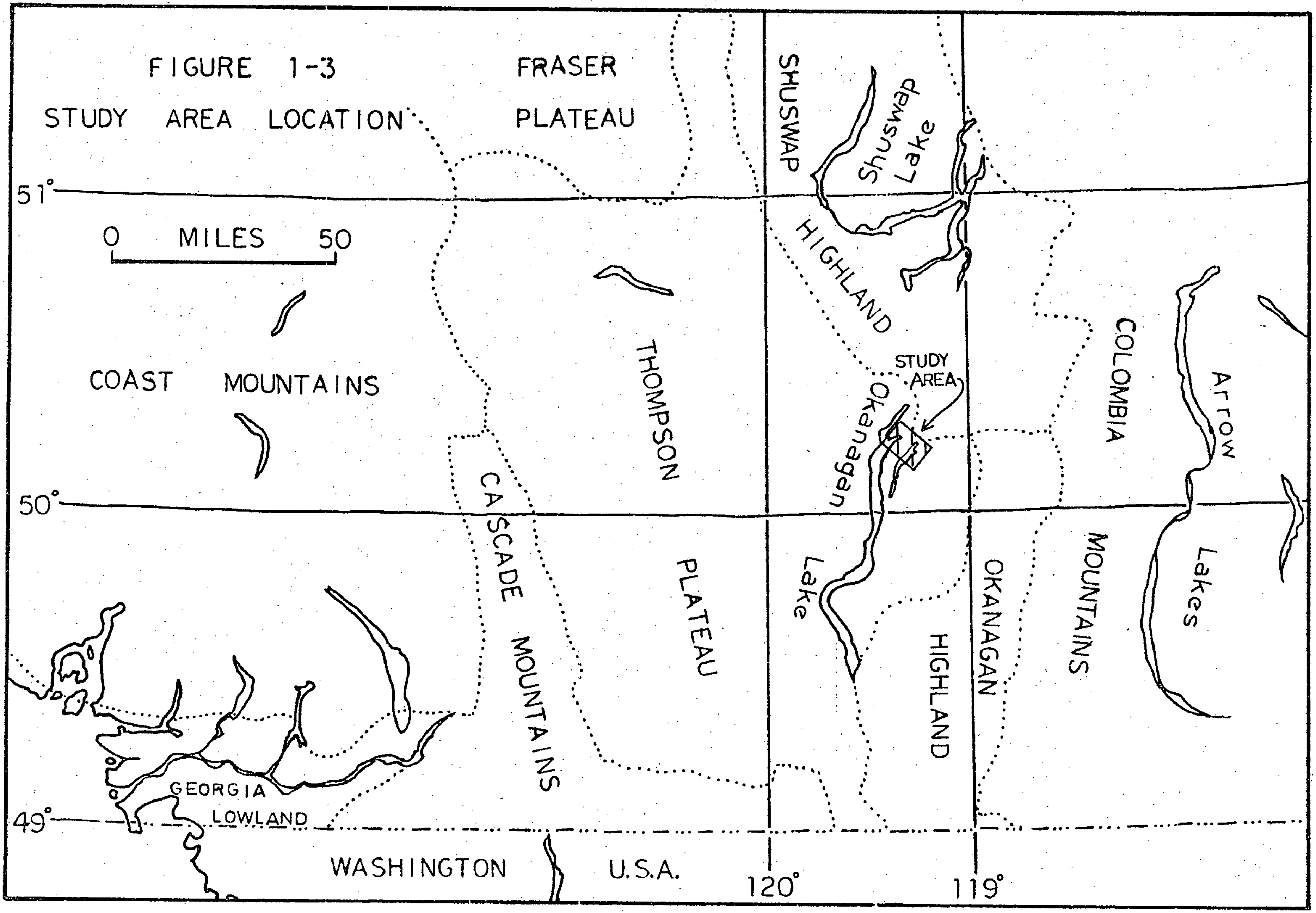
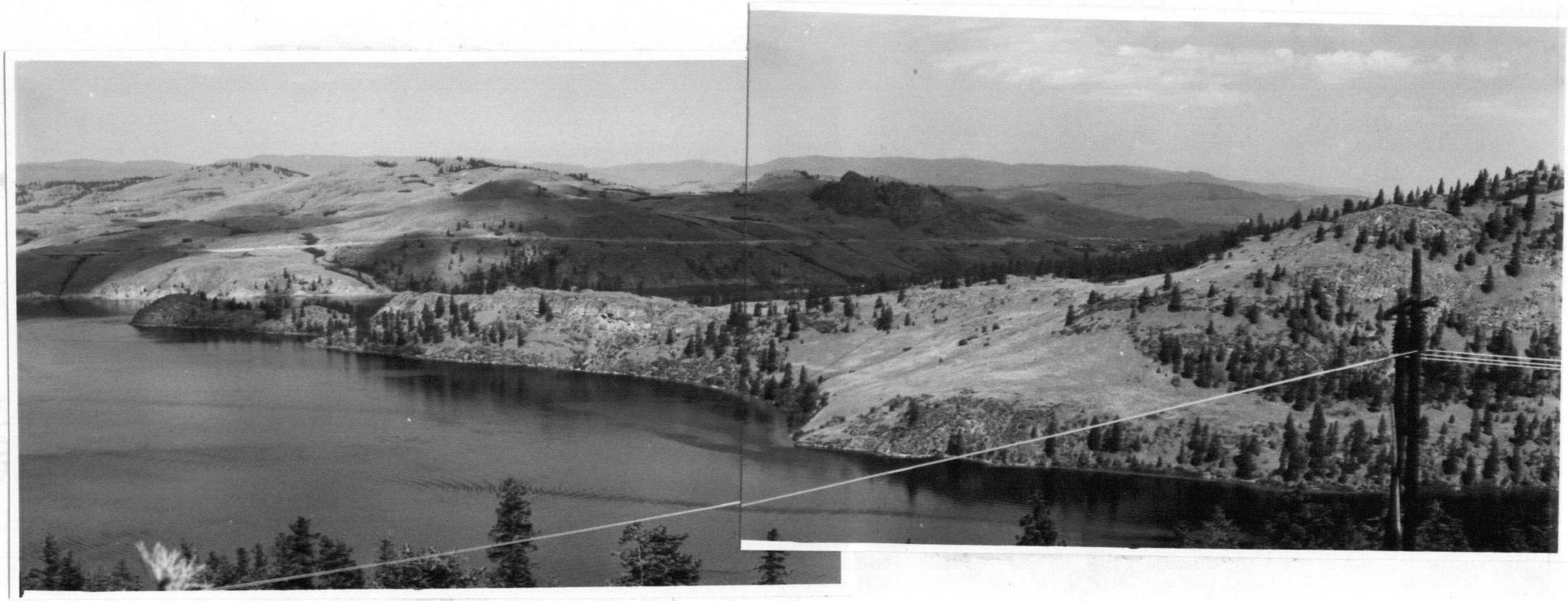


FIGURE 1-3
STUDY AREA LOCATION

Vancouver. It is crossed by British Columbia highways Six and Ninety-Seven and lies immediately south and west of Vernon around the northern end of Kalamalka Lake. The area mapped lies between latitudes 50°15' and 50°20' and longitude 119°15' and 119°30'.

The area is located in the Interior Plateau at the south-west boundary of the Shuswap Highland and Thompson Plateau. The topography was produced by Pliocene dissection of the Tertiary erosion surface (Holland, 1964). Relief is generally moderate, not greater than approximately 3,000 feet. Some rather large glacially carved scarps occur providing excellent exposures. The best example of these, south facing cliffs to the north of Cozens Bay, Kalamalka Lake, are shown in figure 1-4.



1-4 Panoramic view of the area of study, facing north. Foreground is Shuswap Terrain; eastern background is "Cache Creek" Group; western background is quartz monzonite intrusives.

2. STRATIGRAPHY

Jones (1959) mapped high grade metamorphic rocks to the southeast of Vernon as the Monashee Group of the Shuswap Complex. Although he found no recognizable marker horizons he estimated the total thickness of the group to be greater than the 50,000 foot section accoss Mount Thor in the Gold Range,50 miles to the east of Vernon. As noted previously, Jones (1959) considered the Shuswap rocks in the Vernon area to be uncomformably overlain by Cache Creek Group metasedimends. These he subdivided into three units (Jones, 1959, p.g. 39):

"The lowermost unit (Division A) is about 8,000 feet thick and is predominantly argillite; the middle unit (Division B) is about 8,000 feet thick and consists of andesitic lava, tuff, argillite, quartzite, and limestone; the upper unit (Division C) is at least 10,000 feet thick and consists of limestone, quartzite, argillite, and volcanic rock. A rough estimate of the minimum thickness of the whole group is 25,000 feet."

Recent work (Monger, 1975; Danner, personal communication) indicates that these low grade metasediments do not correlate with the Cache Creek Group of the type locality, therefore the present author will refer to the assemblage as the "Cache Creek" Group for the remainder of this study. The generalized distribution or rock units in the thesis area is shown in figure 1-2.

No evidence for stratigraphic base, top, or correlations with other sections was found in Shuswap rocks of the thesis area. Layered units I through IV comprise a structural succession ranging from 500 to 1,300 feet in total present thickness. Unit thicknesses are derived from the cross sections in plate C.

Unit I consists of banded hornblende gneiss and although it attains the maximum thickness of the succession, 600 feet, it is at one location tectonically eliminated.

Unit II is a granular hornblende-biotite gneiss which attains a maximum thickness of 250 feet.

Unit III is a distinctively rusty weathering well foliated biotite schist which varies from 20 to 300 feet in thickness.

Unit IV, although the thinnest unit of the succession with a maximum 150 foot thickness, is the most distinctive, consisting of light buff to white calcareous quartzite. It outlines the geometry of the areas major phase 2 synform.

All of these layered units were intruded by a series of granitic dikes and sills, comprising unit V, prior to phase 3 deformation. The quartz monzonite sill at location F-8, figure 1-2, was dated at 42$\pm$ 10 m.y. by the Sr/Rb whole rock method, appendix 1.

"Cache Creek" rocks of the thesis area,which are composed of sandstone, siltstone and limestone, attain a maximum overall present thickness of 9,000 feet. Limited evidence of graded bedding in lithic arenites implies that the sequence increases in age to the north. Lithologic repetitions and dip variations indicate possible large scale folding but no megascopic folds were observed in the field. Cross sections of "Cache Creek" units are shown in plate C.

North of Kalamalka Lake and west of Vernon "Cache Creek" metasediments, comprising unit VI, consist of limestone, siltstone and minor volcanics. These dip steeply southward and attain a maximum present thickness of 3,000 feet. South of Vernon and west of Kalamalka Lake is unit VII which also dips steeply southward. It comprises two subunits: (a) siltstone, overlain by (b) an immature lithic arenite containing minor chert bands. The subunits occur in bands of roughly similar thickness ranging from 600 to 1,500 feet, and the overall unit thickness, assuming stratigraphic not tectonic repetition, is at most 6,000 feet. Included in unit VI are numerous limestone pods which reach one half mile in length.

A large amphibolite sill, unit VIII, forms the contact between "Cache Creek" units VI and VII north of the Vernon Arm of Okanagon Lake. It was dated by the K/Ar method at 178$\pm$ 6 m.y., appendix 1.

The largest plutonic body in the area, a foliated granodiorite - quartz monzonite, unit IX, forms an igneous contact with the southernmost "Cache Creek" rocks. The contact lies roughly parallel to the strike of "Cache Creek" bedding.

Finally, the entire map area has been involved in abundant Tertiary igneous activity, rocks of which comprise unit X. Andesitic volcanics cover parts of all underlying groups and related dikes intrude Shuswap rocks; one isolated outcrop of volcanic breccia caps underlying volcanics just south of Vernon.

Petrographic descriptions of individual rock units comprise the remainder of this chapter. Optically estimated, representative modes are listed in figure 2-1.

Unit I - Hornblende Gneiss

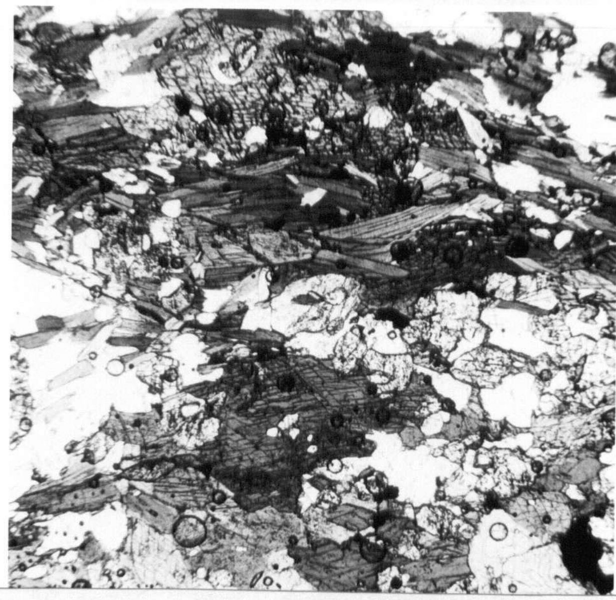
This unit comprises medium to coarse grained beige to dark brown banded hornblende gneiss. It exhibits distinctive banding on a scale of two to six inches produced by varying proportions of hornblende (figure 2-2), and fractures into equant blocks. It is composed of quartz, plagioclase (An 31), major hornblende and minor biotite. Hornblende generally dominates over quartz. Sphene and epidote are common accessories. Hornblendes are fractured but define a strong lineation contained

Figure 2-1

PETROGRAPHIC MODES

Station	Locat.	Unit	Qz	Pl	An	Or	Hb	Bi	Gar	Chl	Di	Opq	Ca	Other
73	D-9	I	15	10	37	10	55	5		3		1		ep 2
7	F-9	I	35	25	26	10	20	2		2		1		sph 5
79	F-8	I	10	15		15	45	8		5		2		
B-13	E-10	Ia	70	10				1	5		10	1		sph 3
2	F-7	II	24	34	36	23	8	8		.5		2		ap 5
9	F-9	III	70	5	29	5		10			5	3		ep 1; sph 1; cumm Tr
17	F-10	III	53	25	26	15		10			1	2		ep 1; sph 1, mus 1
5	G-7	IV	40	10	30						45		1	sca 2; ep 1; sph 1
56	G-7	IV	66	5	32	5			1		13	1	7	ep 1
10	F-9	IV	67	5							25		2	sph 1; ep 1, sca 1
22	F-9	IV	40	15	40	25					15		5	sca Tr
22k	F-9	IV	45						1	Tr	15		35	sph 3; ep 1
60	F-8	IV	61	5	36	5			1		20	2	4	ep 1; sca 1
16	F-9	V	75	15	32	5		2		3				
C-38	F-10	V	15	25		40				5		5		ep 10
64	F-8	V	30	25	31	30	3	10				1		sph 1
10s	F-9	Hb sill	5	5	27	5	80	5						ap 5; ep 5
C-146	C-5	VI	1									1	98	
C-51	E-6	VII	10	20		1?						1	8	rx frags 30; matrix 30
24	E-5	VII	55					25		4		3	5	mus 10; lim 2
23	E-7	VII	88							10		2		
C-46	E-5	VII	8	18	5							2	60	hem 2
C-139	C-4	VIII	1?	1	7		55			3	Tr	4		ep 10; zo 23, sph Tr
C-140	C-4	VIII					50			5		1		ep 10; zo 34
34	F-4	IX	20	30	37	30		10				1	4	ep 4; sph 1
49	F-8	X		11	37		5	3				3		g.m. 73
18	D-7	X		40	36							2	3	glass 50, zeo Tr

2-2 Tight phase 3 folds in banded hornblende gneiss, unit I.



2-3 Photomicrograph showing roughly equal proportions of biotite and hornblende in unit II. Plane polarized light. Field of view is 3.2 m.m. across.

in the phase 2 metamorphic foliation plane. Quartz exhibits a high degree of recrystalization and polygonization tending toward mortar texture. The texture in thin section is nematoblastic.

Unit Ia - Quartzite

A diagnostic feature of unit I is the common occurrence of discontinuous but mappable diopsidic quartzite lenses. The quartzite is fine grained, olive green to beige, nonfissile and highly fractured. In outcrops it is structureless and often appears aphanitic. Compositionally it is very quartz rich with minor plagioclase (An 25), diopside, and possible grossularite garnet, biotite, and sphene. It does not contain calcite. The texture is equigranular granoblastic.

Unit II - Hornblende - Biotite Gneiss

This unit is fine to medium grained brown feldspathic hornblende - biotite gneiss. Granular even grained texture and lack of pronounced banding differentiate it from units I and III in the field. It contains essential quartz, plagioclase (An 36), orthoclase, and roughly equal amounts of hornblende and biotite though never over twenty percent total mafics. Quartz is generally equant, undulose, and partly recrystalized. Feldspars are commonly fractured. Both hornblende and crenulated biotite outline a poorly developed lineation. A photomicrograph of Unit II is shown in figure 2-3.

Unit III - Biotite Schist

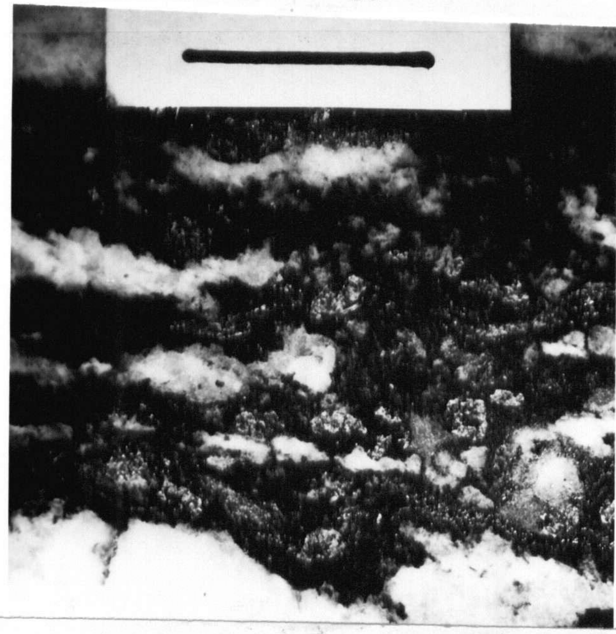
This unit comprises medium grained beige to brown rusty weathering well foliated biotite schist. It is composed of abundant quartz, orthoclase, plagioclase (An 30), biotite and minor almandine garnet. Diopside and cummingtonite occur sporadically and sphene and epidote are common accessories. Texture varies from lepidoblastic to granoblastic depending on quartz content.

Grain boundaries tend toward 120 degrees. Biotite lies in the foliation plane. Quartz exhibits undulatory extinction but only a low degree of preferred orientation due to large grain size and generally equant shape. The appearance of unit III is illustrated in figures 2-4 and 2-5.

At several localities concordant hornblende sills are enclosed in the biotite schist. They are coarse grained, dark green to black and consist chiefly of vaguely aligned hornblende with minor biotite and quartz. Hornblende is highly fractured. Contacts with the surrounding schist are sharp.

Unit IV - Calcareous Quartzite

This unit is fine to medium grained buff to blue-gray, lineated, foliated, and contains essential calcite. It weathers to a pitted surface permitting accurate measurements of elongate minerals. In the cores of recumbent phase 2 folds one often finds segregations containing up to 50 percent diopside. This unit outlines the highly conspicuous nearly three mile long phase 2 fold in the southeast portion of the map area, location F-8. It is composed of at least 50 percent quartz, plagioclase (An 36), calcite, dipside, and accessory scapolite, sphene and epidote. Quartz tends to form undulatory ribbon grains subparallel to compositional layering. Feldspar and diopside are fractured and similarly aligned although not nearly as recrystalized. Notably,



2-4 Prominent garnets lie in biotite matrix of biotite schist, unit III. Scale bar = 1 c.m.

2-5 Photomicrograph of unit III. Strong biotite alignment in phase 2 foliation plane. Plane polarized light. Field of view is 3.2 m.m. across.

calcite is everywhere fine grained. Figure 2-6 is a photomicrograph of Unit IV. Texture in thin section is granoblastic to poorly developed nematoblastic.

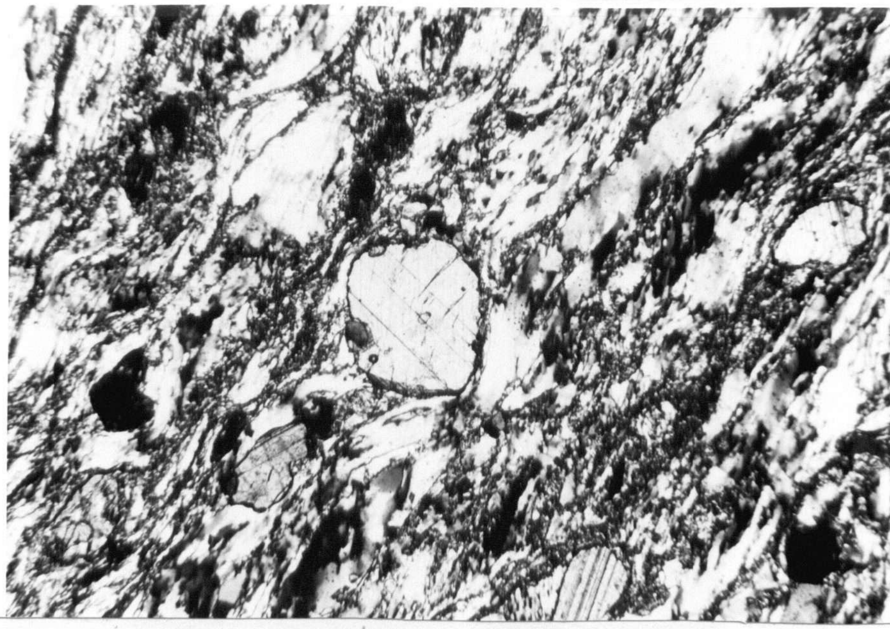
Unit V - Granitic Dikes and Sills

A large number of light colored dikes and sills ranging compositionally from granodiorite to quartz monzonite intrude layered units I through IV. Although no chilled margins were identified contacts with intruded units are sharp down to a scale of a few millimeters, suggesting an intrusive origin. Structural evidence, chapter 3, indicates that intrusion predated phase 3 deformation.

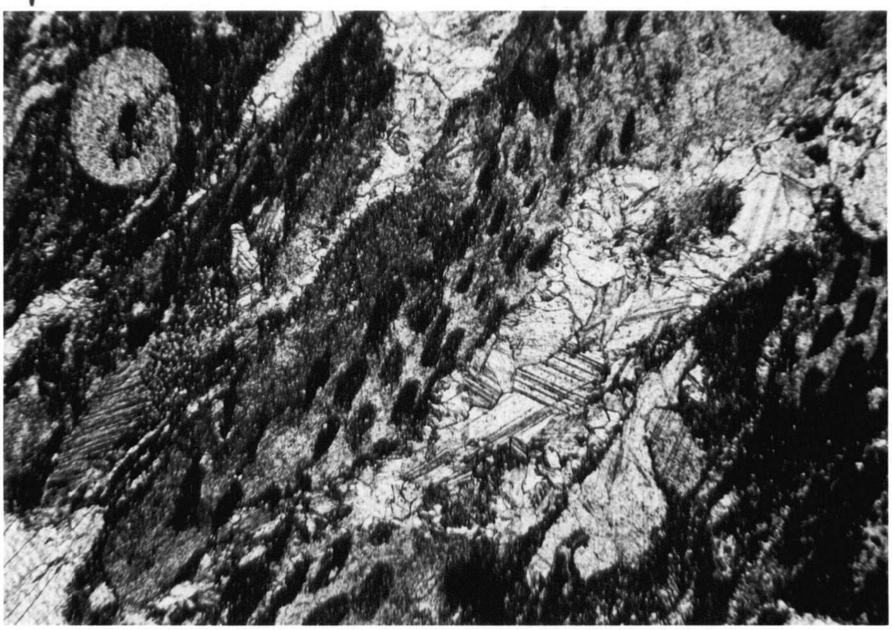
Petrographically, unit V is medium to coarse grained hypidiomorphic to porphyritic with an average monzonitic composition. Commonly myrmekitic orthoclase predominates over normally zoned plagioclase (An 26-34), major quartz and minor biotite. Quartz exhibits undulatory extinction and both quartz and feldspars are highly fractured. Biotite is extensively chloritized. The only intrusive large enough to be shown on plate A exhibits a biotite alignment foliation parallel to surrounding phase 2 metamorphic foliation. It was dated by the Sr/Rb whole rock method at 42 $\pm$ 10 m.y., appendix 1.

Unit VI - Limestone and Siltstone

West of Vernon and north of Kalamalka Lake massive limestone pods are imbedded in a siltstone matrix. Although limestone appears to dominate over matrix, a difficult sampling problem exists due to the massive limestones relative resistance to weathering. This is especially true north of Kalamalka Lake where exposures are generally poor, often completely obscuring the less resistant siltstone.



2-6 Unit IV. Calcareous quartzite. Fine grained granular calcite and undulatory quartz envelope diopside porphyroblasts. Cross polarized light. Field of view is 2.3 m.m. across.



2-7 Crinoid stem and bryozoa in limestone pod of unit VII. Plane polarized light. Field of view is 4.6 m.m. across.

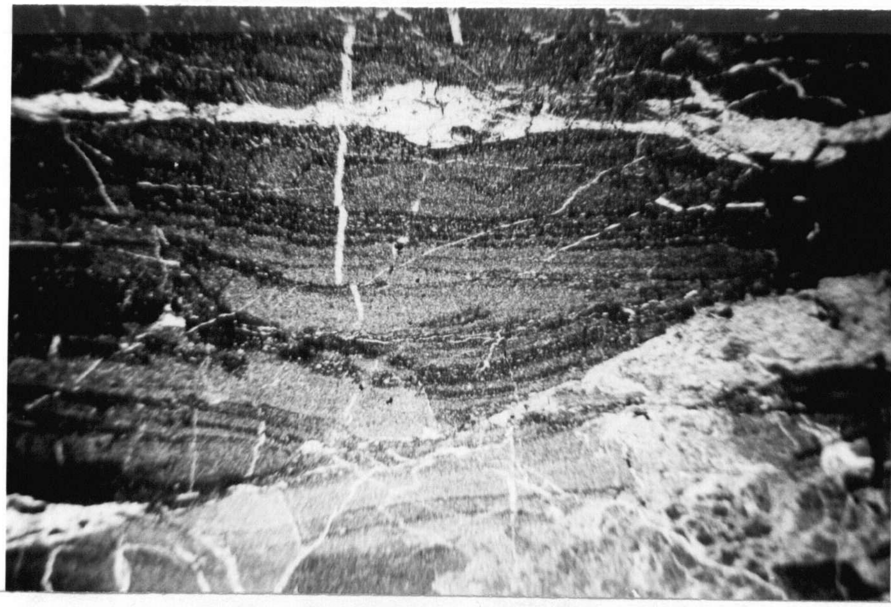
The limestone is medium to fine grained, light to dark gray, massive weathering with bedding only recognizable as poorly defined parting planes and planar fossil hash segregations. In thin section the limestone is seen to be a recrystalized biomicrite composed almost entirely of calcite. The siltstone matrix is described in detail as unit VIIa below.

Unit VII - Sandstone and Siltstone

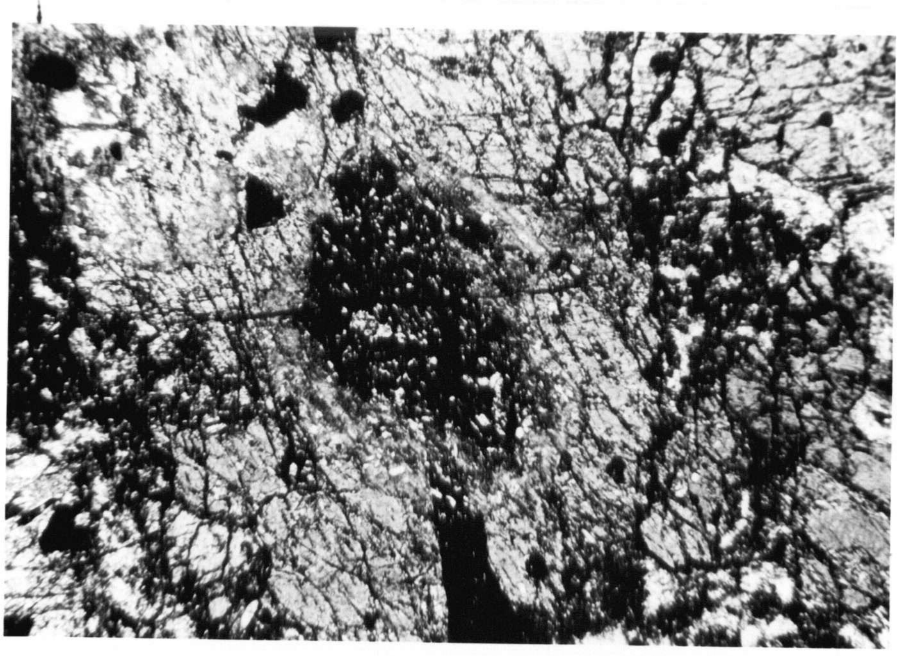
West of Kalamalka Lake a repeated sequence of immature lithic arenite and siltstone contains limestone pods. The limestone appears mineralogically identical, both in field and detailed study, with that of unit VI; but contains fairly well preserved crinoid stems, bryozoa, and rare enchinoids, figure 2-7. As the siltstone and sandstone are separable in the field, they are described separately as units VIIa and VIIb.

Unit VIIa - Siltstone

In hand specimen unit VIIa is dark gray, aphanitic, and highly fractured into small equant blocks. Stratification is convoluted, broken, and discontinuous on a very small scale, see figure 2-8. This unit could be genetically classified as a siltstone pseudoconglomerate (Pettijohn, 1957, p.190). In thin section the unit is extremely fine grained with a maximum grain size of ten microns and is composed of angular, poorly sorted quartz grains, biotite, calcite, white mica, and chlorite.



2-8 Convoluted and microfaulted stratification in siltstone, unit VIIa. Cross polarized light. Field of view is 4.6 m.m. across.



2-9 Clinopyroxene (at extinction) cores complexely zoned hornblende of unit VIII. Cross polarized light. Field of view is 4.6 m.m. across.

Unit VIIb - Lithic Arenite

In the field unit VIIb is dark gray-green fine grained and highly fractured with prominent calcite fracture fillings. Limited evidence of graded bedding in the field implies that age increases to the north. In thin section the rock consists of poorly sorted, slightly rounded, angular lithic fragments of albite and rutilated quartz, possible volcanic shards, and calcite fragments floating in a micro crystaline ground mass. The largest grain size recognized is 0.2 millimeters. Quartz vein filling exhibits undulatory extinction. Unit VIIb contains rare gray micro crystaline highly fractured banded chert lenses. In thin section the chert appears highly recrystalized with all grain boundary intersections approaching 120 degrees. It is quite dirty with ten percent kinked chlorite and small euhedral opaques.

Unit VIII - Amphibolite

This unit consists of a large hornblende rich body lying concordantly between units VI and VII. It is basically a bimineralogical unit with medium grained dark green hornblendes poikalitically enclosed in a subordinate anhedral apple-green epidote groundmass. Hornblendes are concentrically zoned, with actinolitic rims identified by X-ray diffraction. Hornblendes contain ragged anhedral olivine and clinopyroxene remnants, figure 2-9, and epidote contains rare albite (An 07) remnants. Thus unit VIII appears to be an altered igneous sill. Because hornblende dominates over epidote in all cases an original gabbroic composition is suggested assuming mafics alter to hornblende and plagioclase alters to albite plus epidote. Hornblendes show a poorly developed linear alignment and the unit exhibits a macroscopic banded character although neither of these structures were investigated in detail. Because of its intriguing compositional and structural characteristics, and lack of possible stratigraphically correlative units, a K/Ar geochronologic study of this unit was undertaken. Hornblendes yielded an age of 178 ± 6 m.y. (appendix 1), the significance of which is discussed in section 5.

Unit IX - Quartz Monzonite Batholith

The large plutonic body just west of Kalamalka Lake was previously dated by Fairbairn et. al. (1964) at 58 m.y. using the Sr/Rb method. The present author did not redate the pluton but field evidence confirms a pre-Eocene origin as it is overlain by probable Eocene volcanics at locality G-6 (see figure 1-2). Jones (1959) mapped the unit as part of the Cretaceous Coast Intrusives. It is in igneous contact with "Cache Creek" rocks to the north and commonly includes altered pods of country rock.

In hand specimen the rock is a medium grained foliated highly altered quartz monzonite. In thin section it is seen to be porphyritic with subhedral highly saussuratized plagioclase (An 37), and anhedral dentate quartz,poikalitically enclosed in late anhedral orthoclase. Abundant calcite veining and secondary chlorite and epidote, indicate extensive hydrothermal alteration.

Unit X - Tertiary Volcanics

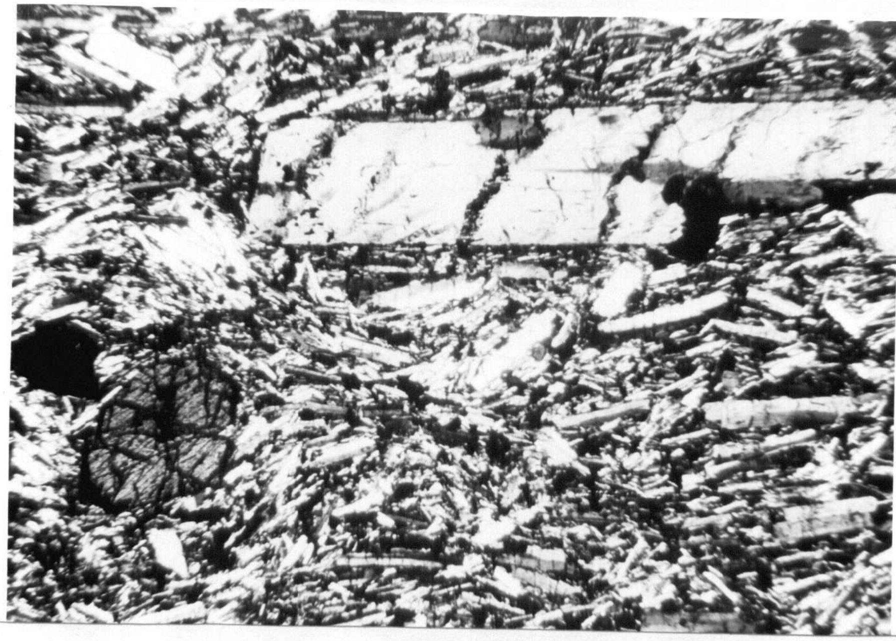
Outcrops of Tertiary volcanics cap underlying rocks in isolated areas throughout the map area (see plate A and figure 1-2). Jones (1959) classified them as the Kamloops Group of Eocene to Miocene age. They appear stratigraphically equivalent to Marron Formation volcanics which Mathews (personal communication) has dated at 49 ± 2 m.y. using the K-Ar method. Plateau basalts of probable Miocene Age (Mathews, personal communication) encroach on the very south-east corner of the map area but were not considered in this study.

The volcanics range from basalt to andesite in composition and rarely include altered tuff bands. They are aphanitic, vesicular to amygduloidal, and various shades of green in hand specimen. In thin section trachytic texture is well developed with felted plagioclase (An 36) microlites and glomeroporphyritic segregations of zoned plagioclase, clinopyroxene and possibly hornblende, figure 2-10. The segragations are highly altered. Vesicles are calcite filled.

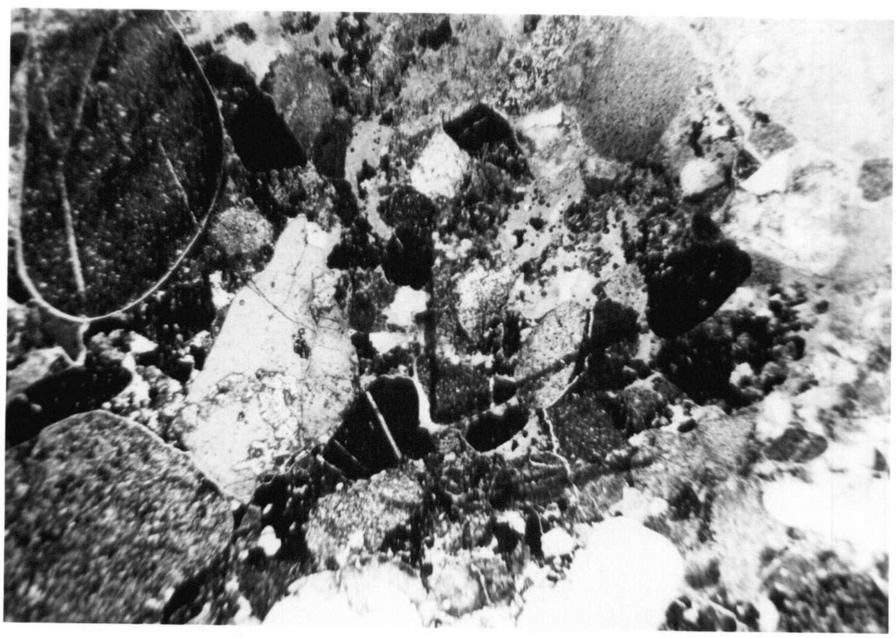
At one location, approximately F-8 (see plate A), a two inch thick lamprophyre dike occupies a north striking vertical phase 5 fracture. The aphanitic groundmass contains glomeroporphyritic clumps of subhedral plagioclase (An 37), pyroxene, biotite and hornblende, and exhibits a vague flow banding parallel to the strike of the dike. Compositionally, the rock classifies as a Spessartite and is probably genetically related to the overlying mafic volcanics, unit X. Ross (1974) has dated a similar foliated phase 5 dike at 43 ± 2 m.y. using the K-Ar method.

Unit Xa - Volcanic Breccia

At one locality, C-9, a sequence of volcanic breccia overlies volcanics of Unit XI. The outcrop exhibits poorly developed flow planes in which clasts are vaguely aligned. The breccia consists of poorly sorted angular to well rounded volcanic and sedimentary fragments with maximum clast size of one centimeter, set in a buff to brown aphanitic groundmass. The groundmass is microcrystaline partially devitrified



2-10 Well developed trachytic texture with aligned plagioclase microlites and plagioclase and hornblende phenocrysts in unit X. Cross polarized light. Field of view is 4.6 m.m. across.



2-11 Volcanic and sedimentary fragments in volcanic breccia, unit Xa. Plane polarized light. Field of view is approximately 3 c.m. across.

glass composed of quartz, feldspar, biotite, and relict shards. The matrix never comprises more than thirty percent of the whole rock. Figure 2-11 illustrates the character of unit Xa.

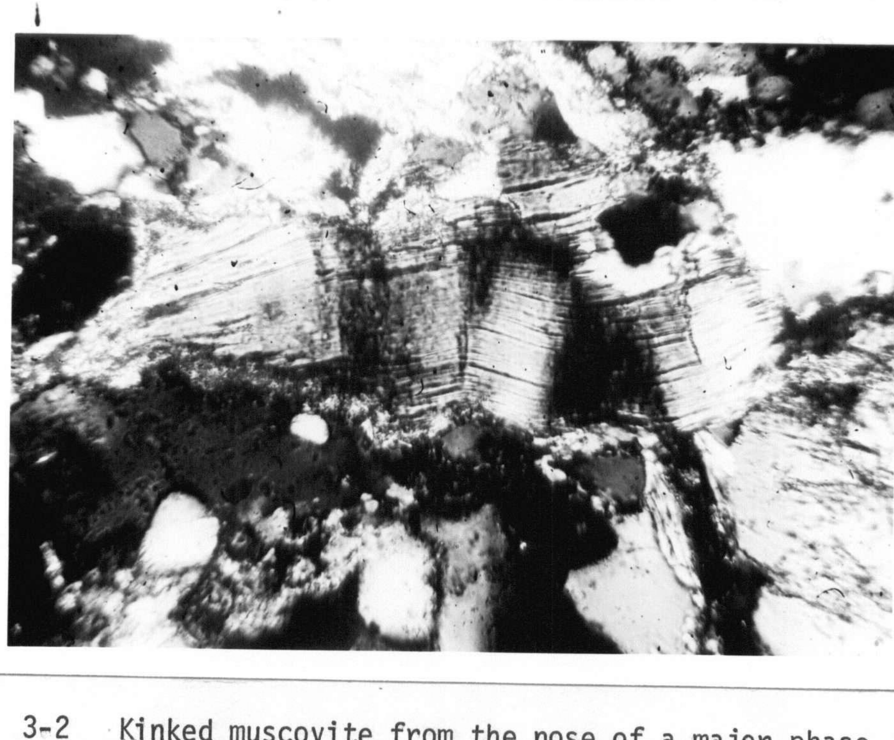
3. STRUCTURE

Shuswap rocks have undergone five and "Cache Creek" rocks four superposed deformational phases on scales ranging from millimeters to several kilometers. All outcrops contain abundant mesoscopic structures and at each station stratification or compositional layering and recognizable later structures (minor fold axes and axial planes, lineations, foliations, and fractures) were recorded. Superposition of up to three phases of deformation in one outcrop is occasionally seen as in figure 3-1. This permits direct assignment of fold sequences to particular deformational styles and orientations which are interpreted as comprising single phases. Lithologic and mesoscopic structural data was used to infer the position and geometry of macroscopic structural elements. The results are not unique but represent the best estimate of the structural history of the map area.

Stratification in "Cache Creek" rocks comprises the earliest recognizable structure and consists of finely spaced alternating light and dark layers in both sandstone and siltstone. Compositional layering on a scale of up to five c.m. is well developed in Shuswap layered units I through IV and may represent stratification but no relict primary structures were observed.

A profusion of later mesoscopic structures occur throughout the map area. Shuswap rocks contain at least one penetrative metamorphic schistocity, consisting of planar aligned biotites, which parallels transposed compositional layering except near isoclinal fold cores where it diverges to produce axial plane foliation. Related mineral alignment lineations (hornblende and diopside alignment along with

3-1 Superposition of phase 1, 2 and 3 folds in a single outcrop of calcareous quartzite, unit IV.



3-2 Kinked muscovite from the nose of a major phase 3 fold, in unit III. Cross polarized light. Field of view is 1.2 m.m. across.

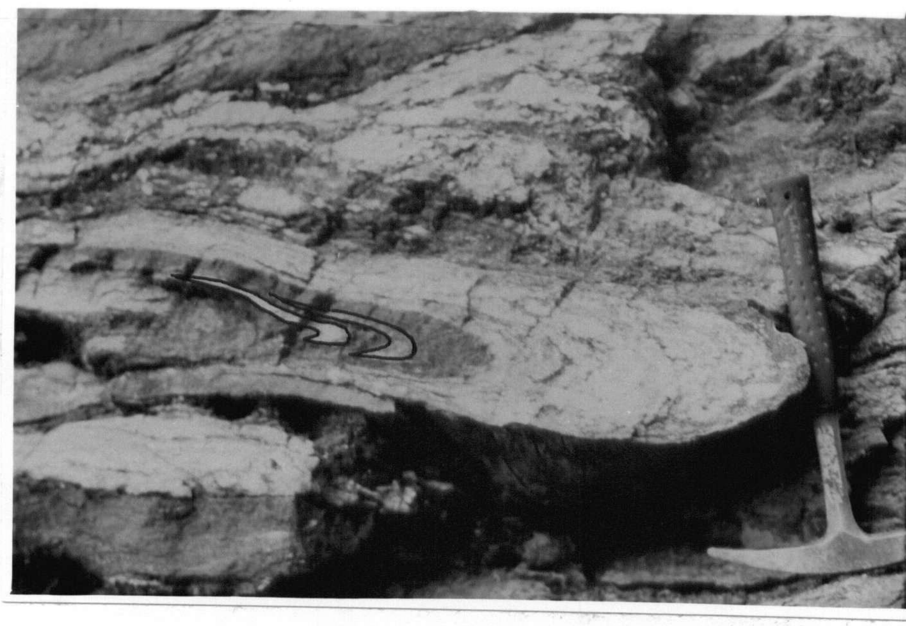
ribbon quartz elongation in Units I, III and IV) are commonly, but not always parallel to minor isocline axes. Some isoclinal folds refold earlier rootless isolines and their axial plane foliations; others do not. Compositional layering surfaces in layered units almost always exhibit ribbon quartz and mica edge intersection lineations.

"Cache Creek" rocks contain a penetrative metamorphic foliation produced by mica alignment but constituent clasts do not exhibit recognizable preferred orientation. Metamorphic micas parallel stratification except in the cores of isoclincal folds, where a weak axial plane foliation is occasionally recognizable in the field. Quartz elongation in metachert lenses produces the only identifiable mineral alignment lineation. Poorly defined linear structures developed on stratification surfaces are weathered stratification - metamorphic foliation mica edge intersection lineations.

Less pervasive minor structures occur throughout both rock types related to later, more brittle, phases of deformation. Microscopically kinked micas produce a crenulation cleavage and lineation (figure 3-2) in layered Shuswap units near some major fold hinges. Crenulation cleavage in "Cache Creek" rocks is developed by kinking of the metamorphic foliation on a scale of one to five centimeters. Both Shuswap and "Cache Creek" rocks develop nonpenatrative fracture cleavages parallel to axial planes of minor buckle folds, figure 3-4.

All Mesoscopic structural data is plotted on lower hemisphere equal area projections. The map area is subdivided into a number of structural domains, chosen such that particular deformational characteristics are homogeneous throughout that domain. Differences in mesoscopic structures

3-4 Phase 4 buckle folds with fracture cleavage developed along axial planes. In biotite schist, facing N.E.



3-5 Phase 2 refolding rootless phase 1 isoclines in hornblende gneiss, unit I. Distorted phase 1 lineations faintly visible.

between domains are used to substantiate large scale structural features. Structural domains are shown in figure 3-3. Structural elements of Shuswap and "Cache Creek" Complexes are described separately. Possible structural correlations between the two groups are discussed in Section 5.

Shuswap Structure

Shuswap rocks appear to have undergone five phases of deformation. The most easily recognized, phase 2, produced gently northerly dipping subhorizontally easterly plunging isoclinal folds. These refold earlier gently northerly dipping and plunging reclined isoclines defined as Phase 1. Some lithologic repetitions and mixed vergences are unexplainable in terms of phase 2 folding alone. Phase 3 folds plunge subhorizontally to the northeast with variably dipping axial planes. Unusual phase 3 geometry consists of sharp hinged angular folds with one steep and one gently dipping limb. Phase 4 and 5, which trend northeasterly and northerly respectively, are late brittle events characterized by upright buckle folds and abundant fractures.

Igneous activity, which occurred contemporaneously with phase 2 and 5 deformations, is discussed below. Metamorphism, discussed in section 4, may have occurred during phase 1 deformation and culminated in amphibolite facies during and following phase 2 deformation. Widespread hydrothermal alteration occurred in Tertiary time, contemporaneous with phase 4 and 5 deformation.

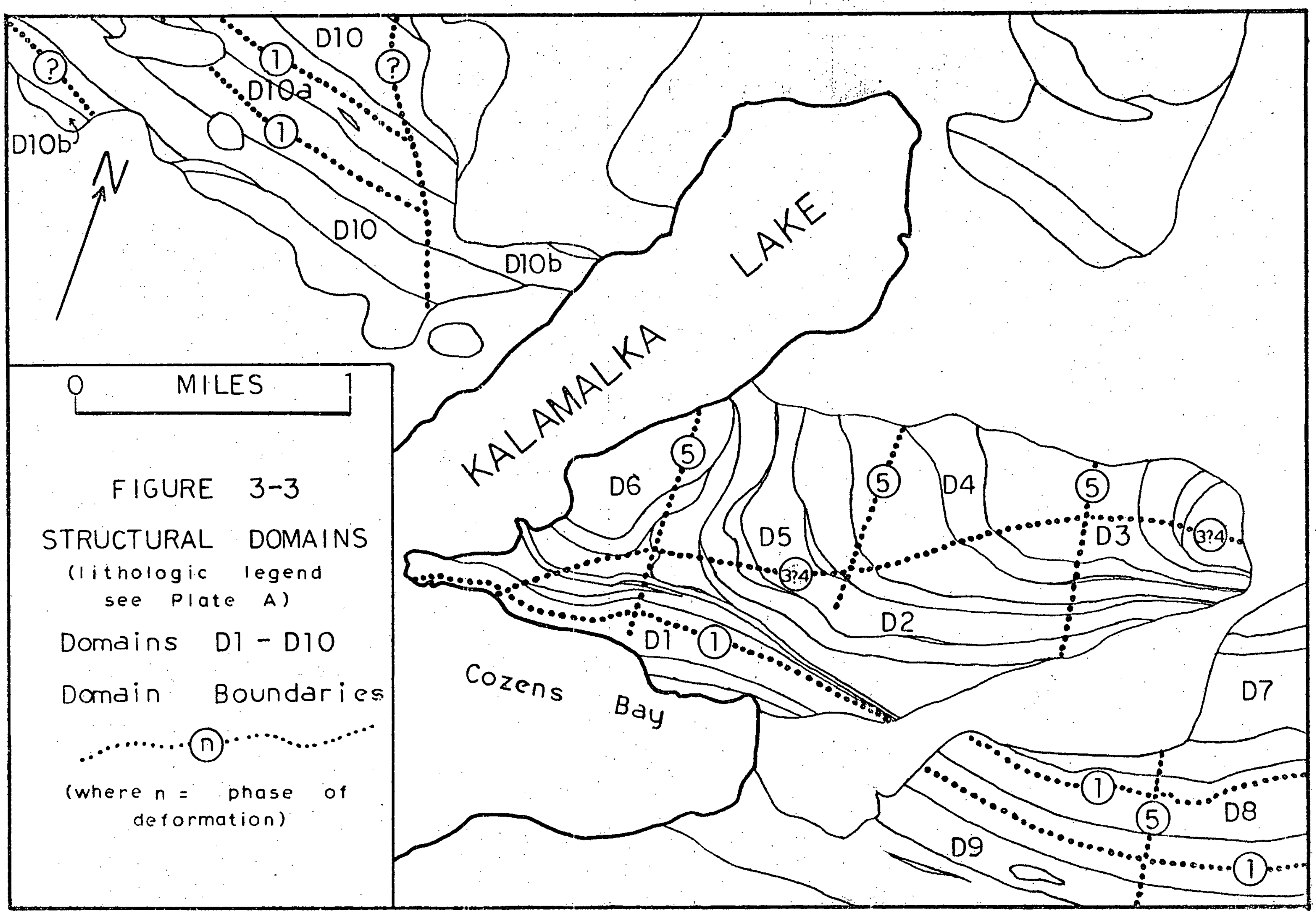


FIGURE 3-3

STRUCTURAL DOMAINS

(lithologic legend see Plate A)

Domains D1 - D10

Domain Boundaries ·····(n)·····

(where n = phase of deformation)

Shuswap Phase 1

Shuswap rocks contain evidence for a northerly trending isoclinal reclined phase of deformation, folds of which never refold any structures other than compositional layering. These earliest recognizable structures are defined as phase 1. In some instances southeast trending phase 2 folds refold north trending phase 1 isoclines as in figure 3-5, which illustrates the relative dating of the age of phase 1. This early phase in high grade Shuswap rocks has been recognized by previous workers to the south of the thesis area (Ross and Christie, 1969; Christie, 1973; Ross, 1973; Ryan, 1973).

Mesoscopic phase 1 isoclinal folds, although not plentiful, are found in all layered Shuswap units throughout the map area (figure 3-6). In calcareous quartzite, unit IV, elongate quartz produces a penetrative lineation parallel to fold axes. Penetrative foliations are well developed by planar biotite alignment in units II and III, and linear hornblende alignment in units I and II. Because phase 1 foliations parallel mesoscopic axial planes and phase 1 lineations parallel minor fold axes, they are interpreted as axial plane foliations and axial lineations, respectively.

Mesoscopic structural data for phase 1 deformation is plotted in plan view, figure 3-7, and an equal area projection, figure 3-8. Minor fold axes and axial lineations concentrate at $000^{\circ}/16^{\circ}$. Poles to phase 1 axial planes and axial plane cleavage fall on a great circle locus. Axial plane cleavage appears to closely parallel minor fold axial planes and the pole to the great circle locus coincides with the average phase 2 fold axis discussed below. The spread of poles to axial planes is interpreted as a result of refolding by phase 2 deformation. The average axial plane

3-6 North trending phase 1 fold which folds compositional layering in calcareous quartzite, unit IV.

3-11 Décollement style phase 2 fold in a granitic sill, unit V.

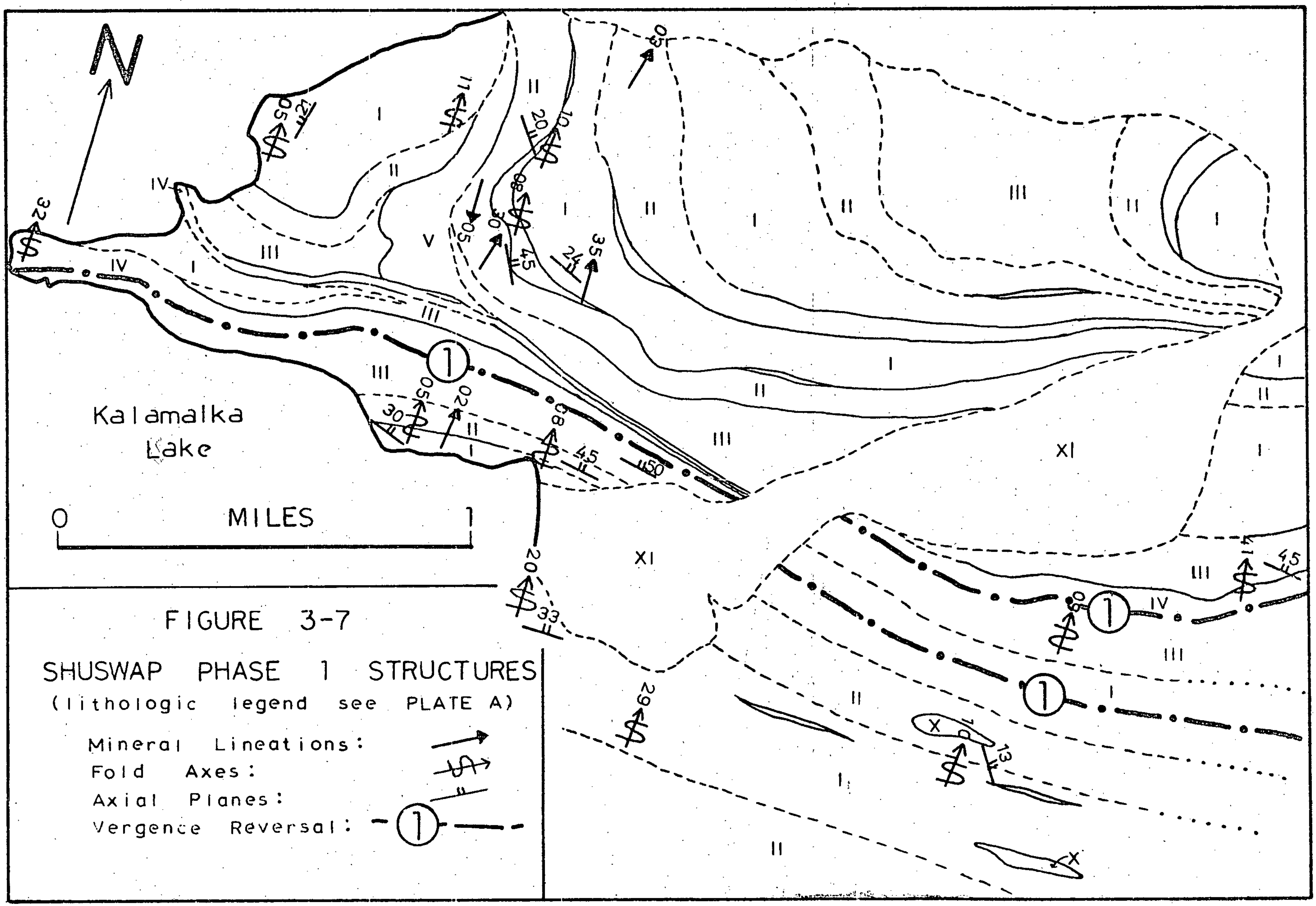
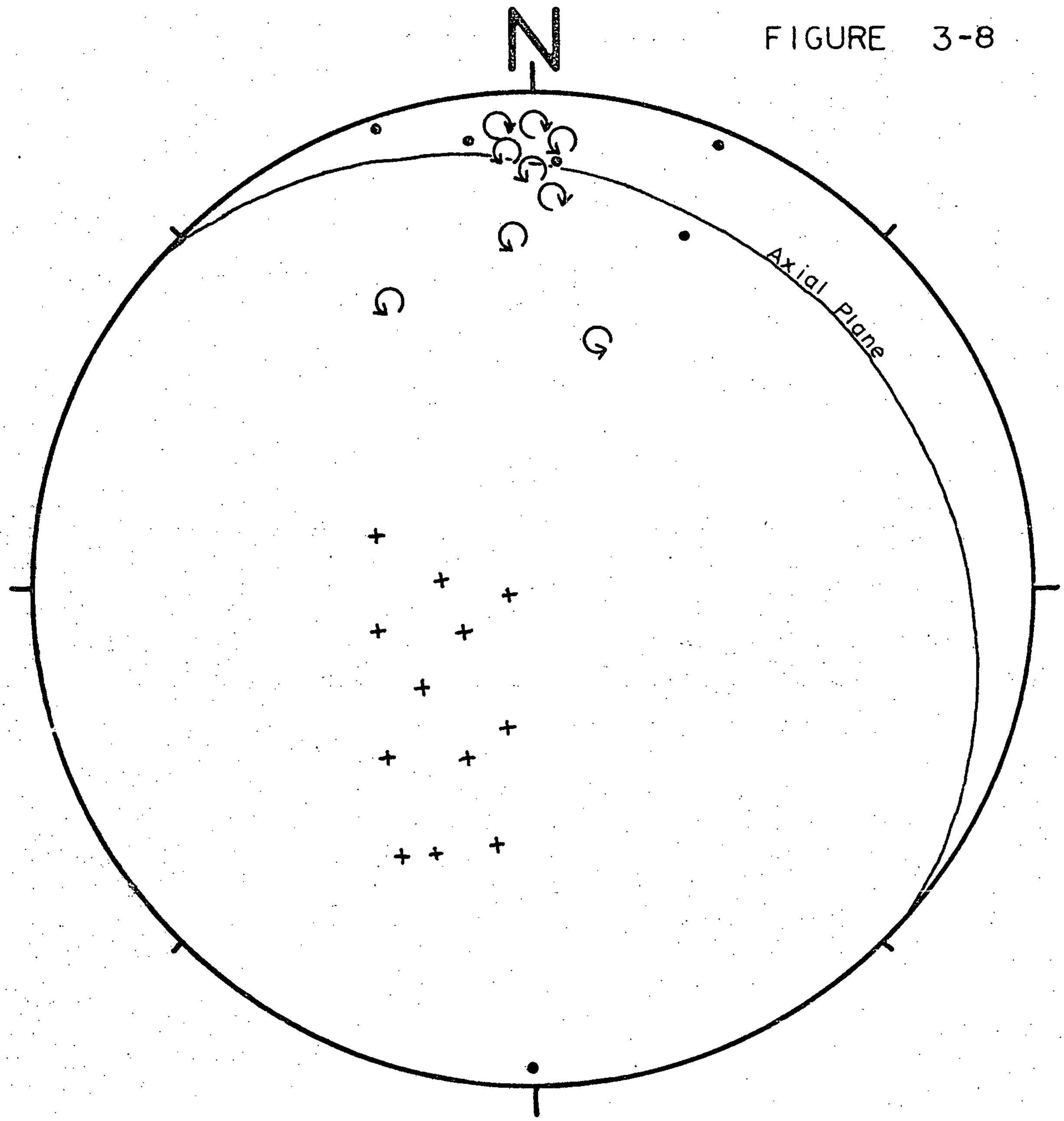


FIGURE 3-7

SHUSWAP PHASE 1 STRUCTURES

(lithologic legend see PLATE A)

FIGURE 3-8



Shuswap Phase 1

- • Phase 1 mineral lineations
- ↻ Phase 1 fold axes showing vergence
- + Poles to Phase 1 axial planes

orientation, $132^{o}/20^{o}N$, contains the concentration of minor fold axes and lineations. Because of the present isoclinal geometry, refolding by phase 2, and the relatively small amount of structural data, original phase 1 style and orientation is indeterminate.

Mesoscopic phase 1 folds have consistent counter clockwise vergence in domains D2 through D6, D7 and D9, as shown in figure 3-3. Phase 1 exhibits clockwise vergence within domains D1 and D8 which define a south east trending strip of reversed phase 1 vergence. The lithologic succession with the effects of phase 2 deformation removed still shows lithologic repetitions. The large aerial extent of mesoscopic phase 1 folds, the macroscopic band of reversed phase 1 vergence and lithologic repetitions unexplained by phase 2 folding indicate widespread and possibly large scale effects of early phase 1 folding.

Shuswap Phase 2

Phase 2 deformation of Shuswap rocks is the best developed in the map area. It produces well defined structures on all scales up to the prominent gently northerly dipping isoclinal synform outlined by calcareous quartzite, unit IV. Other major phase 2 folds to the north and south are defined by lithologic repetitions and vergence studies. Mesoscopic phase 2 folds are seen to refold rootless phase 1 isoclines in figure 3-5. Figure 3-1 illustrates interrelationships of phase 1, 2, and 3 mesoscopic folds.

Mesoscopic phase 2 folds cores commonly contain mineral segregations; diopside in unit IV and hornblende in units I and II. Diopside and hornblende alignment plus linear quartz elongation produce a penetrative axial lineation; biotite alignment produces a penetrative foliation parallel to minor fold axial planes. Mica and quartz edge lineations found on many compositional layering surfaces parallel mesoscopic phase 2 fold axes. They are interpreted as compositional layering-metamorphic foliation intersection lineations.

In one instance where a phase 2 fold refolds phase 1 rootless isoclines in unit 1, Figure 3-5, two penetrative hornblende lineations are present. The most prominent parallels the phase 2 fold axis. The other is curvilinear, wraps around the phase 2 hinge, and likely represents distorted phase 1 axial lineation.

Structural data for phase 2 deformations is plotted on plan view, figure 3-9, and equal area projection, figure 3-10. Minor fold axes, which exhibit mixed vergences and penetrative lineations described above, show a well defined concentration with orientation $106^{o}/06^{o}$. The pole of the great circle locus of poles to phase 1 axial planes has orientation $95^{o}/10^{o}$, nearly coincedent with the statistically defined phase 2 axis. Poles to phase 2 axial planes cluster at a diffuse concentration. From this, phase 2 axial plane orientation is statistically defined as $117^{o}/30^{o}$ N. Phase 1 axial planes and compositional layering have been transposed into near coincedence with phase 2 axial plane orientation.

Four macroscopic phase 2 folds are recognized in Shuswap rocks of the thesis area. Synform 2-1, outlined by unit IV illustrates the extremely tight nature of macroscopic phase 2 folding. At the edge of Kalamalka Lake, location F-4, figure 1-2 and plate A, the two calcareous quartzite limbs diverge exposing cores of biotite schist, unit III, and hornblende gneiss, unit I. Unit IV limb separation at this point is approximately 500 feet. Unit I pinches-out down plunge at location F-8. At the end of outcrop, location F-9, unit III still separates the quartzite limbs, though total outcrop width is less than 50 feet. South of

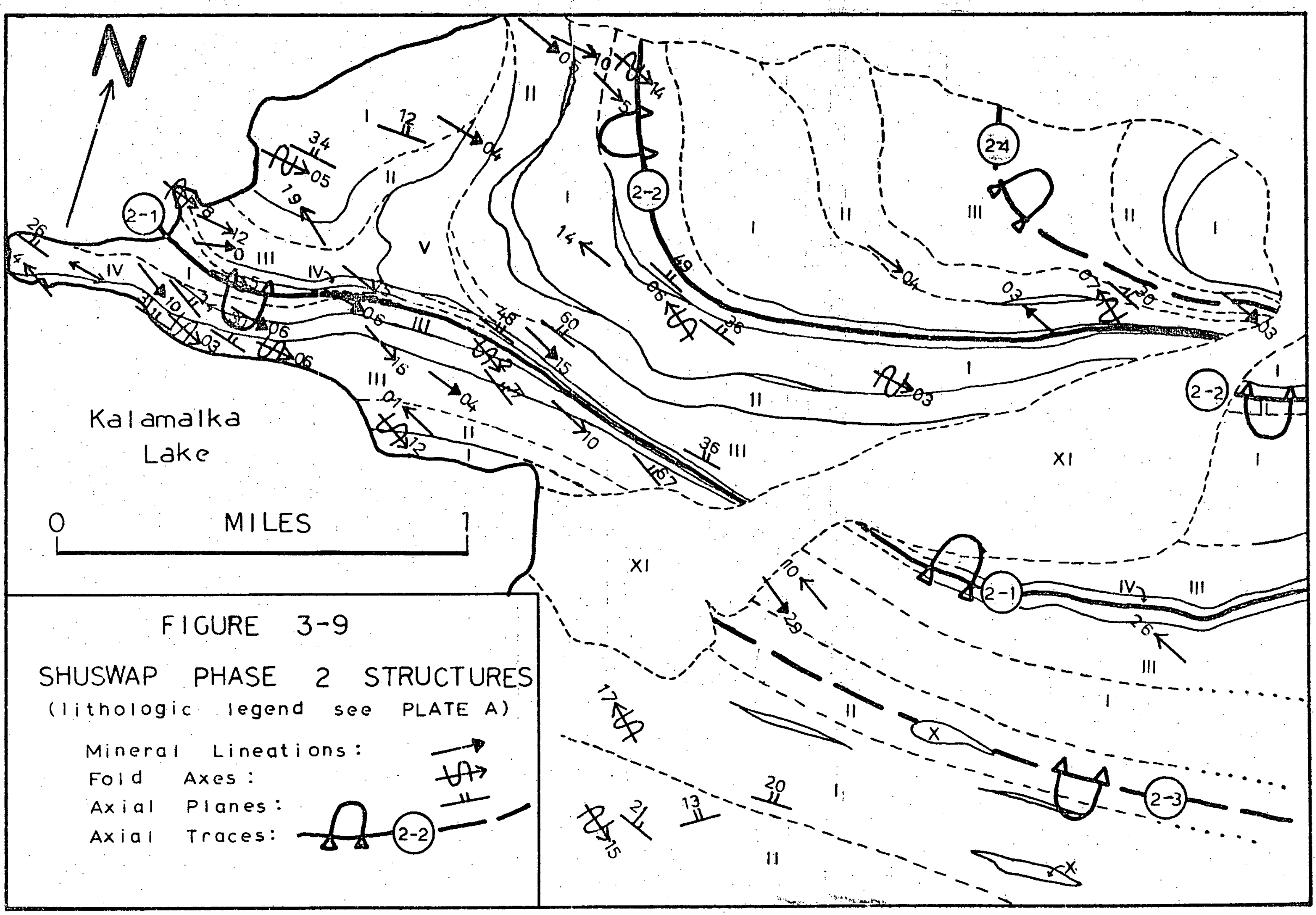
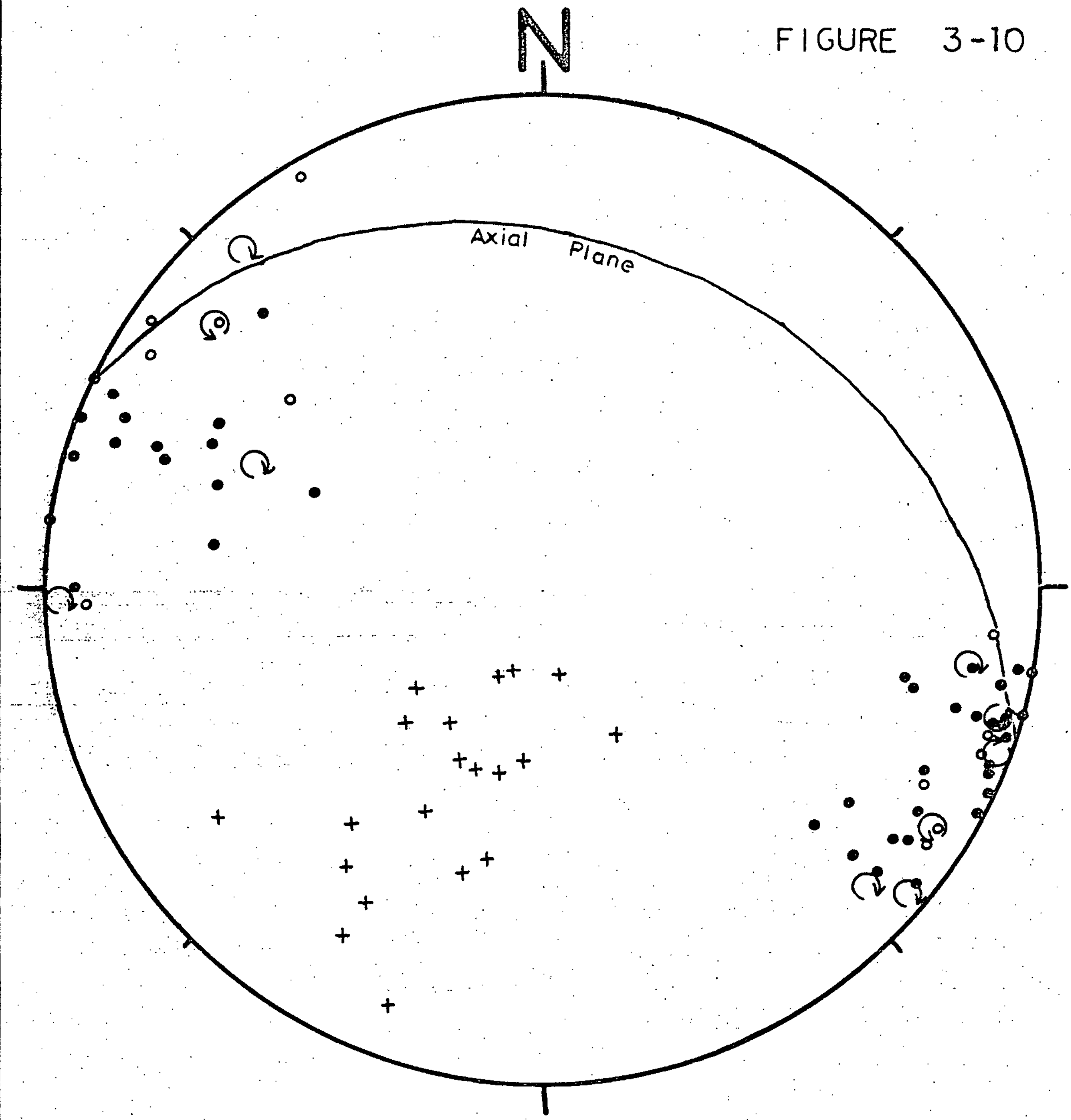


FIGURE 3-9

SHUSWAP PHASE 2 STRUCTURES

(lithologic legend see PLATE A)

FIGURE 3-10



Shuswap Phase 2

● Mineral Lineations

○ Fold axes

↺ Fold axes with vergence

+ Poles to axial planes

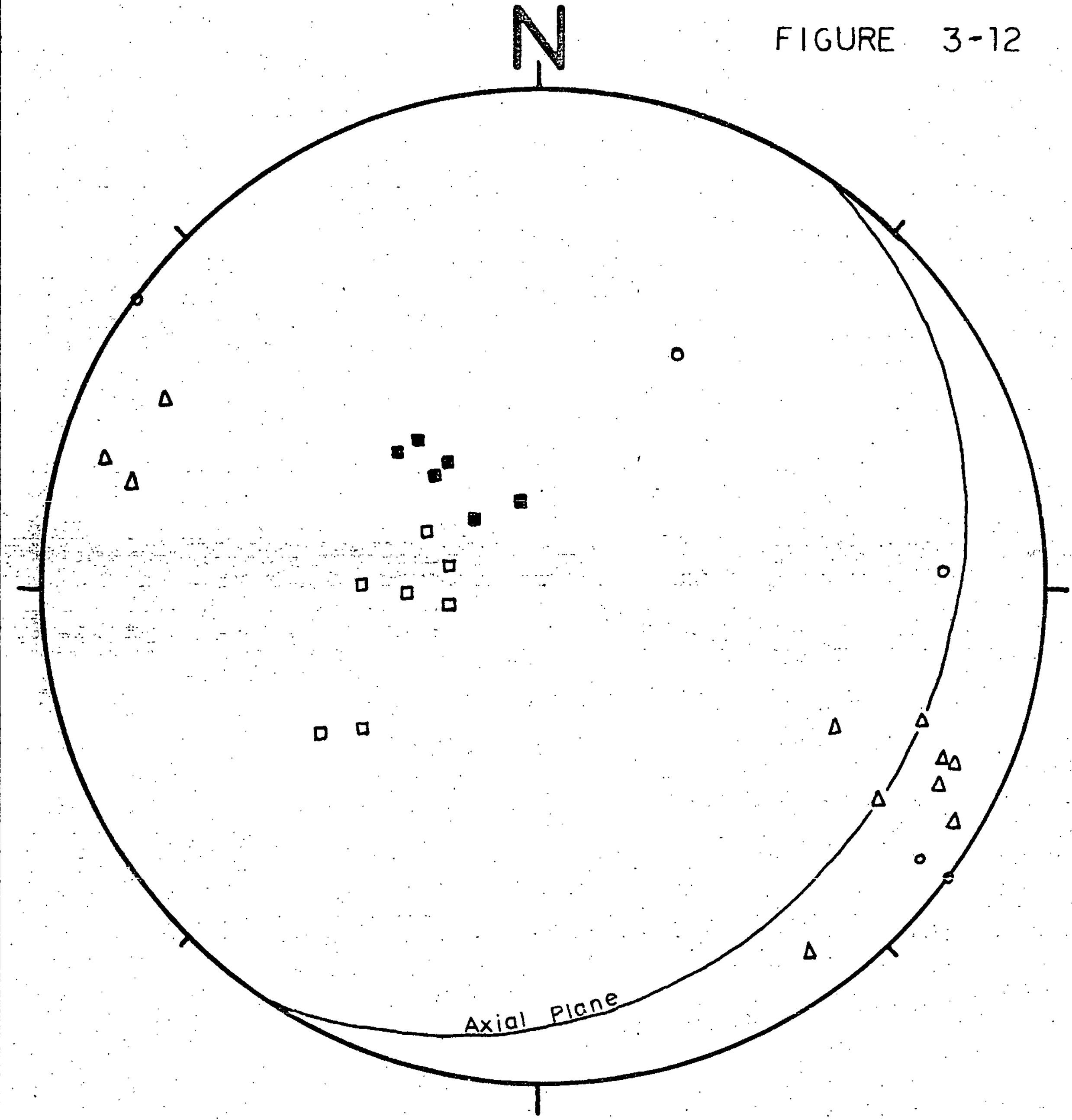
Cozens Bay the biotite schist pinches out although the now single coring quartzite band continues eastward out of the map area for a distance of over three miles! Mesoscopic phase 2 folds exhibit consistent clockwise vergence north of fold 2-1 but counter clockwise vergence to the south, figure 3-9, confirming a synformal nature. The concentrations of poles to compositional layering on opposite sides of fold 2-1 cannot be distinguished, indicating isoclincal macroscopic geometry.

Evidence for antiforms 2-2 and 2-3 is less conclusive. Hornblende gneiss, unit I, is repeated around cores of hornblende-biotite gnesis, unit II. Reversed mesoscopic fold vergence around fold 2-2 confirms antiformal geometry but evidence for fold 2-3 is ambiguous. Fold 2-4 is only poorly defined by lithologic repetitions of units I and II around a core of biotite schist, unit III. Moreover, the single vergence measurement, shown in figure 3-9, is consistent with a synformal nature. Poles to compositional layering around folds 2-2, 2-3, and 2-4 show no recognizable divergence indicating isoclinal geometry.

Numerous granitic dikes and sills, petrographically described in section 2, are related to phase 2 deformation. They contain mesoscopic phase 3 folds and décollement folded phase 2 folds, figure 3-11, but no earlier structures.

The largest intrusive sill shown on plate A at location F-8 exhibits a well developed phase 2 biotite alignment foliation and late brittle fractures. Structural data for this unit is shown in figure 3-12.

The sill was dated by the Sr/Rb whole rock method at 42 $\pm$10 m.y., appendix 1. A possible thermal resetting origin for the Sr/Rb date is suspected. Mathews secured similar Eocene ages from Shuswap gneiss of the Trinity Hills at the north of the map area. He utilized the K/Ar



UNIT V STRUCTURES

- • Mineral lineations
- ▷ Poles to fractures

Poles to foliation:
- □ Domain D2
- ■ Domain D5

method which is susceptible to thermal resetting at relatively low temperatures and pressures. He nonetheless concludes that the results are anomalous (Mathews, 1976, p.47):

"Explanation of the very young apparent ages of the gneisses remains elusive."

The susceptibility of the Sr/Rb isotopic system to thermal resetting is at present virtually unknown. Contradictory results have two possible explanations: (1) The Tertiary date represents the time of phase 2 deformation in which case phases 2 through 5 all occurred in Tertiary time or later: (2) The 42 m.y. age represents a thermal event which updated the Sr/Rb isotopic clock. Neither possibility seems readily acceptable. Speculatively, however, thermal resetting seems more compatible with large scale Cordilleran tectonics and the results of other workers than four deformational phases occurring in Tertiary time.

Shuswap Phase 3

Phase 3 deformation produces mesoscopic structures throughout the map area but appears to have little macroscopic effect. Lithologic repetitions and mesoscopic structural evidence may suggest the existence of a large scale synform. Mesoscopic fold geometry and the development of microscopic phase 3 crenulation cleavages indicates less ductile conditions than for phase 2 deformation. Figure 3-1 illustrates phase 3 refolding both phase 1 and 2 mesoscopic folds.

Unusual phase 3 fold geometry consists of alternately shallowly and steeply dipping planar limbs with angular hinges, figure 2-2. An interlimb angle of 70° was determined by averaging measurements of six mesoscopic folds. Kinked micas, figure 3-2, produce crenulation cleavages and lineations in phase 3 fold cores in units I, II, and III. This results in discontinuity surfaces along mesoscopic axial planes and lineations on fold hinges parallel to minor fold axes.

Mesoscopic phase 3 data, shown in figures 3-13 and 3-14, is not amenable to simple interpretation. Phase 3 axial planes strike northeasterly but dips vary extensively. Because phase 1 and 2 axial planes do not exhibit similar variations in orientation, the effect cannot be due solely to later refolding. Poles to phase 3 axial planes may be interpreted to define two concentrations, (see figure 3-14). If so Shuswap phase 3 folding may comprise a pair of conjugate axial planes, one dipping moderately northward, the other gently southward. Both Christie (1973) and Medford (1976), arrived at similar conclusions about a possible correlative phase of deformation to the south, and assigned the conjugate axial planes to subphases 3a and 3b. The limited data of the present study does not permit such quantitative subdivision but is suggestive of similar structural development. Axial lineations and minor fold axes plunge gently northeastward but also exhibit considerable variation in orientation. They are seen to lie on a northeast centered, small circle locus (figure 3-14). Phase 2 linear structures show a similar north-south spread, indicating possible parallel style refolding by a later deformational phase.

North of Cozens Bay Shuswap lithological contacts and macroscopic phase 2 axial traces veer from northwesterly trends in the north to easterly trends in the south, outlining a probable macroscopic phase 3 fold (figure 3-13). Locations of maximum lithologic curvature define the axial trace position. Orientational variation of compositional layering indicates synformal geometry. The change in mesoscopic phase 3 fold vergence from counterclockwise in the north to clockwise south of

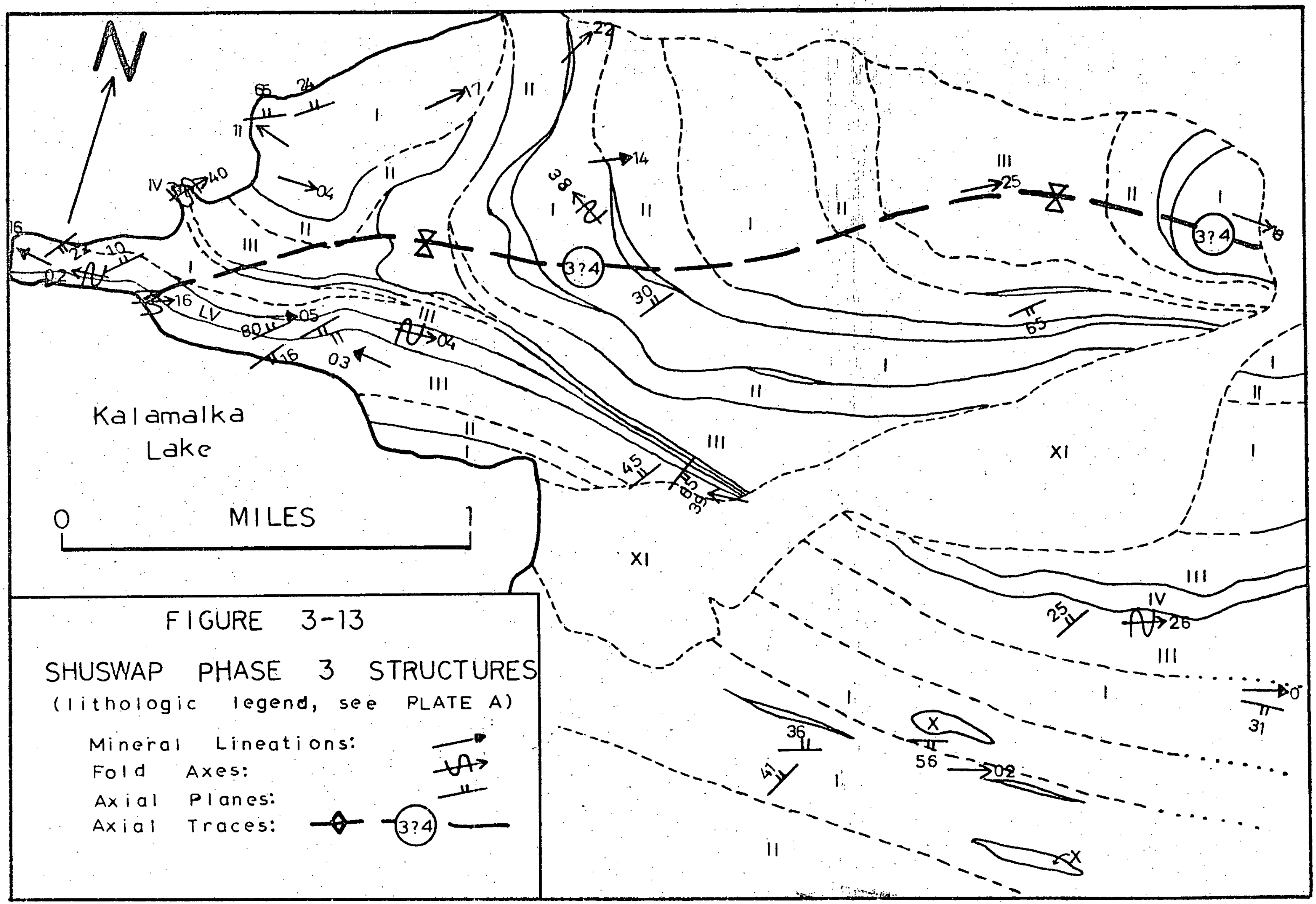
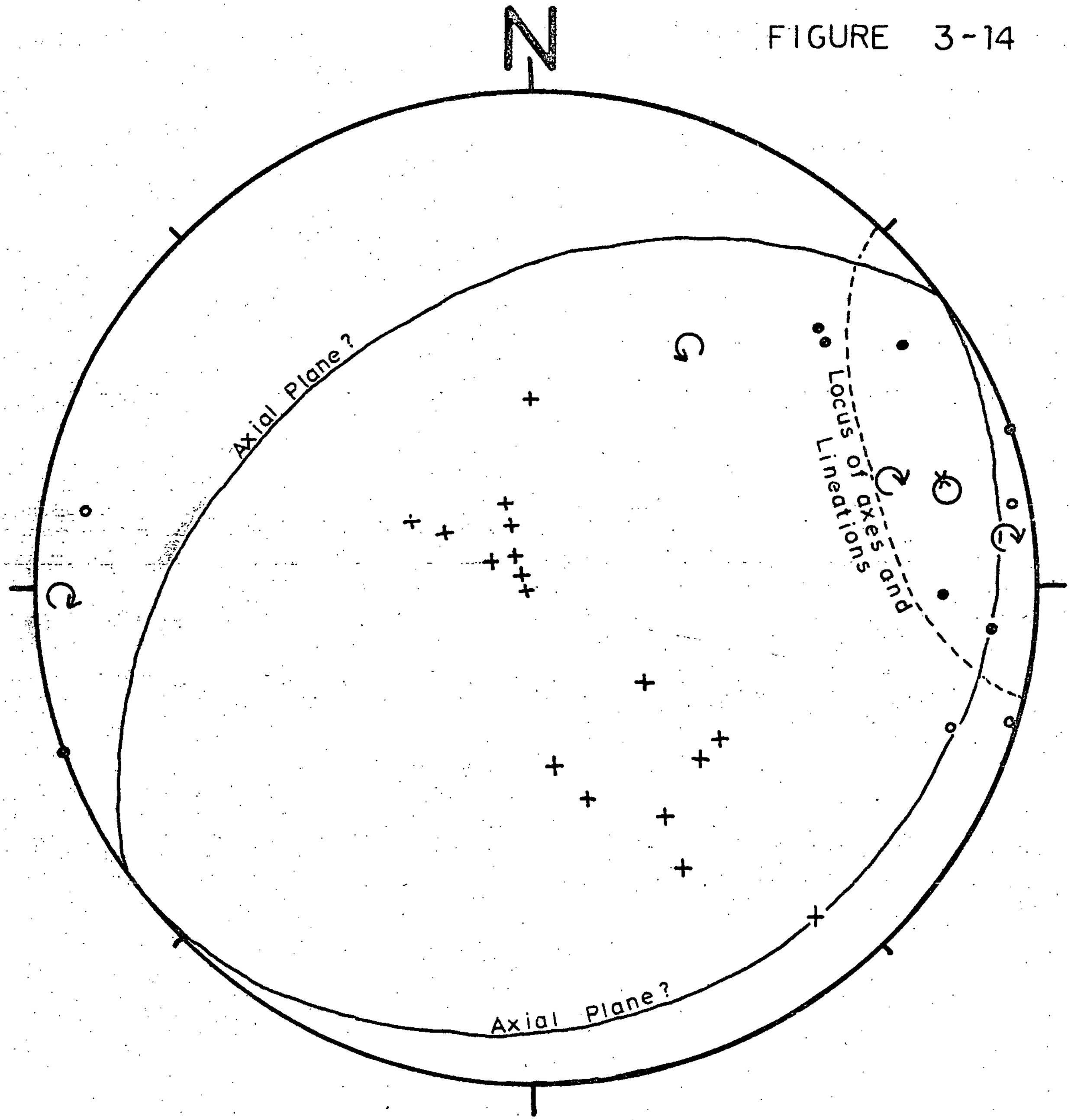


FIGURE 3-13

SHUSWAP PHASE 3 STRUCTURES

(lithologic legend, see PLATE A)

FIGURE 3-14



Shuswap Phase 3

• Mineral lineations

o Fold axes

↻ Fold axes with vergence

+ Poles to axial planes

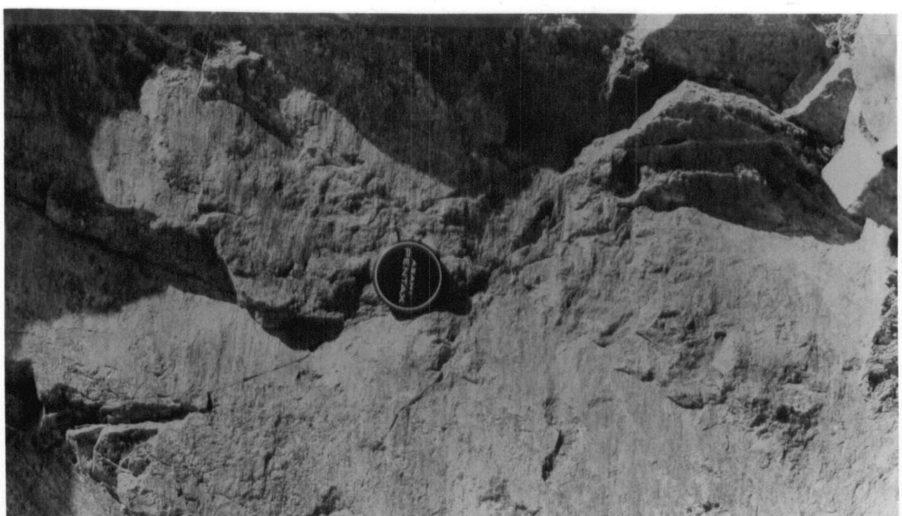
the fold, confirms such an interpretation. Mesoscopic phase 3 folds at location F-7 exhibit no vergence, consistent with the major phase 3 fold hinge positioning. It should be noted that the macroscopic phase 3 axial trace is gently curvilinear probably as a result of later refolding.

Shuswap Phases 4 and 5

Phase 4 and 5 deformations are low temperature brittle events which likely occurred during the Tertiary. They are responsible for open buckle folds, fractures, and minor cataclastic breccia. Some previous authors (Ryan 1973, Ross 1974) considered phase 4 and 5 to comprise a single deformational event whereas others (Christie, 1973) consider them separable but probably coeval in nature. In the thesis area north trending phase 5 post dates northeast trending phase 4.

Phase 4 and 5 structural elements are characteristically nonpenetrative and not well developed but occur throughout the map area. Gentle warping of compositional layering surfaces commonly produces minor upright buckle folds with fracture cleavage along axial planes, figure 3-4. Abundant vertical fractures with virtually no offset parallel the fracture cleavage. Country rocks surrounding these fractures are hydrothermally altered. One north trending fracture at location F-8, figure 1-2, contains an undeformed lamprophyre dike described in section 2. It resembles foliated rhomb-porphyry dikes to the south dated by the K/Ar method at 43$\pm$2 m.y. (Ross, 1974). Cataclastic breccia (figure 3-15, location F-10) was probably produced during phase 4 or 5 deformation. Interference of minor phase 4 and 5 buckle folds sometimes imparted an undulatory dome and trough nature to compositional layering surfaces. At location E-10 a vertical north striking phase 5 fault crosscuts phase 4 fractures. The

3-15 Highly sericitized plagioclase and granulated quartz in cataclastic breccia (phase 4 or 5?) of unit V.



3-16 Slickensides on a vertically dipping, N striking, phase 5 fault which truncates phase 4 fractures.

fault surface contains vertically plunging slicken sides, figure 3-16, indicating minor, dominantly dip-slip movement.

Structural data for phase 4 and 5 deformation in Shuswap rocks is shown in figures 3-17, 3-18, and 3-19. Poles to phase 5 axial planes and fracture cleavage define average axial plane orientation of $002^{\circ}/84^{\circ}$W. Average axial orientation defined by minor fold axes concentration is $000^{\circ}/14^{\circ}$. Average phase 4 orientation is poorly defined but distinct from phase 5. Minor axes concentrate at $053^{\circ}/00^{\circ}$; fracture cleavages and fractures at 072°/80S.

A possible northeast trending fault parallels Cozens Bay Valley (location F-10 and plate B) and is tentatively assigned to phase 4 deformation. Fault geometry is peculiar with approximately 500 feet apparent left lateral movement in the west and 300 feet right lateral movement in the east. Overall fault movement is probably less than 100 feet south-up dip-slip with movement on a steeply dipping fault plane. No other macroscopic phase 4 structural elements are recognized.

Four macroscopic phase 5 folds are shown on plate B and figure 3-17. These were defined on the basis of variations in compositional layering orientation, as illustrated on plate A. The folds are upright, very gentle and discontinuous.

"Cache Creek" Structure

"Cache Creek" rocks of the thesis area have undergone four recognized deformational phases. The earliest, phase 1, produced very tight folds axial planes of which dip steeply northward and which plunge subhorizontally westward. These are sometimes refolded by moderately tight steeply dipping southwest plunging folds of the next recognized phase. The final two deformations, phase 3 and 4, trend northeasterly and northerly, produce abundant fractures with attendant hydrothermal alteration, and a small

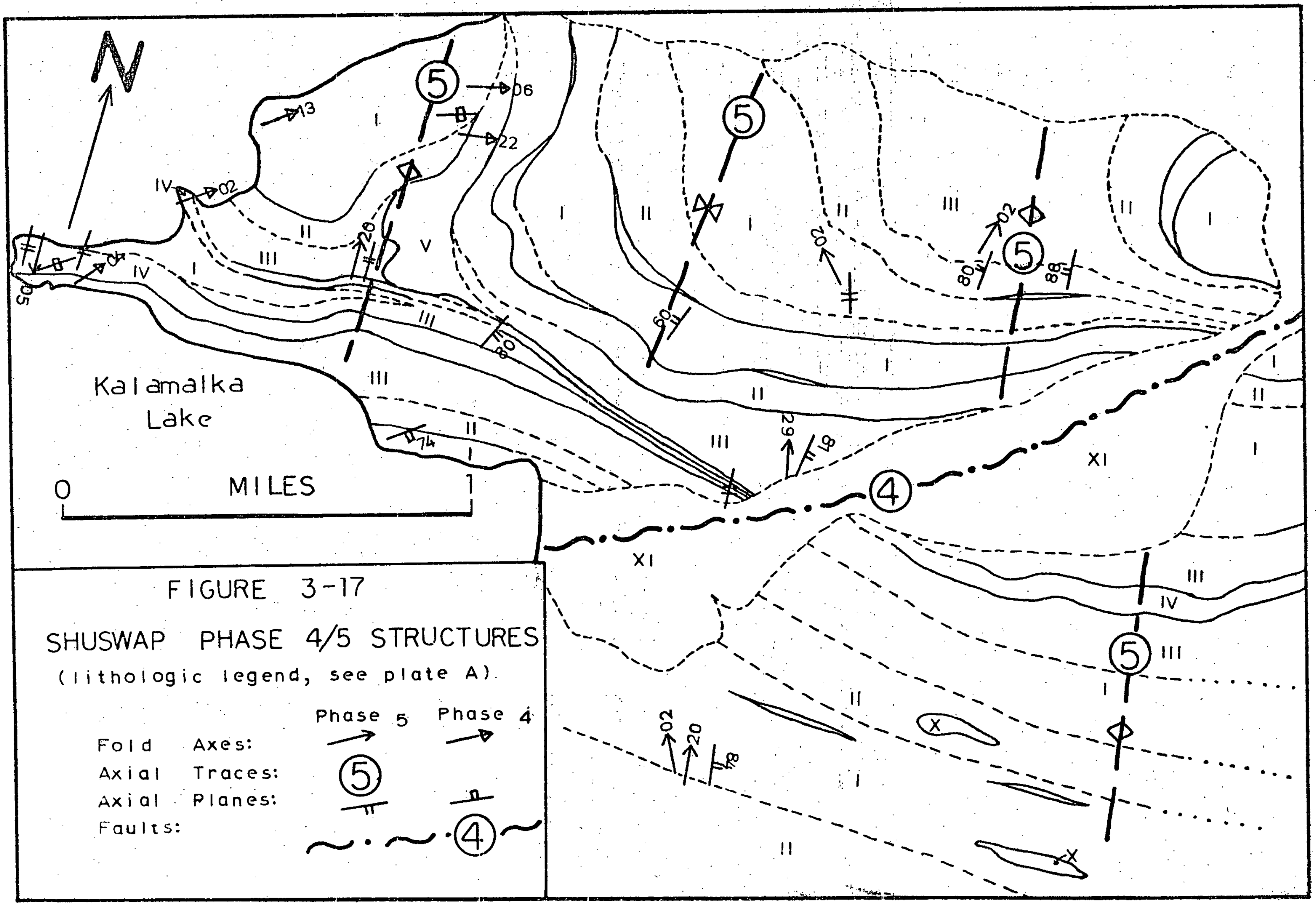
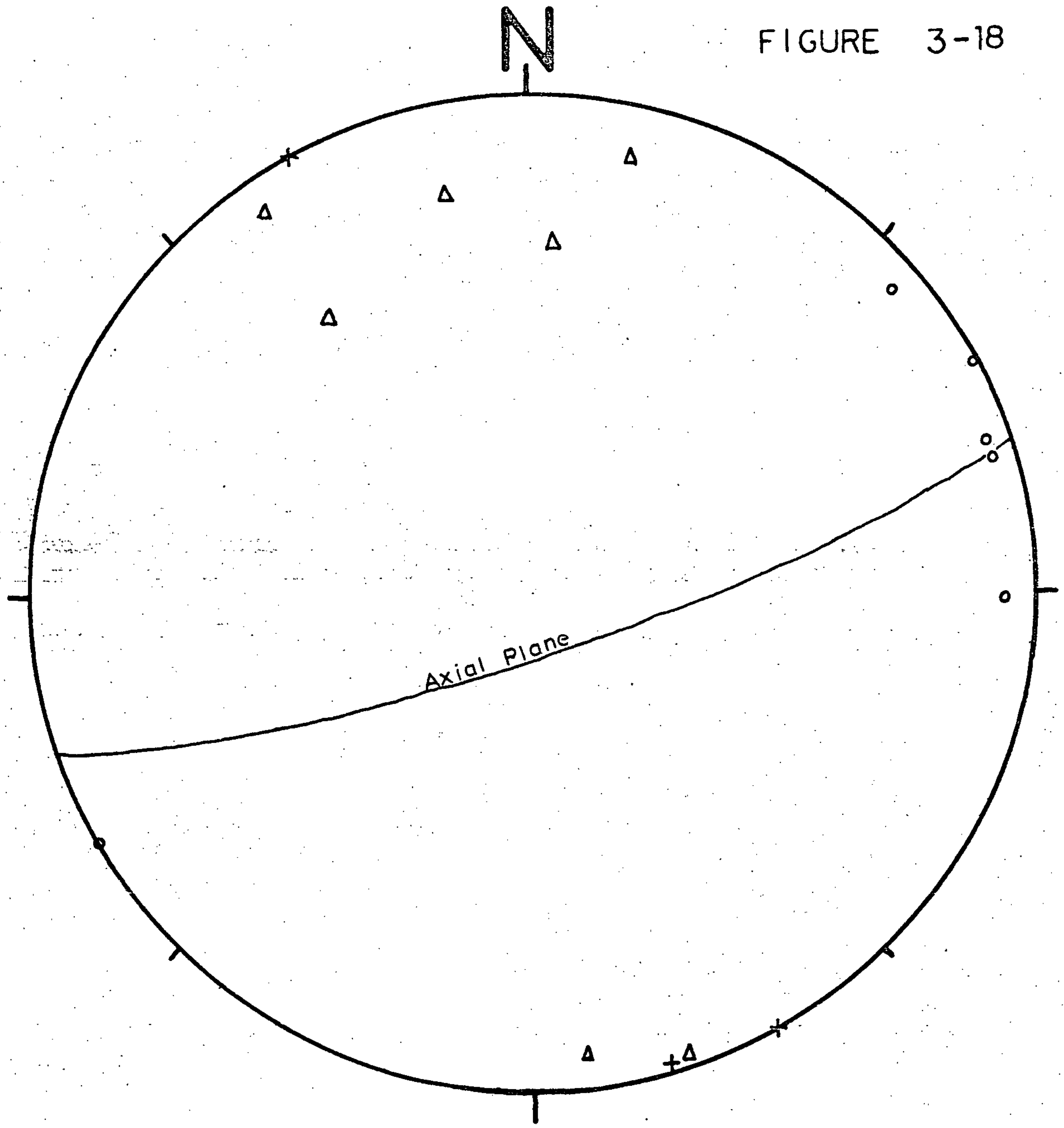


FIGURE 3-17

SHUSWAP PHASE 4/5 STRUCTURES

(lithologic legend, see plate A)

FIGURE 3-18



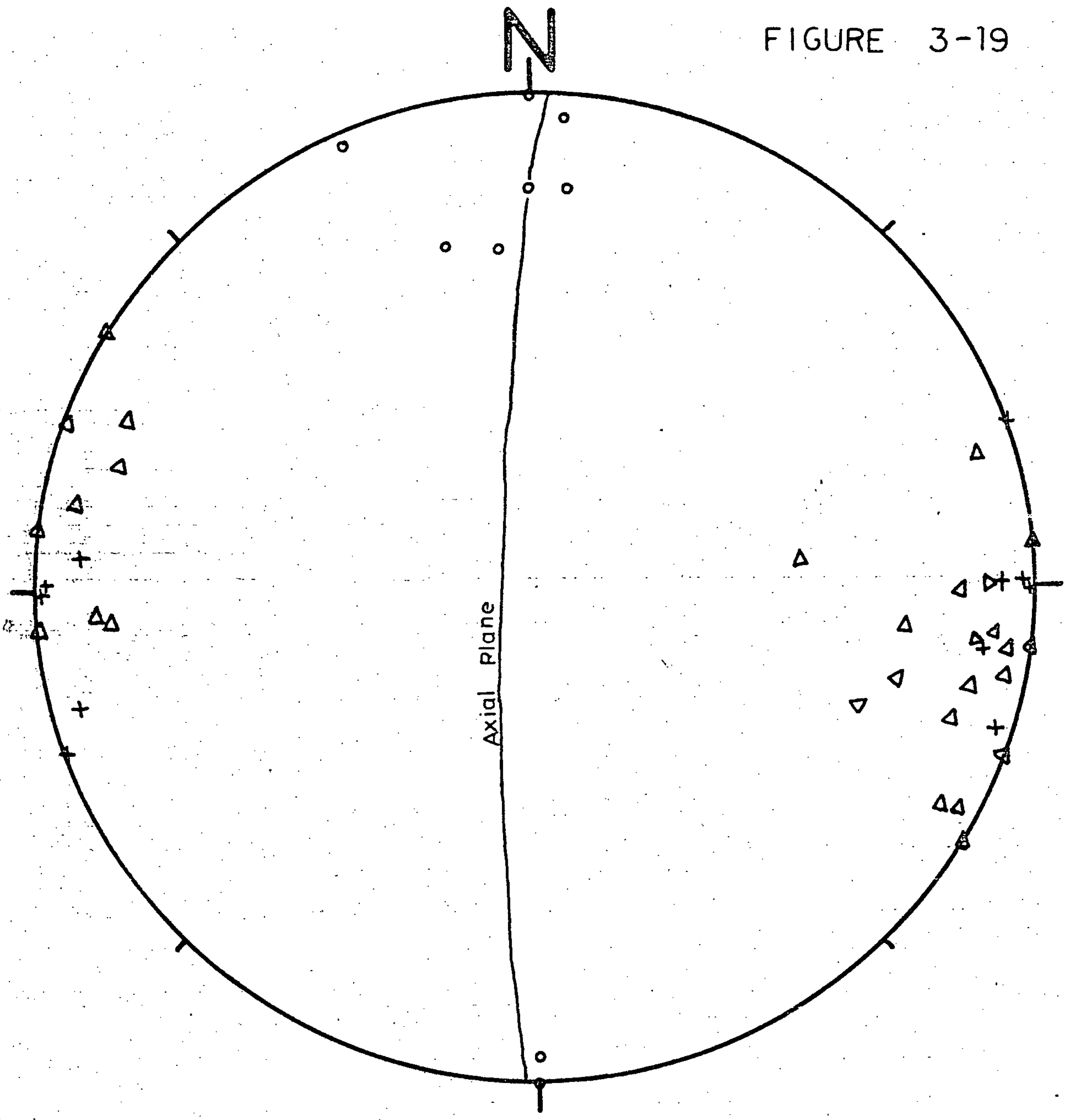
Shuswap Phase 4

o Fold axes

Δ Poles to fractures

\+ Poles to axial planes

FIGURE 3-19



Shuswap Phase 5

o Fold axes

\+ Poles to fractures

Δ Poles to axial planes

number of minor upright buckle folds. Their relative timing in "Cache Creek" rocks is indeterminate. Both the large amphibolite sill, unit VIII, and the quartz monzonite pluton, unit IX, contain evidence of late brittle events but no earlier structures.

"Cache Creek" Phase 1

The earliest phase of deformation in "Cache Creek" rocks, defined as phase 1, produced very tight mesoscopic folds whose axial planes parallel stratification except in fold hinges. Metamorphic foliation due to planar biotite alignment parallels phase 1 fold axial planes and is interpreted as axial plane foliation. On a small number of fold hinges stratification-axial plane foliation intersections produce mica edge lineations parallel to minor fold axes. The penetrative lineation in "Cache Creek" metachert lenses is produced by linear quartz alignment parallel to phase 1 fold axes.

Structural data for phase 1 deformation is plotted on plan view, figure 3-20, and equal area projection figure 3-21. Poles to phase 1 axial planes concentrate nearly horizontally, defining an average axial plane orientation of $107^{o}/90^{o}$ N. Phase 1 fold axes and axial lineations scatter along the small circle locus shown in figure 3-21. The average axial orientation, assumed to be the intersection of the average axial plane and lineation locus, has orientation $289^{o}/20^{o}$. Poles to stratification lie on a steeply dipping surface with pole orientation $288^{o}/05^{o}$, approximately colinear with phase 1 axial orientation. Stratification (see plate A) is generally steeply dipping and closely coplanar with phase 1 axial plane orientation. This structural data indicates that stratification has been almost completely transposed toward the earliest phase of "Cache Creek" deformation. Interlimb angles were never greater

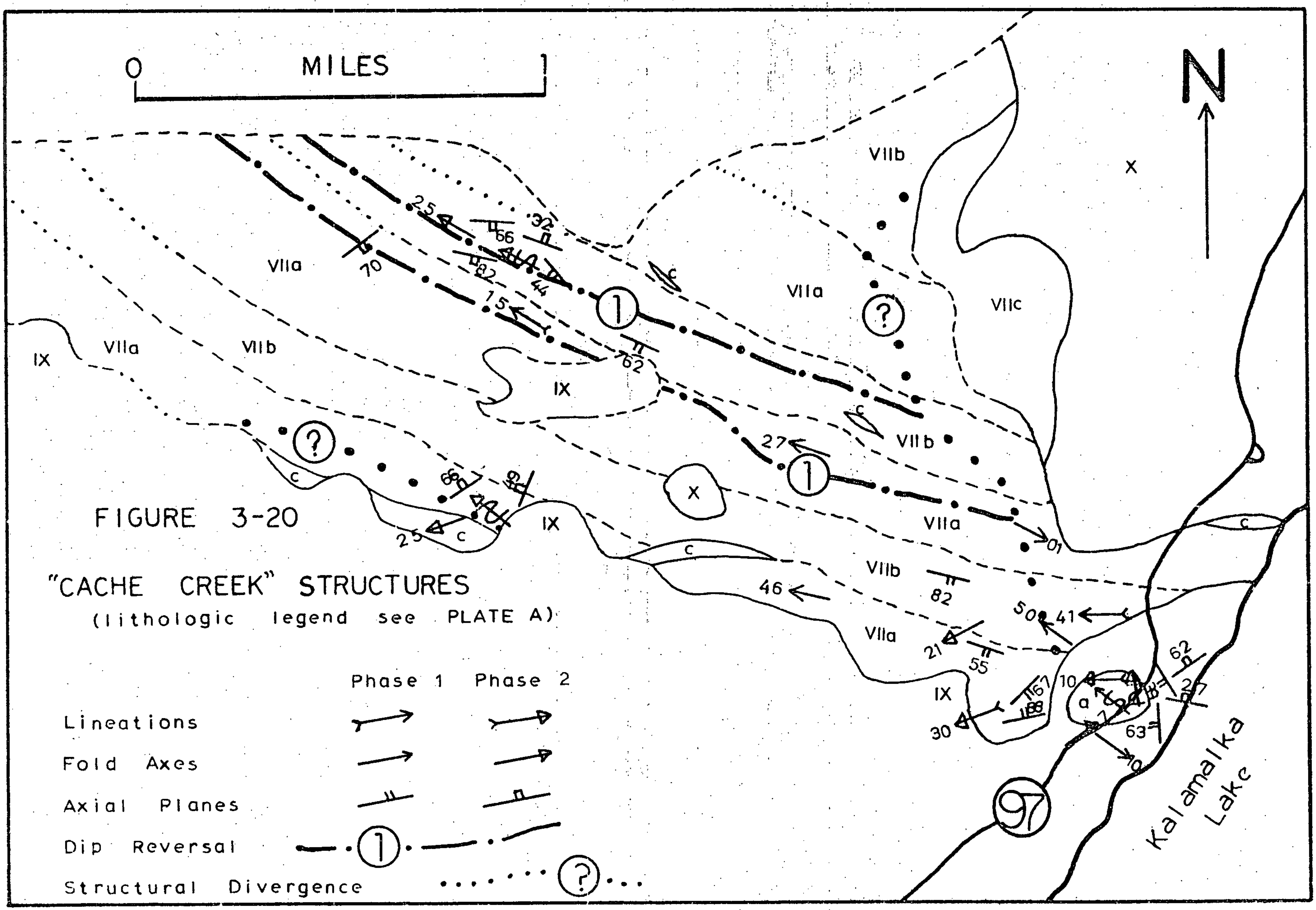
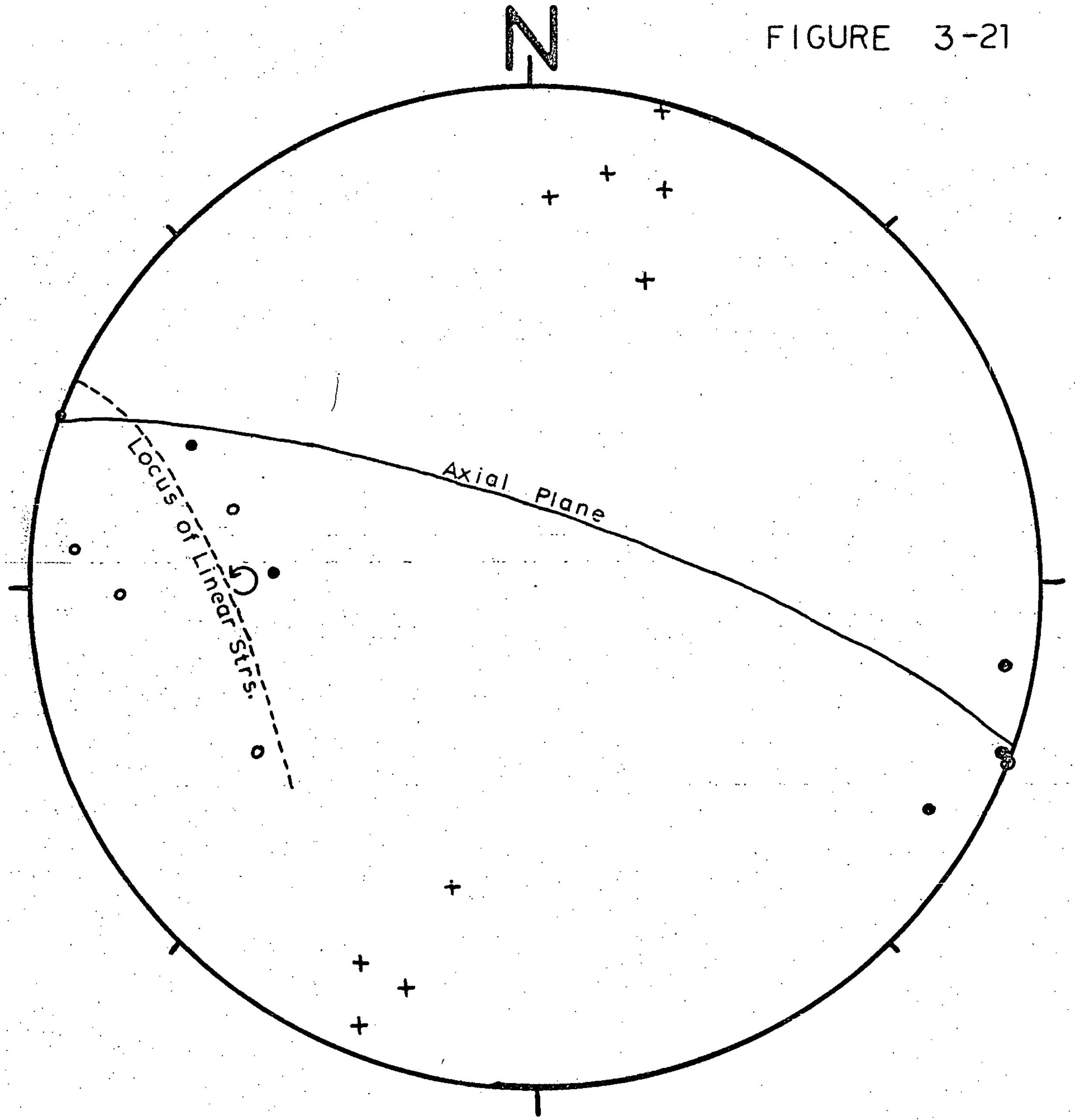


FIGURE 3-20

"CACHE CREEK" STRUCTURES
(lithologic legend see PLATE A)

FIGURE 3-21



Cache Creek Phase 1

- ● Lineations
- o Fold axes
- ↻ Fold axes with vergence
- \+ Poles to axial planes

than 10 degrees.

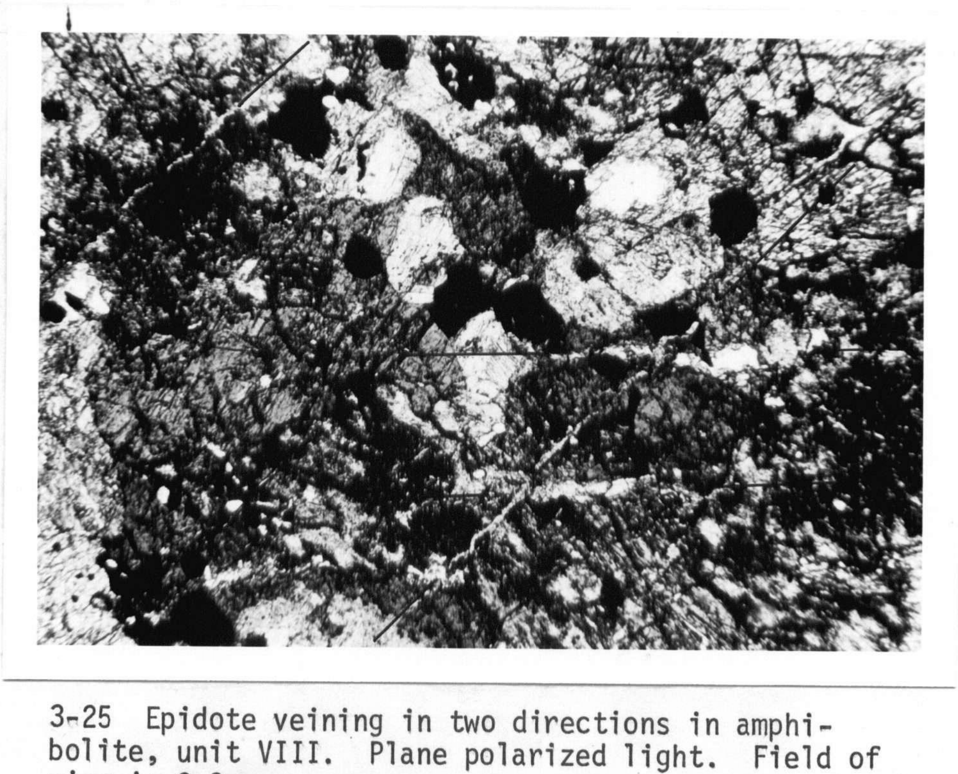
Compositional layering within "Cache Creek" domain D10 generally dips steeply southward. However along an easterly trending band at location E-5, domain D10a, layering dips steeply northward. Both compositional layering and phase 1 axial plane orientation diverge widely from their average orientations in the vicinity of the large limestone pods, domain D10b, figure 3-20. The question of limestone emplacement in "Cache Creek" clastics is discussed in Section 5.

"Cache Creek" Phase 2

Phase 2 deformation in "Cache Creek" rocks consists of mesoscopic angular folds and kinking of phase 1 foliation producing crenulation cleavages and lineations. Folds approach chevron style geometry with planar limbs and angular hinges. As seen in figure 3-22, planar structures are developed along axial planes. These poorly developed, discontinuous surfaces do not appear penetrative in the field but micas in the fold cores are microscopically crenulated suggesting an intermediate style between crenulation and fracture cleavages. No linear structures other than fold axes were recognized associated with mesoscopic phase 2 folds. Most early metamorphic foliation surfaces are crenulated on a scale of from 0.5 to 5 centimeters. Because of similarities in style and orientation, crenulations and structures related to minor folds are both considered to be produced by phase 2 deformation.

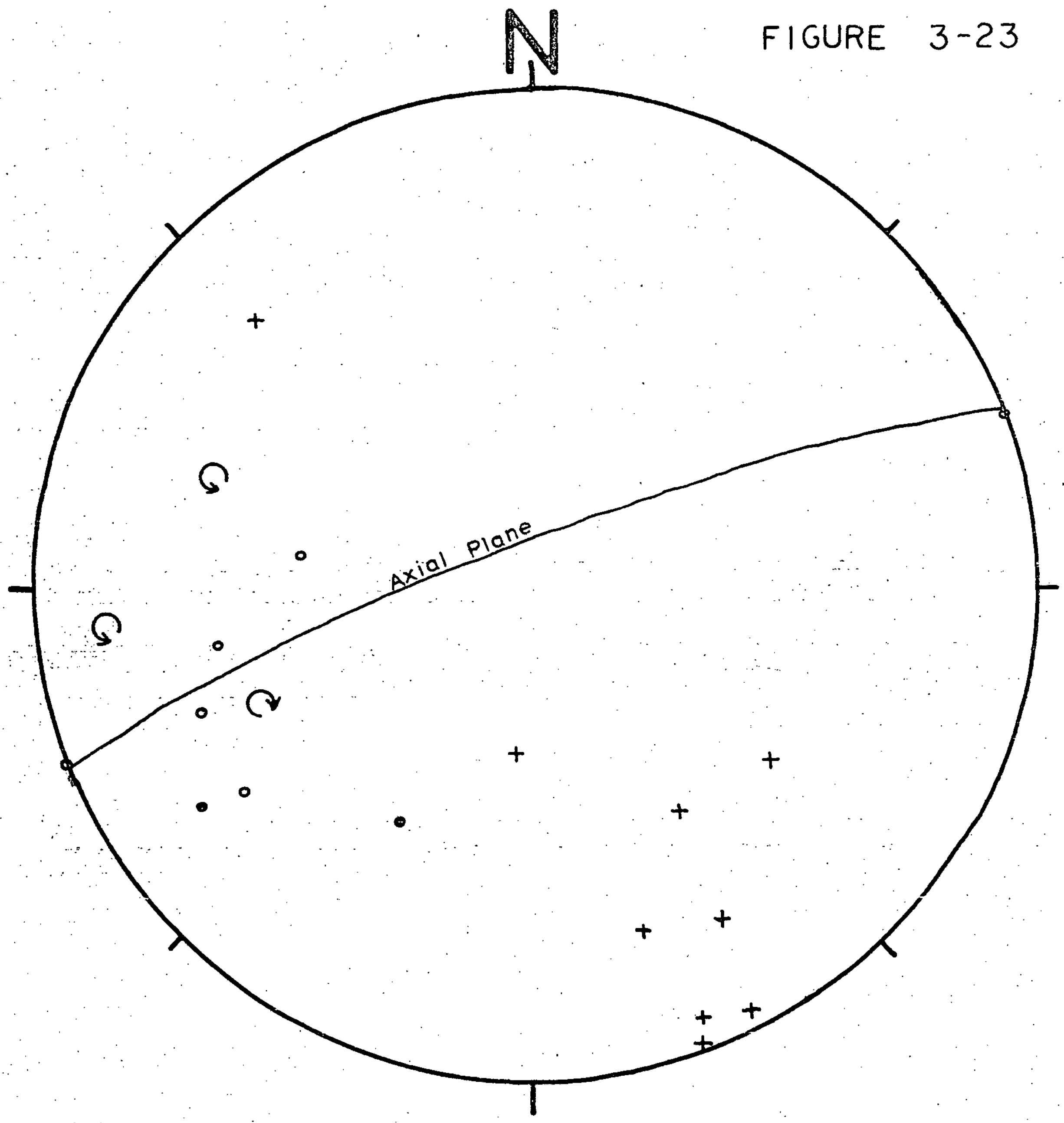
Structural data for phase 2 deformation is shown in figure 3-23. Concentration of poles to axial planes define an average phase 2 axial plane orientation of $066^{o}/80^{o}$ N. Minor fold axes and crenulation lineations concentrate at $253^{o}/36^{o}$. The center of the small circle locus of

3-22 View along the hinge of an angular phase 2 fold in siltstone, unit VIIa. Scale is in inches.



3-25 Epidote veining in two directions in amphibolite, unit VIII. Plane polarized light. Field of view is 3.3 m.m. across.

FIGURE 3-23



Cache Creek Phase 2

• Lineations

○ Fold axes

↻ Fold axes with vergence

+ Poles to axial planes

phase 1 linear structures, $253^{0}/00^{0}$, coincides with phase 2 axial trend, indicating parallel style refolding of phase 1 structures by phase 2. Interlimb angles averaged from five mesoscopic phase 2 folds is 60^{0}. No macroscopic phase 3 structures were recognizable in "Cache Creek" rocks.

"Cache Creek" Phases 3 and 4

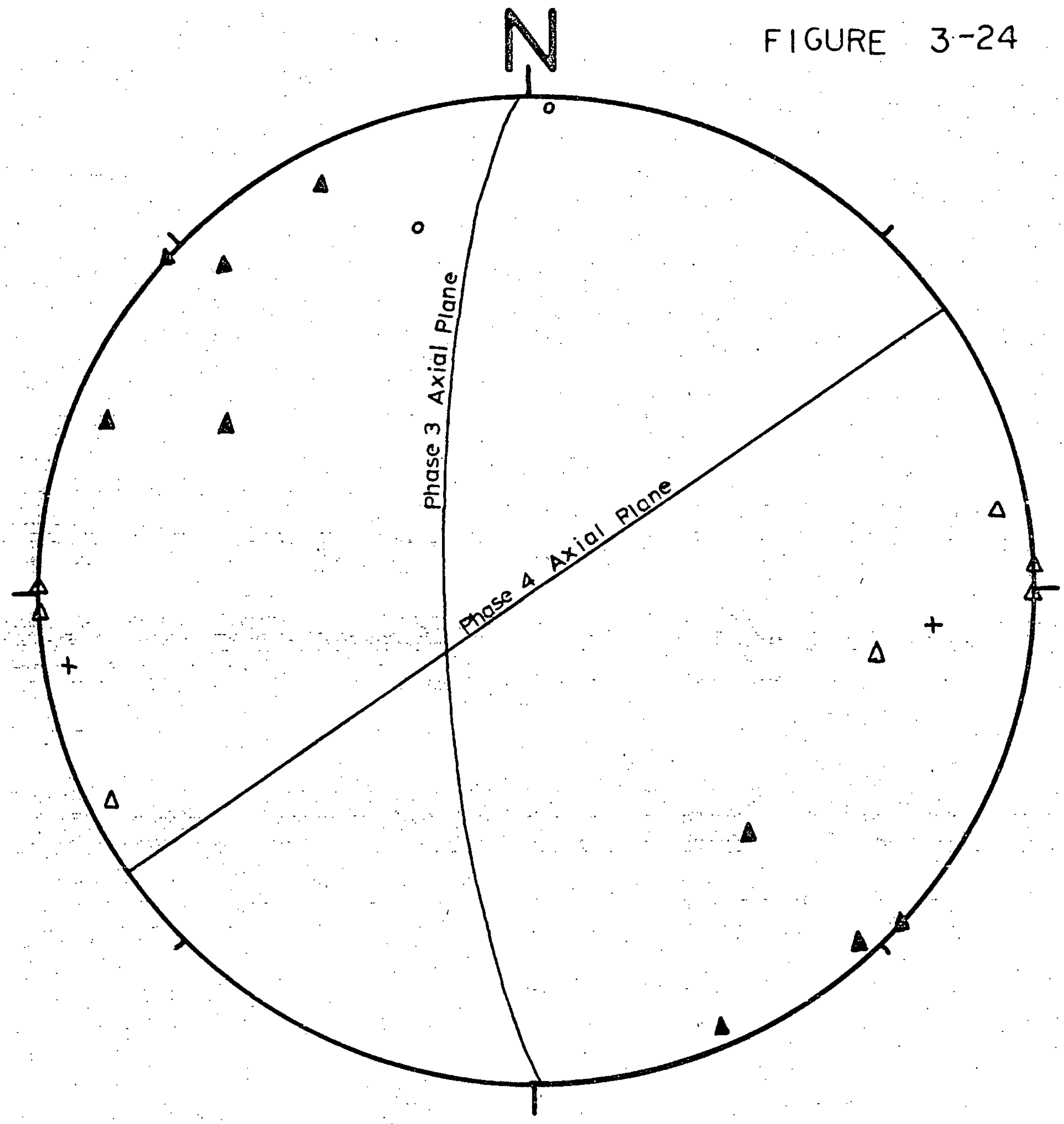
Phase 3 and 4 deformation in "Cache Creek" rocks consist of vertical fractures with no offset and very little separation. Quartz and calcite vein filling as well as chloritization and epidotization of surrounding country rocks is common. In two instances, stratification is warped into minor, upright, north trending buckle folds.

Structural data for phase 3 and 4 deformations is shown in figure 3-24. Fractures all dip steeply. Data could be interpreted as comprising a single deformation with widely varying fracture orientations. Two separate concentrations are recognizable, however, and neither fracture set exhibits shear features. Furthermore, the two recognized mesoscopic folds trend northerly rather than at an orientation intermediate between the two recognized concentrations. From this evidence two deformational episodes, trending northeasterly and northerly, are defined as phase 3 and 4. The relative timing of these episodes is unknown and no macroscopic phase 3 or 4 structural elements are recognizable.

Amphibolite Structure

Amphibolite sill, unit VIII, crops out at the northern tip of the Vernon Arm of Okanagan Lake, location C-3. It contains abundant phase 4 and 5 fractures with quartz, calcite and epidote vein filling, figure 3-25, and clearly predates these structural events. No earlier structures were identifiable. The K/Ar date on hornblendes from Unit VIII of

FIGURE 3-24



Cache Creek Phase 3and4

Phase 3	Phase 4	
	o	Fold axes
▲	Δ	Poles to fractures
	+	Poles to axial planes

178$\pm$ 6 m.y. appendix 1, probably represents a thermal event as the originally igneous sill was metamorphosed to albite-epidote-amphibolite facies, the highest grade attained in "Cache Creek" rocks. It follows that metamorphism may have occurred at about 178 m.y. in "Cache Creek" rocks of the thesis area.

Quartz Monzonite Structure

The large granodiorite-quartz monzonite batholith, unit IX, to the south of "Cache Creek" rocks and west of Kalamalka Lake, also contains evidence of phase 4 and 5 brittle deformation but no earlier structures were recognizable. Although of low precision and questionable accuracy, the 58 m.y. Sr/Rb isochron obtained by Fairbairn et.al. for this body is in agreement with the present structural interpretation.

4. METAMORPHISM

The thermal history of the thesis area, like its deformational history, is complex. Shuswap rocks reached a maximum cumulative metamorphic grade of medium pressure amphibolite facies contemporaneous with and following phase 2 deformation. This metamorphic culmination is termed M2. Extremely limited data indicate that an early metamorphic episode may have occurred in Shuswap rocks prior to phase 2 deformation. Although it is unknown if this was a prograde stage of metamorphism accompanying phase 2 deformation or a separate earlier event, conditions were probably lower than the metamorphic culmination. This tentative early event is termed M1.

Regional metamorphism also occurred in "Cache Creek" rocks but attained a maximum grade of only greenschist to albite-epidote-amphibolite facies. Amphibolite sill, unit VIII, isotopically dated at 178$\pm$ 6m.y., appendix 1, underwent regional metamorphism prior to phase 4 deformation. This date probably represents thermal upgrading rather than the crystalization age, and could be related to the Colombian Orogeny. Abundant hydrothermal activity occurred during Tertiary time causing alteration in the vicinity of fractures, quartz and calcite vein filling, and in some cases cataclastic brecciation. This late thermal event is recognized in both Shuswap and "Cache Creek" rocks. In the remainder of this chapter metamorphic parageneses, reactions, and physical conditions for metamorphic episodes are discussed, starting with the metamorphic culmination.

Shuswap M2

Useful M2 parageneses are listed in figure 4-1. Due to the widely varied mineralogy of units I through IV, amphibolite facies Shuswap

FIGURE 4-1

METAMORPHIC PARAGENESES

Shuswap Complex

1) orthoclase + plagioclase + quartz + calcite (unit III)

2) quartz + zoisite ± plagioclase (unit IV)

3) grossularite + quartz + calcite (unit IV)

4) calcite + quartz + diopside (unit IV)

5) plagioclase + orthoclase + diopside + sphene (unit IV)

6) quartz + muscovite + diopside + magnetite (unit III)

7) quartz + zoisite + diopside + magnetite (unit IV)

8) quartz + scapolite + diopside (unit Ia)

9) cummingtonite + hornblende + plagioclase (unit I)

10) diopside + calcite + sphene (unit IV)

11) quartz + orthoclase + plagioclase + biotite (unit II)

12) almandine + biotite + plagioclase (unit III)

13) muscovite + quartz + plagioclase (unit III)

"Cache Creek" Complex

14) biotite + chlorite + quartz (unit VII)

15) quartz + biotite + muscovite (unit VII)

16) plagioclase + quartz + chlorite (unit VII)

17) hornblende + ilmenite (unit VIII)

19) epidote + actinolite + opaque (unit VIII)

20) epidote + plagioclase (unit VIII)

metamorphism is quite well defined and is discussed first. Orthoclase and plagioclase are commonly found in contact in Shuswap rocks of the map area. Albite substitution in coexisting orthoclase and plagioclase was therefore used, following the technique described by Stormer (1975), to establish a geothermometer or more specifically a P/T coexistence line in Shuswap rocks. Albite substitution in three plagioclase grains coexisting with two orthoclase grains was determined using the ARL electron microprobe. Albite substitution averaged 71% in plagioclase (An 29), and 23% in orthoclase. Using the equilibrium equation:

$$NaAlSi_3O_8 \ (AF) = NaAlSi_3O_8 \ (PF) \qquad (1)$$

(where (AF) and (PF) indicate alkali feldspar and plagioclase mineral phases)

and graphs of Stormer (1975), the pressure - temperature coexistence line (1), figure 4-2, was deduced, with $50^{\circ}C$ uncertainty.

It was of interest to determine the pore fluid composition during M2. Calcareous quartzite, unit IV, was chosen for detailed analysis because of the strong dependence of reactions in carbonate rocks on CO_2 concentration in the pore fluid (Greenwood, 1962). The occurrence of parageneses 2 and 3 indicates that XCO_2 was very low in these rocks and occurred between isobaric invariant points:

$$Gr + Qz + Pr + Ca \qquad (I)$$

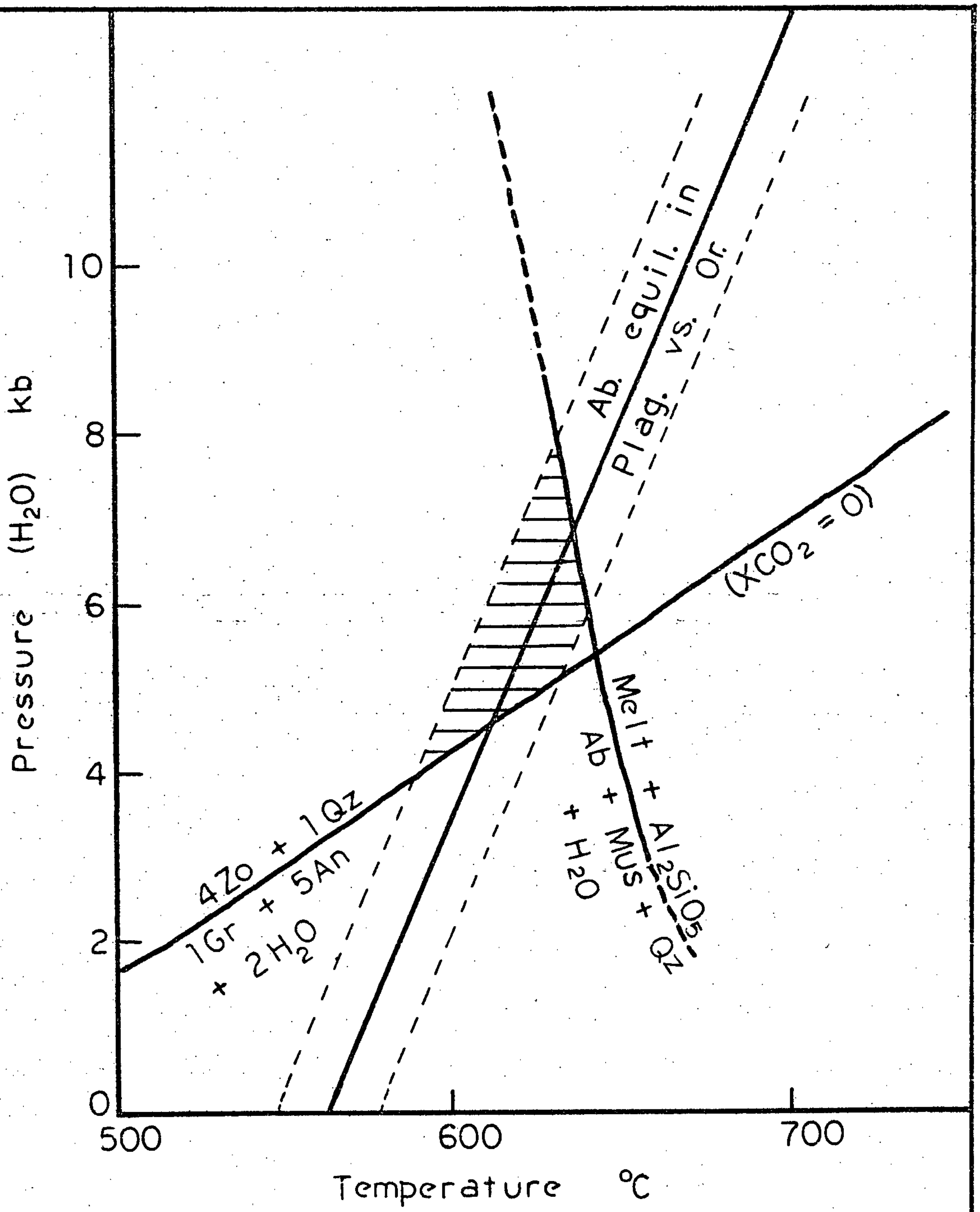
investigated by Gordon and Greenwood (1971) and

$$Zo + Gr + Qz + An + Ca \qquad (II)$$

investigated by Winkler (1974) in the magnesium free system. Assuming six and two kilobars as upper and lower pressure bounds*, isobaric invariant points (I) and (II) indicate the following brackets for the proportion of CO_2 in the pore fluid:

$$5\% \pm 15\% < XCO_2 \lesssim 23\% \pm 5\% \qquad (2)$$

* Six and two kilobars are common upper and lower experimental pressure conditions.



Equilibria for the metamorphic culmination in Shuswap rocks of the study area.

FIGURE 4-2

The low XCO_2 value is expected due to the relatively small volume and low calcite content of unit IV. Analysis of pore fluids was also attempted directly using the crushing stage technique of Roedder (1970 d) on fluid inclusions in quartz. Although inclusions are numerous, giving the quartz its milky appearance, they are so small, never larger than a few microns, that no quantitative results were obtained. Fortuitously, the determination of abundant low XCO_2 pore fluids proved useful in establishing upper bounds on M2 pressure and temperature.

As seen from paragenesis 2 quartz occurs in contact with zoistite in unit IV. Equilibrium is therefore to the left of the equation:

$$4 Zo + 1 Qz = 1 Gr + 5 An + 2 H_2O + (Mag.) \quad (3)$$

experimentally studied by Liou (1973). Because magnetite was commonly observed in unit IV, parageneses 6 and 7, results obtained for equation (3) using a QFM rather than an NNO buffer seem appropriate. Equation (3) defines maximum temperature and minimum pressure because of its positive slope, figure 4-2. Conditions of P(total) = PH_2O or $XCO_2 = 0$ were chosen as $XCO_2 > 0$ would only shift the curve upward and to the left, further restricting pressure and temperature conditions. Equation (3) establishes a lower bound to the P/T line defined by equation (1).

Although not common, muscovite is found in all Shuswap units. The coexistence of muscovite, plagioclase plus quartz, paragenesis 13, and the lack of any aluminosilicates, indicates that equilibrium lies to the left of the equation:

$$Ab + Mus + Qz + H_2O = Melt + Al_2SiO_5 \quad (4)$$

studied experimentally by Storre and Karotke (1971). Combination of equation (4) with the P/T coexistence line defined by equation (1) define upper pressure and temperature conditions for cumulative Shuswap metamorphism.

Equations (1), (3) and (4), shown in figure 4-2, indicate that maximum cumulative metamorphic conditions in Shuswap rocks were approximately 610°C and 5.2 kilobars with a low CO_2 concentration in the pore fluid.

Parageneses 4 through 8 in Shuswap rocks imply that equilibrium lies to the right of equation:

$$1 \text{ Tr} + 3 \text{ Cc} \pm 2\text{Qz} = 5\text{Di} + 3CO_2 + 1H_2O \qquad (6)$$

investigated experimentally by Skippen (1974). Diopside alignment in unit IV produces southeast phase 2 lineations but no north trending phase 1 diopside lineations were observed in unit IV. Phase 2 fold cores commonly contained diopside segregations but phase 1 cores do not. This indicates that M2 metamorphism is at least contemporaneous with phase 2 deformation. Hornblendes defining phase 2 lineations in units I and II exhibit little fracturing or other deformation features. Phase 3 axial plane cleavage however, is dominantly brittle in nature, therefore M2 metamorphism was either retrograde or had ceased entirely by the time of phase 3 deformation. M2 in Shuswap rocks was broadly contemporaneous with and continued following phase 2 deformation, thus the annealing stage enhanced the fabric produced during deformation.

Shuswap M1

The original geometry of early phase 1 deformation in Shuswap rocks is unknown due to isoclinal phase 2 refoldings and later tightening necessitated by phase 3. Theoretically phase 1 could have been a brittle flex-slip event with no attendant metamorphism. Extremely limited evidence suggests that this is not the case. As noted previously unit IV contains marked diopside alignment parallel to phase 2 axes. No diopside alignment in phase 1 axial direction was observed although minor phase 1 folds in unit IV were common (figure 3-6). Although mesoscopic phase 1 folds were observed in all layered Shuswap lithologies, only six recognizable phase 1 lineations were observed. These lineations were produced by hornblende mineral alignment and occur only in units I and II; hornblende-biotite gneiss and hornblende gneiss, not units III and IV. This limited evidence suggests that an early metomorphic event, termed M1, occurred earlier than M2. Metamorphic grade, although probably lower than M2, and relationships with deformations and later metamorphic episodes, are unknown.

"Cache Creek" Metamorphism

Petrographic investigation of "Cache Creek" metamorphic mineralogy proved difficult due to the ubiquitous fine grain size so X-ray diffraction studies of units VIIa, VIIb, and VIII were conducted to provide additional information. Results indicate that these rocks have undergone significant metamorphism of greenschist to albite-epidote-amphibolite facies. Rocks north of the Vernon Arm of Okanagan Lake may have undergone slightly higher grade conditions than those to the south.

Lithic arenities, unit VIIa, contain abundant angular plagioclase fragments which exhibit negative relief and albite X-ray diffraction lines. Fine grained metamorphic biotite and white mica is abundant in siltstone, unit VIIa, and occurs in the matrix of sandstone, unit VIIb. Although not often optically recognizable in the microcrystaline matrices both units produce chlorite X-ray patterns. Relevant metamorphic parageneses from unit VII are listed in figure 4-1.

Paragenesis 14 indicates that equilibrium in unit VII lies to the right of the equation:

Stilp + Phen = Bi + Chl + Qz + H_2O (5)

(Winkler, 1974, p. 202) illustrated in figure 4-3. Unit VII therefore attained greenschist facies metamorphic conditions with temperature greater than approximately 450^oC. Calcareous fossils in limestone pods contained in unit VII, figure 2-7, are partly recrystalized but recognizable. Biotites are aligned in the phase 1 foliation plane which wraps around brittle phase 2 axial plane cleavage, figure 3-22, suggesting that metamorphism culminated prior to phase 2 deformation.

The large amphibolite sill just north of the Vernon Arm of Okanagan Lake provides informative metamorphic mineralogy. Ragged albite remnants occur within abundant granular to fibrous manganiferous epidote (piedmontite) and possible clinzoisite. Rare clinopyroyene and possible olivine remnants form cores within subhedral complexly zoned aluminous hornblende, figure 2-9. X-ray diffraction study indicates pale green hornblende rims to be actinolitic. Chlorite, magnetite and spene are common accessories with occasional minor quartz.

The common association of epidote and actinolite, paragenesis 19, indicate that equilibrium lies to the right of the equation:

Pre/Pü + Chl + Qz = Ep + Act + H_2O (6)
(Winkler, 1974, p. 70).

This temperature dependent equation, shown in figure 4-3, indicates a temperature in excess of approximately $350^\circ C$. Actinolitic rims on complexly zoned hornblendes suggest that the causative thermal event was protracted in nature with a pronounced retrograde stage. Winkler (1974), p. 166, states that:

"the change from actinolite to hornblende will probably take place at about 500°C, rising only slightly with increasing pressure."

Liou (1973) experimentally investigated metamorphic reactions concerning epidote and in particular the equations:

$$Ep + Qz = Gr + An + (Mag) + F \qquad (7)$$

and

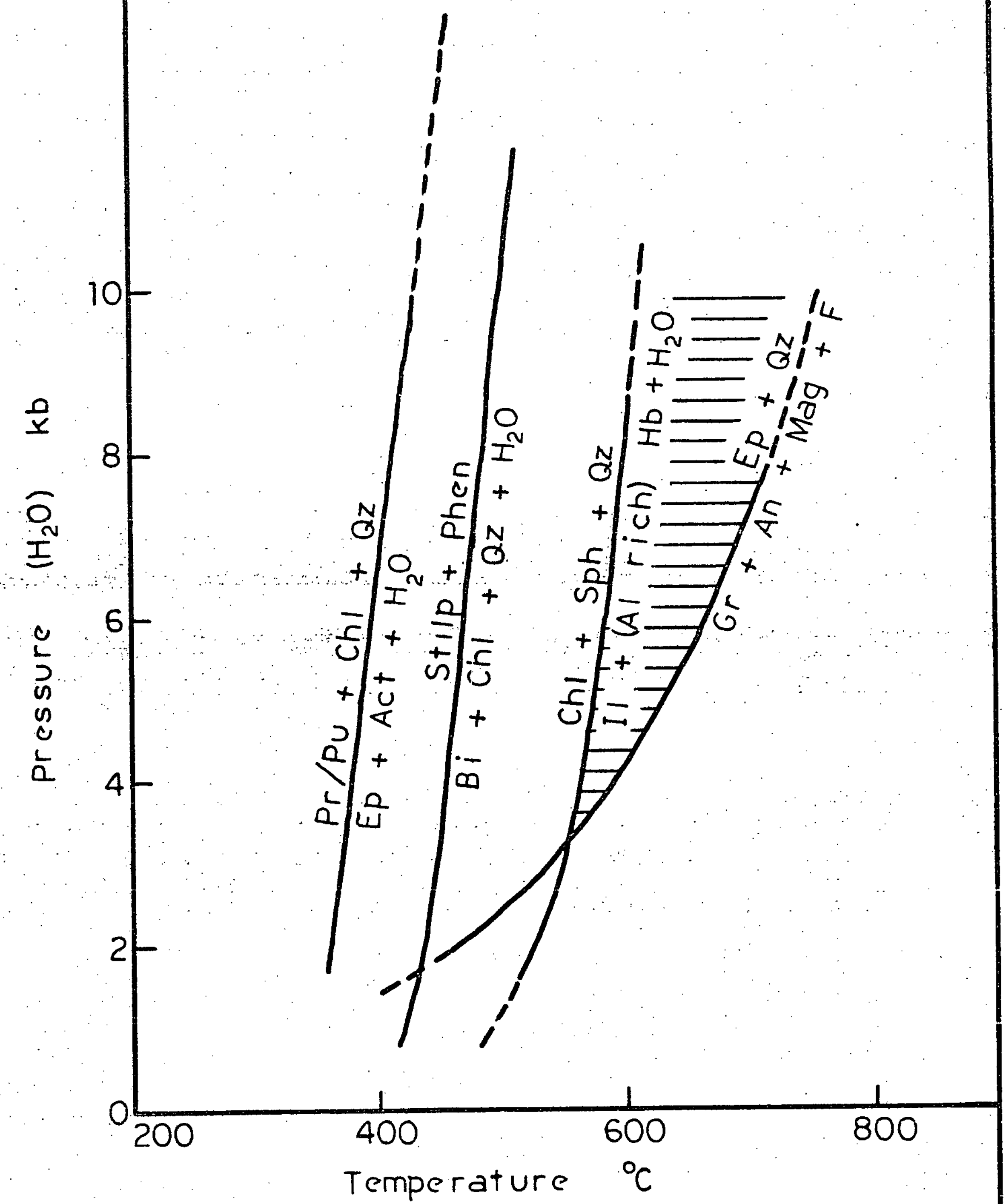
$$Chl + Sph + Qz = (Alrich)\ Hb + Il + H_2O. \qquad (8)$$

Paragenesis 18 indicates that equilibrium lies to the left of equation (7) shown in figure 4-3, whereas paragenesis 17 lies to the right of equation (8), as hornblende is in contact with ilmenite.

The metamorphic culmination in "Cache Creek" rocks reached albite-epidote-amphibolite facies conditions with pressure in excess of 3 Kb and temperature of about 550°C, Liou (1973). The highly recrystalized nature of the limestone in unit VI and the metamorphic parageneses of the associated amphibolite sill, unit VIII, suggest that metamorphism may have been more intense north of the Vernon Arm of Okanagan Lake than in unit VII to the south. Lack of definitive parageneses in unit VII precludes direct assignment of a particular isograd.

Mineralogical and textural relationships in the amphibolite strongly suggest an igneous parentage. Clinopyroxene and olivine remnants coring subhedral hornblendes and remnant plagioclases in the epidote matrix indicate an original gabbroic composition assuming simplistically that mafics alter to hornblende and plagioclase alters to albite plus epidote. Unfortunately, contacts with surrounding metasedimentary units VI and VII were not observed.

Hornblendes from unit VIII were dated by the K/Ar method at 178± 6 m.y., appendix 1. The secondary replacement nature of the hornblendes, the hypothesized original igneous composition, and the super-



Equilibria for the metamorphic culmination in "Cache Creek" rocks of the study area.

FIGURE 4-3

posed albite-epidote-amphibolite facies metamorphism all point to thermal upgrading of the K/Ar radiogenic clock. The 178 ± 6 m.y. date represents a metamorphic event rather than crystalization of the original igneous body. Unit VIII contains abundant phase 3 and 4 fractures, attendant hydrothermal alteration and possible open warping. No earlier structures were recognized.

Unit VIII structurally predates brittle deformation and hydrothermal alteration of probable Tertiary age and underwent a regional metamorphic episode, possibly attaining albite-epidote-amphibolite facies conditions, at about 178 m.y. Regional implications of "Cache Creek" structural and metamorphic history are discussed in section 5.

Tertiary Thermal Activity

Abundant hydrothermal activity occurred during Tertiary time related to late brittle deformations. Chlorite, epidote, and calcite veins occupy steeply dipping northerly and northeasterly striking fractures in both Shuswap and "Cache Creek" rocks, figure 3-25, and Mafics and feldspars in surrounding country rocks are highly altered. In one instance, a northeast trending band of hydrothermally altered catclastic breccia was observed at station C-38, figure 3-15. Abundant igneous activity at this time may have provided the heat necessary for this localized thermal event, however, the vast areal extent of Tertiary hydrothermal activity suggests alternate heat sources. This could be frictional heating, due to easterly directed tectonic underthrusting during Tertiary time.

5. DISCUSSION

Age, Origin, and Stratigraphic Correlation of Shuswap Units

Any statement concerning the origin of Shuswap rocks in the thesis area is entirely speculative as no whole rock chemical analyses were performed and no relict structures observed. The ubiquitous layered nature of units I through IV probably reflects metamorphically accentuated stratification. Christie (1973) suggested a possible graywacke suite origin for high grade Shuswap metamorphics near Vaseaux Lake based on mineralogy. Ryan (1973), however, favored a volcanic, possibly andesitic origin from Sr/Rb isotopic and mineralogical data.

Neither the base nor top of the local Shuswap sequence is exposed in the thesis area. The present author has identified two phases of isoclinal folding in layered units I through IV. Similar high grade rocks to the south, in the Oliver-Osoyoos area (Ryan 1973), and the Vaseau Formation (Ross and Christie, 1969; Christie, 1973) have also undergone two isoclinal deformational phases. Mineralogical similarities of amphibolite gneiss, biotite schist, and calcareous quartzite in the thesis area to similar lithologies in the south are striking. Actual lithological correlation, however, is not possible.

The controversy over the origin and age of the Shuswap metamorphic complex has continued since Dawson (1898) first mapped the rocks (see section 1). White (1959) presents an entertaining review of the rapid evolution of ideas prior to 1959. Ross (1970, p.64) studied the structural evolution of the Kootenay Arc, east of the thesis area and notes that:

"the northerly extension of the arc trends into; and becomes an integral part of the Shuswap complex."

He suggests that parautochthonous granitic gneiss basement of possible

Hudsonian age was actively involved in the core of the Frenchman's Cap gneiss-dome; one of the Shuswap structural culminations. The earliest causative Shuswap deformation occurred in pre-Mesozoic time. To the east major allochthonous fold cores produced by the same early deformation override passive Purcell basement. Campbell (1973), in a study of Cordilleran tectonics, amplifies Ross' contentions. He concludes that "thick skinned" tectonics with actively involved basement and dominantly vertical movements dominate in the Omineca Crystalline Belt (Shuswap Complex). To the east however, "thin skinned" tectonics dominate, causing horizontal thrusting to the east over a passive, non-involved basement.

Lead isotope analyses of zicons from the Shuswap Terrain have provided promising results which "see through" the thermal events which have consistently confounded other radiogenic dating techniques. Wanless and Reesor (1974) derive a 1960 m.y. Proterozoic age for "crystalization" of zircons from granodiorite of the core zone of the Thor-Odin gneiss dome northeast of the thesis area. Based on limited evidence they suggest an igneous origin of the granodiorite not representative of the Shuswap Complex as a whole on which they comment (Wanless and Reesor, 1974, pg 331):

"The mantling gneisses of great areal extent throughout the Shuswap, have been derived from rocks ranging in age from probable Cambrian to Triassic age."

They further suggest that the 175 m.y. lead isotope lower intercept represents the metamorphic and deformational culmination of the Colombian Orogeny. Okulitch et.al. (1975) find a 375 m.y. Devonian minimum crystalization age of zircons from the Mount Fowler Batholith northeast of the thesis area. They suggest that this plutonism may be related to the Late Devonian-Early Mississippian Caribooan or Antler

Orogeny (Ross and Barnes, 1972; Wheeler et.al., 1972; White, 1959). In the most recent study to date Wanless and Okulitch (1976, p.47) summarize their existing geochronologic data concluding:

"The Shuswap Metamorphic Complex, floored by mid-Proterozonic gneiss, was formed from late Proterozoic to Late Triassic sedimentary and volcanic rocks during the Jura-Cretaceous Columbian Orogeny."

In conclusion the present state of knowledge indicates complex Precambrian through Mesozoic origin and deformation of rocks constituting the Shuswap Metamorphic Complex. The present study, other than reaffirming Paleozoic, Mesozoic and Cenozoic deformational and Metamorphic events provides no new information concerning the origin and stratigraphic correlation of the complex.

Age, Origin, and Stratigraphic Correlation of "Cache Creek" Units

No whole rock chemical analyses were performed on "Cache Creek" rocks. Lithic arenites are very immature, containing up to thirty percent of fine grained matrix. They occasionally exhibit graded bedding and contain metachert lenses. Fine (1 m.m.) compositional layering in siltstone, Unit VIIb, is convoluted and discontinuous with abundant microfaults (figure 2-8) indicative of early soft sediment deformation. This evidence is suggestive of a distal turbidite, marine graywacke suite origin.

Massive limestone pods in Unit VII form sharp contacts with surrounding clastics down to a scale of a few milimeters. Stratification and all later structures except brittle phase 3 and 4 fractures in siltstone and sandstone in the vicinity of the limestone pods, domain D10b, are disrupted from their average orientations. This structural disruption was noted in section 3. No structures other than phase 3 and 4 fractures were recognized in the limestone. Absence of penetrative structures in the limestone pods, coupled with the abundance of disrupted early structures in surrounding sediments, suggests possible tectonic emplacement of the limestone into surrounding previously deformed sediments.

Okulitch (1974) assigned complexely folded, low grade metasediments northwest of Okanagan Lake to the Pennsylvanian-Permian Cache Creek Group, based on re-evaluation of the fossil locality originally indicated by Jones (1959). He correlated these with "Cache Creek" rocks of the thesis area, southeast of Okanagan Lake, apparently on the basis of lithologic similarities.

"Cache Creek" clastics of Unit VII consist of interlayered siltstone and fine grained poorly sorted sandstone containing angular rock, quartz, and feldspar fragments. This sequence shows marked similarities to the basal division of the Pennsylvanian-Permian Chilliwack Group which Monger (1970, p.6-7) describes as, 'pelite siltstone, and fine grained sandstone ... composed of poorly sorted angular fragments.' The present author suggests that these groups are possible stratigraphic equivalents based on lithologic similarities. Definitive fossil evidence in "Cache Creek" rocks of the thesis area is lacking but ten miles to the northwest along the same structural trend Danner (personal communication) has identified Pennsylvanian-Permian fusulinids. He speculates that poorly preserved bryozoa from limestone pods of Unit VII, figure 2-7, may be Devonian in age.

In his discussion of correlation of eugeosynclical assemblages in the Cordillera, Monger (1975) subdivides upper Paleozoic rocks into three distinct north-south trending belts. The middle belt in Canada consists of the Mount Roberts, Cache Creek near Kamloops, Chapperon, Anarchist, Kobau and Chilliwack Groups. Danner (1976, p.68) has considered depositional environments of these rocks and finds:

"Late Paleozoic Cache Creek, Chilliwack, and Sicker Groups in south western British Columbia and their counterparts to the north and south, form distinctive faunal and lithostratigraphic sequences which originated in the much larger Paleozoic Pacific Ocean ...."

In summary "Cache Creek" rocks of thesis area are Paleozoic, possibly Carboniferous in age and may correlated lithostratigraphically with the basal member of Chilliwack Group to the west. Deposition occurred in a marine environment, probably as distal turbidity flows.

Shuswap - "Cache Creek" Structural Correlation

Structural and metamorphic correlation between Shuswap and "Cache Creek" complexes would be extremely useful in determining the overall geological history of the map area. Similarities in structural styles and orientations indicate that the complexes may be structural equivalents. Two factors, however, necessitate caution in this course of analysis. Shuswap rocks have undergone medium to high pressure amphibolite facies metamorphism whereas "Cache Creek" cumulative metamorphic grade attains only upper greenschist to albite-epidote-amphibolite facies. Furthermore, specific structures are not directly tracable between complexes. The presumed Shuswap-"Cache Creek" contact in the thesis area is not exposed. A review of the literature indicates widely differing attitudes towards the feasibility of structural correlation between assemblages of differing tectonostratigraphic positions.

Fyson (1970, p.107) working along the western margin of the Shuswap

Complex near Shuswap Lake concludes:

"Attenuated F_1 isoclines with an axial-surface schistosity prominent in the structurally lower rocks are absent in argillite, indicating a dying out upward of the initial deformation. F_2 recumbent folds in the schistosity trend constantly in some areas, but in others veer abruptly without mutual interference to form a complex map pattern. Thus the change from folds that are upright in the suprastructure to recumbent in the infrastructure is due to the dominance at each level of different generations."

Reesor (1970, p.73) regarding the Thor-Odin gneiss dome northeast of the thesis area concludes:

"In general the locus of gneiss domes is not determined by superposed, large-scale cross folds."

Okulitch (1973, p.1516) notes that different conclusions are reached after more comprehensive study:

"Reesor and Moore (1971) indicate that although folding phases may be intensely developed in one depth zone and insignificant in another, evidence of all phases of deformation is present in all successions."

This seems to affirm the possibility of structural correlation through differing structural levels. Working to the south of the thesis area Ryan (1973) directly traced early recumbent isoclinal folds in the high grade Vaseaux Formation to similarly trending tight, steeply dipping folds in the Anarchist Group, which may correlate with "Cache Creek" rocks of the thesis area (Monger, 1975). The present author feels that Reesor and Moores' (1971) contention of the presence of all phases in all structural levels tends to refute Fysons' (1970) view of folds dying out with depth. In conclusion structural correlation between assemblages of differing tectonostratigraphic positions based on structural similarities appears feasible.

The generalized styles and orientations of the deformations recognized in Shuswap and "Cache Creek" rocks are listed in figure 5-1. Structural styles and orientations of phase 4 and 5 deformations in

FIGURE 5-1

Structural and metamorphic relations between Shuswap and "Cache Creek" Complexes

SHUSWAP	"CACHE CREEK"
Phase 1	
Isoclinal Reclined Folds	
Axial Planes: 132°/20°N	
Axes: 000°/16°	
Low Grade Metamorphism ?	
Phase 2	**Phase 1**
Isoclinal Folds	Nearly Isoclinal Folds
Axial Planes: 117°/30°N	Axial Planes: 107°/90°N
Axes: 106°/06°	Axes: 253°/36°
Amphibolite Facies Metamorphic Culmination	Albite-Epidote-Amphibolite Facies Metamorphism
Phase 3	**Phase 2**
Tight Angular Folds	Tight Angular Folds
Axial Planes: 054°/40°N	Axial Planes: 066°/80°N
Axes: 046°/14°	Axes: 253°/36°
Phase 4 and 5	**Phase 3 and 4**
Open Buckle Folds and Fractures	Fractures
Ax. Plns.: (4) 072°/80°S (5) 002°/84°W	Ax. Plns.: (3) 056°/90°W (4) 000°/76°W
Axes: (4) 053°/00° (5) 000°/14°	Axes: (3) 056°/00° (4) 356°/05°
Hydrothermal Alteration	Hydrothermal Alteration

Shuswap rocks and phase 3 and 4 deformations in "Cache Creek" rocks are nearly identical. Great circle locii of poles to phase 3 axial planes in Shuswap rocks, and phase 2 axial planes in "Cache Creek" rocks, indicate that these late brittle events are cylindroidal in nature. Lack of concentrations of poles to compositional layering around macroscopic phase 5 Shuswap folds, and the gentle buckle geometry of mesoscopic folds implies a brittle,flex-slip style. The associated thermal events consist of quartz and calcite vein filling, and hydrothermal alteration of country rocks in the vicinity of fractures. Thermal effects are of similar limited extent in both complexes.

Similarities of these deformations and thermal events in Shuswap and "Cache Creek" rocks indicate that both complexes occupied similar tectonostratigraphic positions, possibly close to their present positions, at that time. Assuming that the 42 ± 10 m.y. Sr/Rb date for Unit V represents thermal resetting rather than Shuswap phase 2 deformation, an Ecocene age for phase 4 and 5 deformations and metamorphism in Shuswap rocks is deduced. This is consistent with the results of other workers (Ross, 1974; and Ross and Barnes, 1975) and regional tectonics in the Cordillera at this time.

Phase 3 Shuswap and phase 2 "Cache Creek" deformations produce tight angular folds with easterly striking axial planes. Fold geometry is somewhat unusual, comprising one steeply and one shallowly dipping limb, but is consistent within the two complexes. Similarities between Shuswap and "Cache Creek" mesoscopic folds are illustrated in figures 2-2 and 3-22. Average interlimb angles and axial trends are also similar. Axial plunges vary from gently westward plunging in "Cache Creek" rocks to gently eastward plunging in Shuswap rocks.

Fold axes of the earliest recognized deformational phase in "Cache Creek" rocks are nearly coincident with Shuswap phase 2 axes, as are axial traces of the two respective phases. Fold geometry approaches isoclinal form in both complexes. Axial surfaces dip northerly; Shuswap gently and "Cache Creek" steeply. Based on these similarities in style and orientation, and the fact that no prior structures other than stratification were observed in "Cache Creek" rocks, the author concludes that these are equivalent deformational phases in Shuswap and "Cache Creek" rocks. The differences in axial plane orientation between the two complexes may be related to differences in tectonostratigraphic levels at the time of deformation. Metamorphic grades of Shuswap and "Cache Creek" rocks; amphibolite and upper greenschist facies respectively, support this hypothesis (see figure 5-1). It is interesting to note that Ryan (1973) found similar variations in axial plane orientations from low dips in the amphibolite facies Vaseaux Formation to high dips in the contiguous greenschist facies Anarchist Group along coincident structural trends.

As discussed in section 4, amphibolite sill, unit VIII underwent a regional metamorphic episode at 178$\pm$ 6 m.y. attaining albite-epidote-amphibolite facies. This thermal event structurally predated phase 3 and 4 deformations in "Cache Creek" rocks but no further structural limitations are possible.

If Unit VIII, which lithologically defines the "Cache Creek" metamorphic culmination, is related to the earliest recognized deformation in "Cache Creek" rocks, then this phase and Shuswap phase 2 occurred at most 178$\pm$6 m.y. B.P. and probably represent effects of the Colombian Orogeny. This point however, is speculative due to the lack of substantive structural evidence.

Evidence of an early deformational phase in Shuswap rocks, phase 1, not recognized in "Cache Creek" rocks of Paleozoic, possibly Carboniferous age, indicates that some deformation and possible metamorphism occurred in the Paleozoic. Although of unknown magnitude, the early event was of regional extent, as phase 1 structures are found throughout Shuswap rocks of the thesis area. Phase 1 deformation could be related to the Cariboоan or Antler Orogeny discussed by White (1959), and Ross and Barnes (1972). Stratigraphic relations between Shuswap and "Cache Creek" rocks remain elusive but the present study suggests that Okulitch's contention of an unconformable relationship with "Cache Creek" sediments deposited on previously deformed Shuswap basement seems plausable. The actual contact remains to be found, possibly because of partial obliteration by the later structural culmination which involved both complexes.

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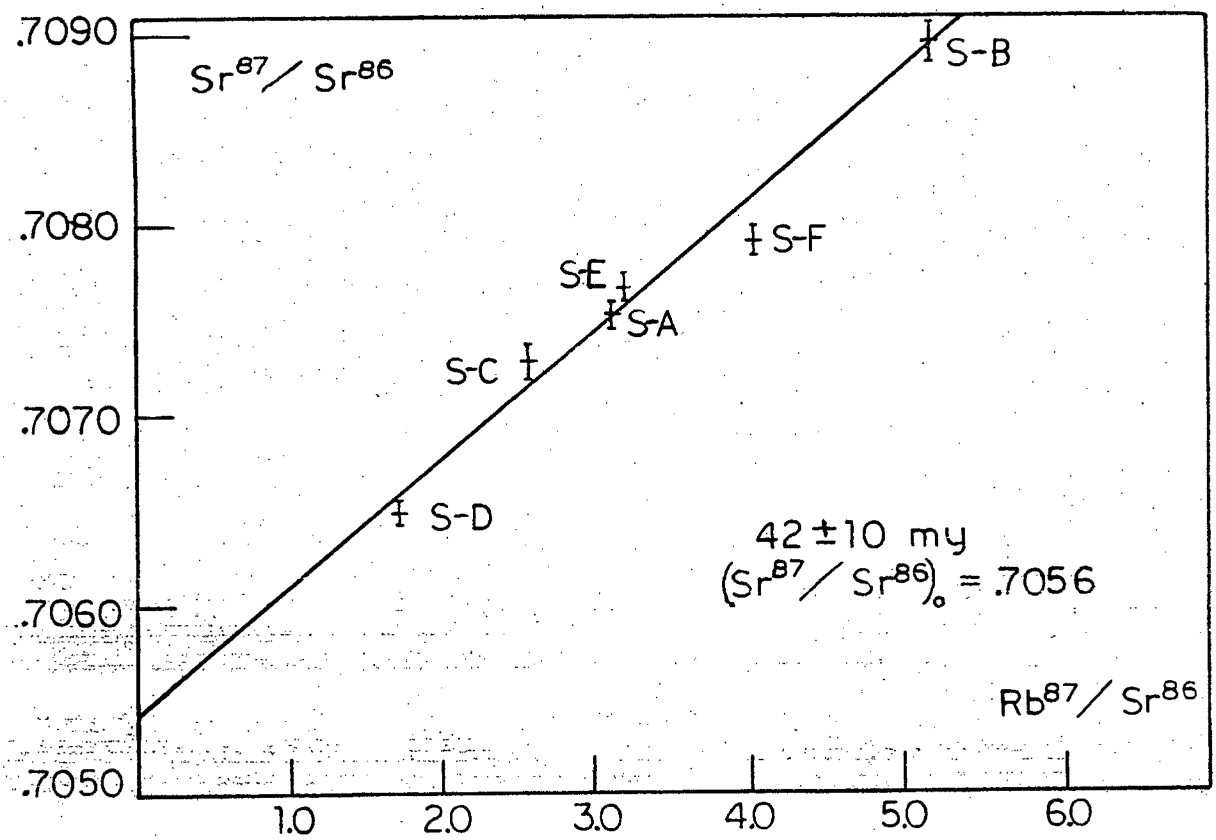
APPENDIX 1

Sr/Rb Geochronology

Six fresh samples of quartz monzonite, Unit V, were dated by the Sr/Rb whole rock method using the University of British Columbia, Department of Geology, facilities. The standard experimental procedures involved will not be discussed. The samples define a 42 ± 10 m.y. B.P. isochron with an initial Sr^{87}/Sr^{86} ratio of .7055 (figure A-1a). Although no Sr^{87}/Sr^{86} ratio determinations were conducted on surrounding layered units, initial ratios of high grade Monashee metasediments average much higher, up to .710 (Ryan, 1973; Medford, 1976). The upper limit of the uncontaminated basalt field of Eocene age rocks is approximately .703 (Faure and Powell, 1972), therefore Unit V was probably contaminated with Sr^{87} from surrounding Shuswap rocks. The significance of this Tertiary date is discussed in section 3.

K/Ar Geochronology

A hornblende separate from amphibolite sill (Unit VIII) was dated at 178 ± 6 m.y. B.P. by J.E. Harakal, University of British Columbia, using the K/Ar method. Potassium analyses were performed on KY and KY-3 flame photometers and argon analyzes utilized an MS-10 mass spectrometer. Potassium-argon data is listed in figure A-1b. The significance of the Jurassic isotopic date is discussed in section 5.



A-1a 42 ± 10 my Sr/Rb whole rock isochron of quartz monzonite sill, unit V.

A-1b K/Ar data from hornblende separates of amphibolite, unit VIII.

Potassium (% K)	0.864
$^{*40}Ar$ (10^{-5} cc STP/g)	6.4×10^{-1}
$^{*40}Ar$ / Total ^{40}Ar	0.91
$^{*40}Ar$ / ^{40}K	1.092×10^{-2}
Apparent Age	178 ± 6 my