STRATIGRAPHIC POSITION AND PETROCHEMISTRY OF THE LOVE COVE GROUP, GLOVERTOWN-TRAYTOWN MAP AREA, BONAVISTA BAY, NEWFOUNDLAND, CANADA

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STRATIGRAPHIC POSITION AND PETROCHEMISTRY OF THE LOVE COVE GROUP, GLOVERTOWN-TRAYTOWN MAP AREA, BONAVISTA BAY, NEWFOUNDLAND, CANADA

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ABSTRACT

The geology of the Glovertown-Traytown area, Bonavista Bay, Newfoundland, is dominated by the late Precambrian rocks of the Love Cove, the Musgravetown and the Connecting Point Groups. The Love Cove Group, in the map area, is made up of tuffs of acidic, intermediate and basic composition. These rocks are fault bounded and are considered to be the oldest rock in the Bonavista Bay region. Chemically, the Love Cove volcanics display a continental calc-alkaline affinity, similar to that of the Cascades and the Andes.

The Connecting Point Group consists of shales and greywackes with bands of interbedded basic volcanics. No contact relationships are visible between the Connecting Point and either the Musgravetown or the Love Cove Groups. However, at localities outside the map area, it is seen to lie with angular unconformity beneath the Musgravetown Group.

The Musgravetown Group is composed predominatly of clastic sediments with a major unit of extrusive volcanic rocks occurring at or near the base. These volcanics, the Bull Arm Formation, are mainly flow-banded rhyolites. Unlike the Love Cove rocks, they display a more alkaline trend in their chemistry. The sediments are mainly terrestrial, formed in fluvial, lacustrine and aeolian environments. Fluvial deposition is responsible for the Cannings Cove and Crown Hill Formations while aeolian and lacustrine deposits form the major portion of the Rocky Harbour Formation.

The entire map area shows mineral assemblages characteristic of the greenschist facies, mainly transitional between the chlorite and the biotite zones. Structurally, the area is dominated by the Love Cove horst which brings steeply dipping, isoclinally folded, volcanics into contact with more gently dipping sediments of the Musgravetown and Connecting Point Groups.

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CHAPTER I

INTRODUCTION

I:1 Introduction and Purpose

The eastern edge of the Appalachian orogen consists of a wide zone of Late Precambrian volcanic rocks and sediments of both marine and terrestrial origin, extending from Newfoundland to the southern United States. This belt, distinctive in both age and lithology, has been named the "Avalon zone" (Williams et al., 1972). Many Appalachian geologists consider the Acalon zone as having been originally a micro-continent lying between the "African plate" and the "North American plate" (Williams, 1974; Schenk, 1971; Rodgers, 1972) remaining attached to the "North American plate" after the reopening of the Atlantic Ocean.

The volcanic rocks over the entire Avalon zone (H), Figure (I-1), form three distinct belts. The eastern belt comprises the Harbour Main Group volcanics, involving the area south and east of Conception Bay. The central belt occupies the area extending from Placentia Bay, through the Isthmus of Avalon, to the western side of Trinity Bay and is dominated by the volcanics of the Bull Arm Formation. The western belt extends from Bonavista Bay to the tip of the Burin Peninsula, although granite intrusions, which separate it into two parts, make correlation between the two sections difficult. Volcanic rock found in the northern portion of this belt has been placed in both the Bull Arm fm. and the Love Cove

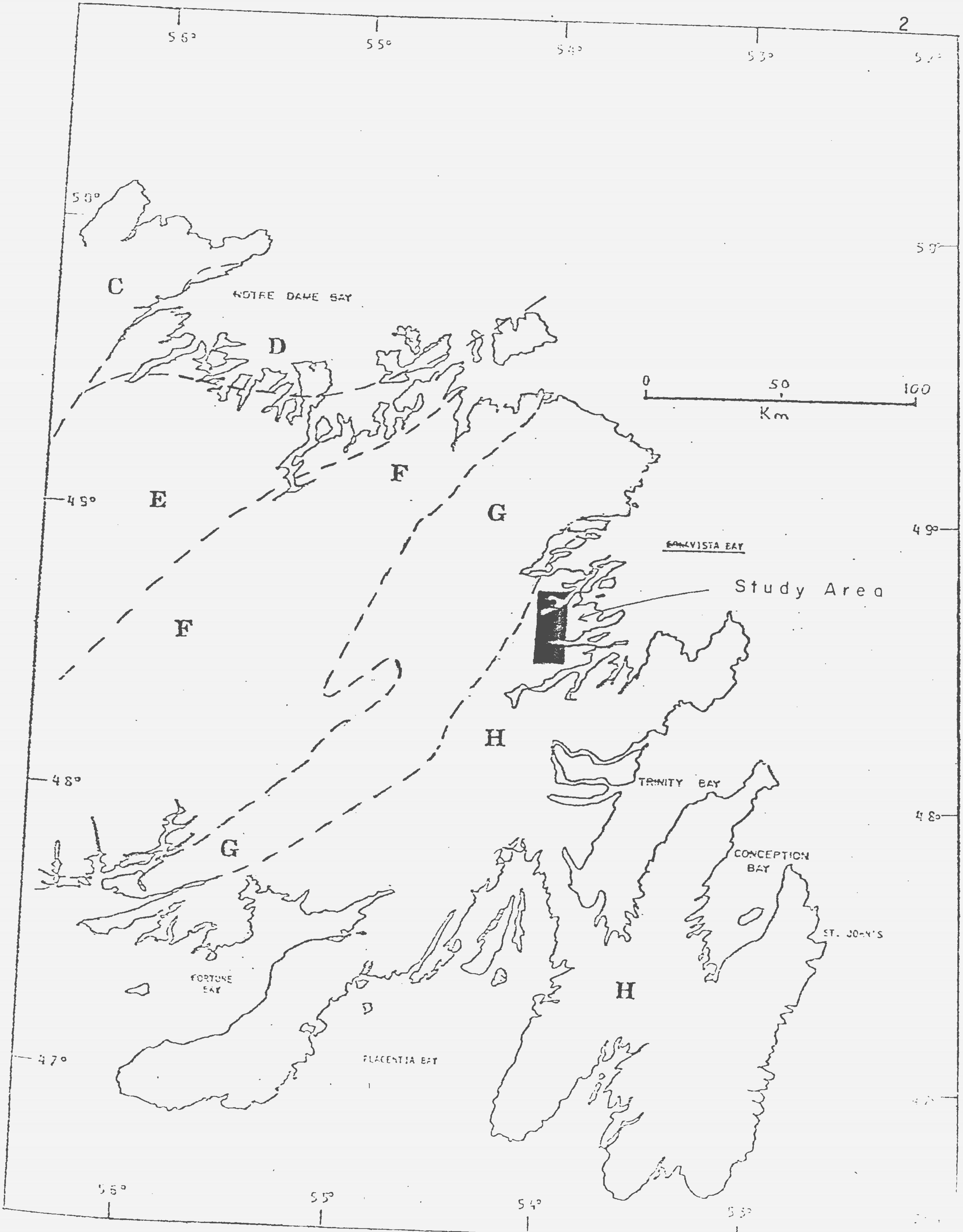


Figure (I-1) eastern Newfoundland

Group (Jenness, 1958b, 1963) with the majority being incorporated within the Love Cove. The southern half consists of the volcanics of the Burin Peninsula and of the Fortune Bay region which have not been correlated with the northern rock types.

All the volcanic belts except for the northern portion of the western one, where this study concentrates, have been chemically and petrologically studied in some detail by a number of workers, (Papezik, 1969; Nixon, 1974; Hughes and Brueckner, 1971; Malpas, 1972; Strong et al., 1976). The Love Cove volcanics, closest to the western margin of the Avalon zone and therefore, of considerable importance to the understanding of the entire zone, have not been investigated to the same degree. Detailed petrography and chemical data are nearly non-existent while even in the areas of structure and stratigraphy sharp differences arise in interpretations, (Christie, 1950; Jenness, 1963; Younce, 1970).

The main purpose of this study, is to provide the raw data on the chemical and mineralogical make up of the volcanic rocks involved (Love Cove, Musgravetown and to some extent, the Connecting Point Group), in order to reinforce or modify the previous theories concerning the environments of formation of the various rock types and their stratigraphic relationships.

I:2 Location and Access

The area of study is situated in the Bonavista Bay region of northeastern Newfoundland, Figure (I-1), comprising 288 sq. km.. It is bounded by latitudes 48° 45' and 48° 30' north and longitudes 53° 60' and 54° 05' west. The map area is bisected by the Trans Canada Highway, which along with secondary roads provides access to all sectors. The region is marked by a gently rolling topography. Thick conifer growth and several swampy areas cause rock exposure to be rather spotty.

I:3 Method of Study

Geological mapping was entirely conducted by foot traverses with the aid of quarter-mile air photographs and forest inventory maps. Over five hundred samples were collected during the field season which lasted from May 10th to August 1st, 1976. Laboratory work included the study of 120 thin sections and 64 complete and partial rock analyses. In addition many of the volcanic rocks were studied by X-ray diffractometer.

CHAPTER II

GENERAL GEOLOGY

II:1 Introduction

The rocks within the study area consist essentially of a series of acid volcanics with minor basic members, interbedded with and overlain by sediments ranging from coarse conglomerate and sandy redbeds to greywacke and shale. The rocks have been traditionally assigned to three major stratigraphic units, the Love Cove, Connecting Point and Musgravetown Groups, (Jenness, 1958b, 1963; McCartney, 1969; Williams, 1967). However, considerable difficulty is caused by the fact that volcanic rocks are present in all of the units. Many of the rocks are similar in appearance and mineralogy, and contacts are poorly exposed and in many cases defined by faults. These may be some of the reasons that have led to different interpretations of the regional geology by several workers.

II:2 Previous Work

A number of workers have undertaken regional and local geological studies in the Bonavista Bay region: (Hayes, 1948; Christie, 1950; McCartney, 1958; Jenness, 1958b, 1963; Younce, 1970). Their respective stratigraphic nomenclature may be seen in Figure (II-1).

This discussion will be restricted to those workers whose maps included the present study area. Christie placed the rocks in the Musgravetown and Connecting Point Groups. He did not recognize the Love Cove volcanics as a separate unit from the Bull Arm Formation volcanics.

	Hayes (1948)	Christie (1950)	McCartney (1958)	Jenness (1958)	Jenness (1963)	Younce (1970)
Cambrian	Bonavista Formation	Bonavista Formation	Bonavista Formation	Bonavista Formation	Bonavista Formation	Bonavista Formation
	Random Formation	Random Formation	Random Formation	Random Formation	Random Formation	Deer End Fm. Random Fm.
Precambrian	Musgravetown Group Bull Arm felsite	Musgravetown Group graywacke Bull Arm felsite conglomerate	Musgravetown Group Deer Harbour Formation: Crown Hill cgl. mbr.; gray silt mbr.; massive red arkose mbr.; lower grn. sltstn. mbr. Bull Arm Formation	Musgravetown Group (undivided)	Musgravetown Group Crown Hill Formation Rocky Harbour Formation Bull Arm Formation Cannings Cove Formation	Musgravetown Group Crown Hill Formation Deer Harbour Formation Bull Arm Formation Cannings Cove Formation
	Connecting Point Group	Connecting Point Group	Connecting Point Group	Connecting Point Group	Connecting Point Group	Connecting Point Group
				Love Cove Group	Love Cove Group	

Figure (II-1)

stratigraphic nomenclature — Bonavista Bay region

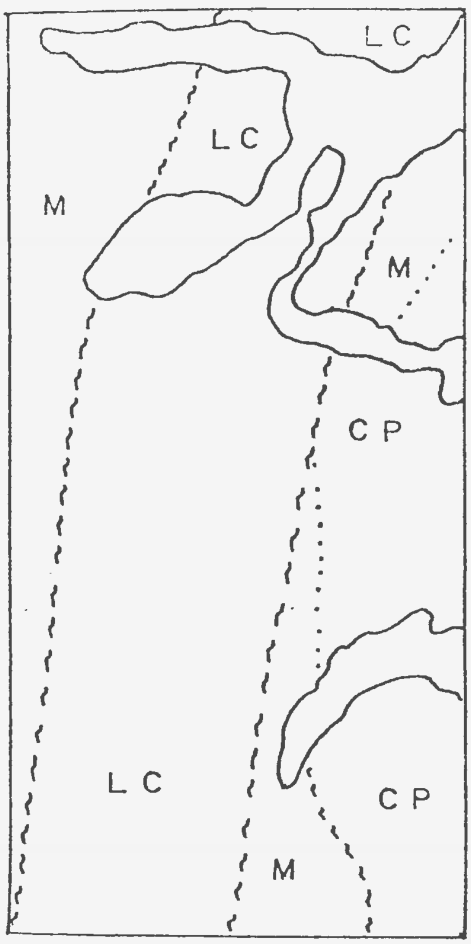
The most recent geological work was completed by Jenness and Younce (Figure II-2). Their work will be reviewed in detail later in this chapter, since they both concentrate on the Love Cove Group, one affirming and one denying its separate identity. Only a brief summary of their arguments is given here.

Jenness (1963) placed most of the present map area in his Love Cove Group. Due to lack of more detailed work he did not break the Group into formations but did suggest two major divisions, metavolcanic rocks with minor interbedded metasediments and metasediments with minor interbedded metavolcanic rocks. The remainder of the rock types were incorporated within the Connecting Point and the Musgravetown Groups, which he, following McCartney (1958) divided into four formations, (Figure II-1).

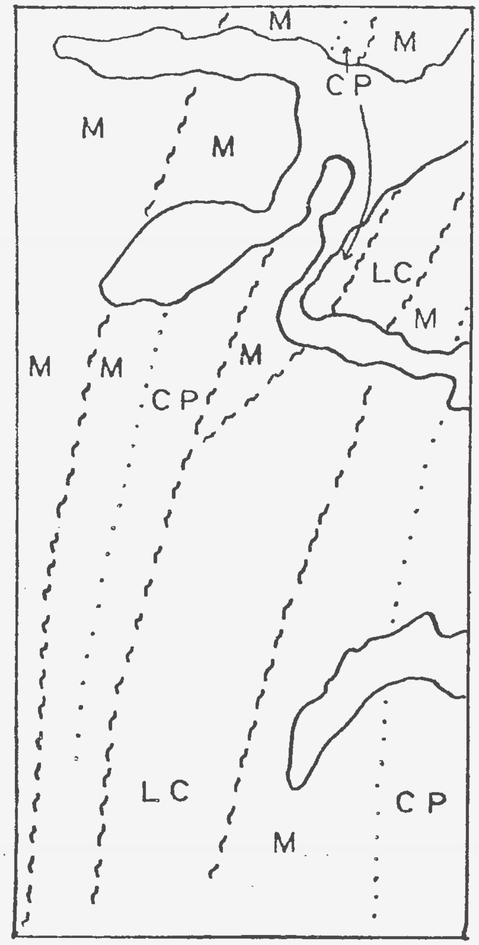
Younce conducted a study during the summers of 1968-1969. His opinion on the separate identity of the Love Cove Group differs sharply from Jenness. He removed the sedimentary rocks from the group and placed them within the Musgravetown and Connecting Point Groups, while considering the volcanics as being locally altered Bull Arm Formation. Younce believed that the "alteration" was caused by intrusions of igneous bodies.

II:3 Discussion of Previous Stratigraphic Concepts based on the Author's Field Work

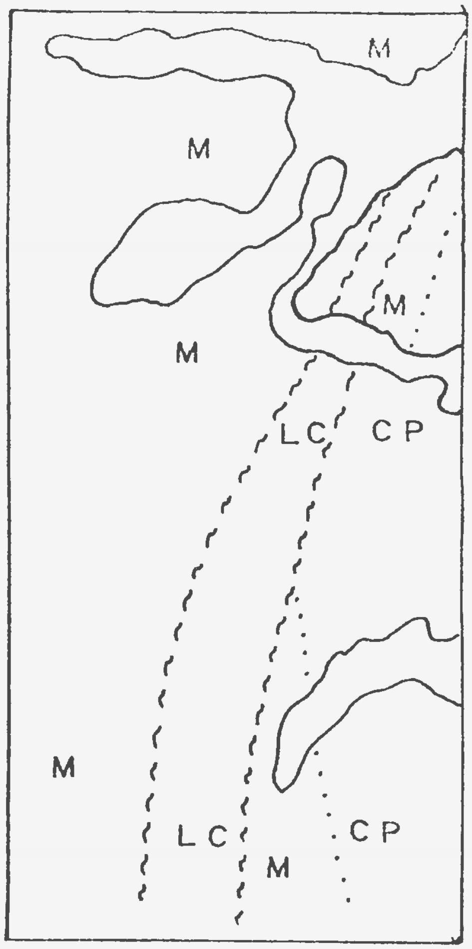
The term "Love Cove Group" was introduced by Jenness (1958b) for two north-south trending bands of schistose sedimentary and volcanic rocks. The type section is found on the southern shore of Clode Sound



Jenness (1963)



Younce (1970)



Dal Bello (1977)

Figure (II-2)
groups of the map area and their positions according to the three most recent workers

M - Musgravetown Group
CP - Connecting Point Group
LC - Love Cove Group - "schists" (Younce)

30 km south of Glovertown; it is a well exposed section of sericite and chlorite schists. Jenness included "rhyolites, trachytes, pyroclastics, andesites and basalts" among the volcanic rocks of the group. All of these, he stated, showed considerable mineral alteration and most displayed a schistosity, especially the more basic rock types. The sedimentary rock found in the group comprised schistose and metamorphosed sandstones and siltstones with minor quartzite and conglomerate. Jenness believed the Love Cove Group to be the oldest rocks of the Bonavista Bay region, basing his belief on observations that the group appeared to be more deformed; appeared to have a higher grade of metamorphism than neighbouring groups and that schistose Love Cove pebbles are found in the Cannings Cove Formation of the Musgravetown Group.

However, detailed geologic mapping carried out by the author has revealed a number of features that are contrary to the interpretation of Jenness for the northern portion of the eastern belt:

1. The laminated sandstone, siltstone and epiclastic volcanic sediments included by Jenness in the group are stratigraphically continuous and conformable with the intensely cross-bedded sandstones to the west which Jenness mapped as Rocky Harbour Formation. Jenness (1963, p. 36): "Schistose metamorphosed sandstones and siltstones are extensively exposed north of Glovertown. Some of them,especially those on the ridge on the south side of Glovertown, closely resemble the cross-bedded buff-green, lithic sandstones of the nearby Rocky Harbour Formation, which makes it difficult to establish the contact between them. Where these sandstones occur over a considerable area, however,

such as north of Glovertown, interbedded schistose units and thin bands of volcanic rocks permit their identification as members of the Love Cove Group."

These "interbedded schistose units" were found to be zones of penetrative cleavage and not separate beds (Plate 23). No volcanic members have been found within the sedimentary succession, however, there are a few flow-banded felsite dykes which may have been mistaken for flows.

Therefore, it would seem that in the northern portion of the eastern belt of the Love Cove Group, the group is represented only by volcanic rocks.

2. Jenness (1963, p. 38): "All contacts between the Love Cove and the Musgravetown rocks are shown as faults. Although faults are nowhere exposed . . . . " Detailed field work by the writer had proved or indicated the presence of the faults bounding the Love Cove Group at the following localities:

(a) 6.5 km ENE of Glovertown, 3 km NNE of Traytown, village of Culls Harbour
- western fault zone, separating Rocky Harbour siltstone from Love Cove acid tuffs.

(b) 6.5 km east of Glovertown, 2 km ENE of Traytown
- eastern fault zone, separating Cannings's Cove conglomerate from Love Cove basic tuffs.

(c) 13 km SE of Glovertown, 11 km south of Traytown
- eastern fault zone, separating Crown Hill shale from Love Cove acid tuffs.

(d) 8 km SE of Glovertown, 7 km SW of Traytown

- western fault zone, separating Rocky Harbour siltstone from Love Cove acid tuffs.

(e) 18 km SSE of Glovertown, 17 km SSW of Traytown

- western fault zone, separating Rocky Harbour sandstone from Love Cove acid tuffs.

The faults separating the schistose acid volcanics from the sediments are thus fairly well defined, but only one of these localities (b) coincides with the boundaries drawn by Jenness (1963).

3. Jenness (1963, p. 38):

"Although the faults are nowhere exposed their presence is assumed because of sharp contrasts in attitudes and metamorphism."

A sharp contrast in attitudes does exist between the Love Cove and the adjacent rocks but no difference in metamorphic facies is apparent. Outcrop appearance, thin sections and X-ray diffraction patterns reveal that the entire map area lies within the boundaries of the greenschist facies.

Thus the writer believes that some of the interpretations offered by Jenness require modification. On the other hand he cannot entirely accept Younce's idea that the "Love Cove Group" consists merely of locally altered rocks of the Musgravetown and Connecting Point Groups. A field observation may be pointed to, to illustrate the disagreement to his interpretation of the map area rocks.

The sedimentary rocks which Younce believes to be part of the Connecting Point Group are in fact siltstones of the Rocky Harbour Formation. This is proven by the occurrence of pebbles of flow banded and massive rhyolite, physically and chemically similar to the rhyolites of the Bull Arm Formation, in narrow conglomeratic bands 5 km NE of Glovertown. These sediments must be part of the Musgravetown Group.

The above discussion was included here to illustrate the uncertainties and disagreements concerning the geology of the area. The writer's own observations and interpretations will be presented in detail in the subsequent chapters.

Mr. E. Hussey, Memorial University, mapped the adjacent area to the south, and is planning radical revision of the stratigraphy in the area. The author does not wish to anticipate his conclusions. Although the auther is aware of the ideas of Mr. Hussey, he has chosen to follow the classical stratigraphy of Jenness (1963), mainly because in the map area most of the contacts between the various units are defined by faults and thus stratigraphic relations are not clear. If the stratigraphic units, to be proposed by Mr. Hussey, can be reliably extended to the north, the stratigraphic sequence followed in this thesis may have to be revised.

CHAPTER III

PETROGRAPHY AND FIELD RELATIONS

III:1 Love Cove Volcanics

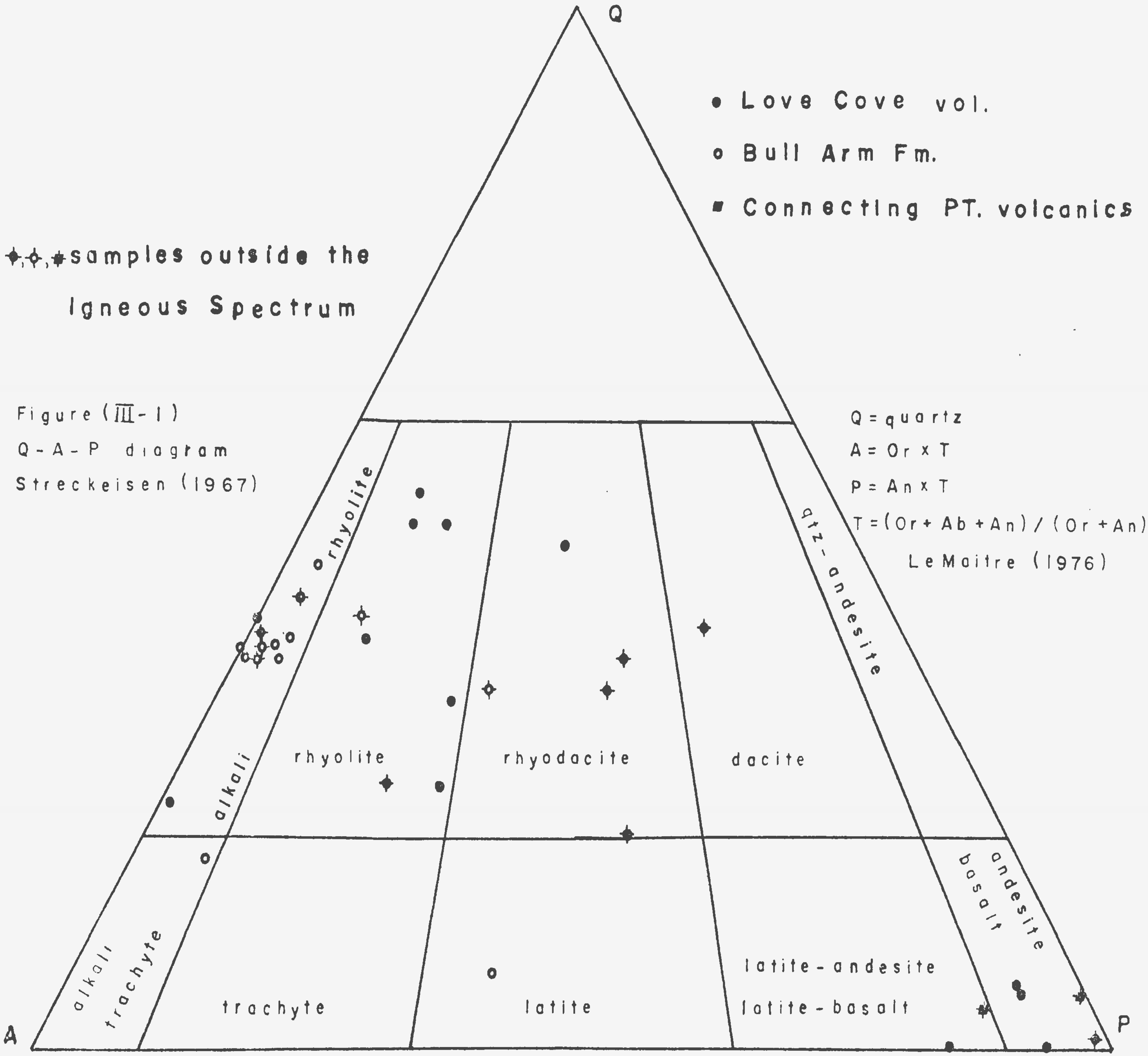
The volcanic rocks included in the Love Cove Group of Jenness form a north-trending horst which is approximately three km wide at the southern boundary of the map area, but narrows to less than one km to the north of Traytown. Most of the rocks within this belt are acid pyroclastics, with lesser amounts of intermediate to basic tuffs. The acid pyroclastics appear to be of ash-flow origin rather than ash-fall; they are not sorted and display no grading, characteristic of ash-falls. Distinction between welded ash-flow tuffs and rhyolite flows can be made on the basis of field evidence, textures and mineralogy. A good summary of both field and microscopic evidence is given by Ross and Smith (1960). However, their paper deals with undeformed, unmetamorphosed flows and is of limited use in deciphering the affinities of the deformed, metamorphosed Love Cove volcanics. Those identifying features given by Ross and Smith which can be distinguished in the Love Cove volcanics support the writer's conclusion. Among these are average thickness of individual units, distortion of phenocrysts and lithic fragments and fracturing of feldspar phenocrysts.

Texturally altered ash-flow tuffs have been studied by Anderson (1970). He found that even highly altered ash-flow tuffs can be distinguished from rhyolite flows by the following three main criteria:

compaction foliation (eutaxitic texture), bent and fractured phenocrysts and snowflake texture. Not all of these are generally accepted; e.g. Green (1970) identified snowflake texture in vesicular Keweenawan lava flows. Rast (1962) suggested that the occurrence of embayment structures in feldspar phenocrysts is an indicator of ash-flow origin.

In the Love Cove volcanics, eutaxitic texture is clearly recognizable at several localities, broken and bent phenocrysts are common and embayment structures in feldspars have been observed in many specimens. The presence of one or more of these microscopic textures in all thin sections from the Love Cove horst suggests that the rocks are either entirely tuffaceous in origin, or that the volume of any rhyolite flows that may be present is very small. Chemically the volcanic rocks vary from rhyolitic through dacitic to basaltic (Figure III-1), though the volcanics of rhyolitic composition are the most abundant.

Because devitrification has destroyed all glass shards and has left little or no trace of their outline, eutaxitic texture in thin sections is not easily detectable and may be confused with schistosity. Therefore "welded" tuffs in the Love Cove volcanics have to be distinguished on the basis of field evidence. In some ash-flows, eutaxitic texture is indicated by a streaked or blotched appearance. However, the main factor in deciding whether a tuff is welded is the degree of schistosity. Field work suggests that the schistosity, which is so prevalent in the Love Cove volcanics of the map area, is controlled to a large extent by the variation in competence of the rock types involved. The basic tuffs and the less welded or non-welded acid and intermediate tuffs are highly schistose while the apparently more densely welded


Q
A
P
• Love Cove vol.
o Bull Arm Fm.
▪ Connecting PT. volcanics
samples outside the Igneous Spectrum
Figure (III-1)
Q-A-P diagram
Streckeisen (1967)
Q = quartz
A = Or x T
P = An x T
T = (Or + Ab + An) / (Or + An)
LeMaitre (1976)
alkali rhyolite
rhyolite
rhyodacite
dacite
qtz-andesite
alkali trachyte
trachyte
latite
latite-andesite
latite-basalt
andesite basalt

rock type displays little or no schistosity. The "welded" tuffs in the map area vary considerably in color from yellow to purple. In most exposures each flow unit is generally underlain by a highly lithic zone, formed by the erosive effects of the flow. The transition from welded tuff to the lithic zones is sharp, occurring within ½ meter. In thin section the ash-flow tuffs consist of broken and bent phenocrysts of albite and phenocrysts of quartz in a devitrified groundmass of anhedral quartz and albite. Lithic fragments in the tuffs include fine-grained, devitrfied particles of acid volcanic rock and minor basic (diabase) fragments. Secondary mineralogy is dominated by sericite, calcite and minor chlorite.

The crystal-lithic (non-welded) tuffs of the Love Cove volcanics vary in color from brown to green (Plate 1 and 2). The percentage of lithic fragments and the size of the individual particles is highly variable. The percentage of fragmental material varies from 10% to as much as 70% while the size of individual fragments ranges from 5 mm by 5 mm to 20 cm by 5 cm. The large fragments are generally more elongated than the smaller ones. The rock fragments probably originated in vent areas and/or earlier flows. The crystal portion of the rock consists of quartz and subhedral plagioclase (An 0-5); the phenocrysts are commonly fractured and bent. The aphanitic groundmass is composed of fine-grained mosaic of quartz and albite, formed by devitrification of volcanic glass. Spherulites and related textures are lacking in the tuffs of the Love Cove belt.

The basic tuffs are dark-green and all are heavily altered to greenschist facies mineralogy, i.e. actinolite,chlorite, epidote, calcite, albite and quartz. In outcrop, only epidote and chlorite are identifiable. Epidote occurs in discontinuous veinlets less than 1/2 meter long and usually no more than 1 cm wide. Chlorite occurs as porphyroblasts 1 cm or less in diameter which are elongated in the direction of cleavage. Only rarely is chlorite seen in veins.

The relative stratigraphic positions of the basic tuffs are difficult to determine because of intense folding. The only evidence found consists of acid volcanic fragments in a basic tuff outcrop one km east of Traytown, (Plate 3). This suggests that this unit of basic tuff is younger than at least some of the acid ash-flows in the vicinity. The physical appearance of the acid fragments is similar to the rock in the SW Arm area, but intense epidotization prevented a meaningful chemical analysis. Although areas where basic tuffs predominate have been recorded on the geological map, the intemate association of felsic and mafic volcanic rocks throughout the area make formal stratigraphic subdivisions difficult and probably meaningless.

The writer attempted to determine flow directions of some of the less altered ash-flow tuffs, following the methods described by Schminche and Swanson (1967). The attempt was largely unsuccessful, due to scarcity of suitable outcrops. At two localities, South West Arm and eleven km SSW of South West Arm, imbrication textures and tension cracks indicated that flow directions were to the ESE, i.e. the source of the ash-flows was to the west of the present map area. In view of the generally steep dips and uncertainty of stratigraphic orientation at many outcrops, it is doubtful whether a reliable indication of the direction of provenance can be obtained in the area.

III:2 Connecting Point Group

The Connecting Point Group was initially recognized by Hayes (1948). The rocks included in the group, mainly black shales and greywackes are typical of a deep marine environment, a "geosynclinal facies" (Jenness, 1963). Neither top nor bottom of the group have been observed but the thickness is estimated to be 8000 meters (Jenness, 1963). The contact between the Connecting Point and Love Cove Groups is not seen but is assumed to be a fault. The contact between the Connecting Point Group and the overlying Musgravetown Group is unconformable, as pointed out by Hayes (1948), Jenness (1963) and Younce (1970). The rocks of the Connecting Point Group have been correlated, on the basis of lithologic similarity, with those of the Conception Group of the Avalon Peninsula.

In the study area, the Connecting Point Group consists of both sedimentary and volcanic rocks (Plates 8 and 9). The sediments include black shale and light grey greywacke. The shale has a uniform texture, and bedding is difficult to distinguish. The greywacke consists of angular grains of sodic plagioclase, quartz and devitrified fragments of acid volcanic rock. Secondary minerals are limited to chlorite and epidote.

The volcanics, found mainly east of Traytown, in the SW Arm area, are brecciated, dark grey-green in color and chemically resemble basalts (Figure III-1). As with the basic rocks of the Love Cove Group, the Connecting Point Group volcanics are completely recrystallized to mineral assemblages characteristic of the greenschist facies (actinolite, brown biotite, epidote, albite, chlorite and calcite). The basic rocks are found in what is believed to be two separate bands interbedded with the sediment. The estimated thickness of these bands is approximately 200 and 400 meters.

III:3 Musgravetown Group

The term "Musgravetown Group" was introduced by Hayes (1948). The group has been divided into formations by McCartney (1958), Jenness (1963) and Younce (1970). Their respective stratigraphic sequences can be seen in (Figure II-1). The only ambiguity is found in the two most recent columns, those of Jenness and Younce. Younce prefers to use McCartney's term "Deer Harbour Formation" instead of Jenness's "Rocky Harbour Formation". The rock type involved is a yellow-green, intensely, cross-bedded sandstone. Although the Code of Stratigraphic Nomenclature requires that a rule of priority be observed, the classification of Jenness is the best known and most widely used in works dealing with the Bonavista Bay area. For these reasons, the name "Rocky Harbour Formation" will be retained in this study.

III:3-1 Cannings Cove Formation

Of the four formations comprising the Musgravetown Group, the oldest is the Cannings Cove Formation. According to Jenness (1963), it consists of red and green conglomerates, sandstones and shales, composed predominantly of acid volcanic fragments, but also including medium-grained pink granite, black chert and sedimentary fragments from the Connecting Point Group. Along with the variety of detritus the Cannings Cove Formation also displays a considerable variation in thickness from 30 meters to 700 meters. The type section is found at the village of Cannings Cove, 50 km SSE of Glovertown.

The Cannings Cove Formation in the study area consists of sandstone and conglomerate, both mainly black in color. The conglomerate is composed of fragments of various origin and size, from 1 cm by 1 cm to 20 cm by 10 cm in dimension. Most of the pebbles are fairly well rounded except for angular sedimentary fragments which appear to be Connecting Point shale. Rhyolite is the most common rock type; it is black, red and pink in color, in places porphyritic. The source of these fragments is probably the Bull Arm Formation. This conclusion is supported by trace element data gained from the pebbles, which indicate Bull Arm affinity. The implications of this for the stratigraphic relationships between the Cannings Cove and the Bull Arm Formations will be discussed later. Red medium-grained granite pebbles are also found in the conglomerates. The granite is made up of pink K-feldspar, quartz and chlorite. The only Precambrian granite (574 ± 11 m.y., Rb/Sr isochron age) in the Avalon zone is the Holyrood pluton, 150 km SSE of the map area. Descriptions of the granite mineralogy by Buddington (1919) and Strong and Minatidis (1975) adequately fit the granite pebbles in the Cannings Cove conglomerates. A few scattered pebbles of massive hornblendite are also present; the origin of these is unknown. The sandstone of the Cannings Cove Formation is usually well-sorted and massive but may be locally cross-bedded (Plate 13). In thin section the rock is primarily composed of devitrified acid volcanic fragments along with plagioclase and quartz grains, and lesser amounts of highly altered K-feldspar. Secondary minerals are mainly chlorite and epidote.

Although the detrital rocks of the Cannings Cove Formation contain a larger percentage of clasts that appear to be derived from the Bull Arm rhyolites, at localities such as Bread Cove 27 km SSE of Glovertown the Cannings Cove Formation is found at the base of the Musgravetown Group, stratigraphically below the Bull Arm volcanics. Thus the two formations appear to be time equivalent, possibly representing a volcanic and an alluvial facies.

III:3-2 Bull Arm Formation

The Bull Arm volcanics were given formational status by McCartney (1958) after being first recognized by Hayes (1948). Jenness (1963) defined the formation as consisting of all volcanics overlying the Cannings Cove Formation and underlying the Rocky Harbour Formation, estimating its thickness at approximately 750 meters.

Volcanic rocks of the Bull Arm Formation are found at the crests of anticlinal structures at several locations in the map area. As in the case of the Love Cove volcanics, the Bull Arm Formation is dominated by one rock type, but unlike the Love Cove pyroclastics, the prominent rock of the Bull Arm volcanics is a flow-banded rhyolite. At one locality (Rosedale, north of Traytown), the attitudes of the flow-banding suggest the possibility of one or more rhyolite domes, although the apparent "wrap-around" effect of the flow-banding, where present, may represent merely distal portions of thick flows. The rhyolite flows are associated with lesser amounts of acid and basic tuffs.

The rhyolite is reddish, brown or grey, aphanitic, with sparse, small phenocrysts. The groundmass consists of devitrification minerals (quartz and alkali feldspar), containing phenocrysts of K-feldspar, plagioclase and rounded grains of quartz. The K-feldspar of the Bull Arm volcanics is microcline, as shown by thin section and X-ray diffraction methods; microcline is the stable form of K-feldspar under conditions of greenschist facies metamorphism. Imperfect cross-hatched twinning is common but Carlsbad twins are also present. The plagioclase displays fine albite twinning. X-ray diffraction and thin sections studies show that the plagioclase composition lies in the An_{0-5} range. Secondary minerals, present in small amounts, include chlorite, epidote, sericite and calcite. All original glass is devitrified; spherulitic and axiolitic textures are common.

The acid pyroclastics are deep red in color due to the large amount of iron oxide disseminated in the rocks. They consist of various proportions of crystal and lithic components. Although all glass is recrystallized to a fine-grained mosaic of quartz and alkali feldspar and no distinct shards have been observed, the tuffaceous rocks can be distinguished from the more typical rhyolites by the presence of broken and bent phenocrysts and lithic clasts. Eutaxitic textures (compaction foliation) are poorly developed, if present at all.

Basic tuffs belonging to the Bull Arm Formation were seen at two localities, Norton Cove and Cary Cove. They are dark green, schistose and consist of brown biotite, actinolite, chlorite, albite, quartz, epidote and calcite. The close stratigraphic association of these rocks, with flow-banded rhyolite of the Bull Arm Formation indicates their Bull Arm affinity. Although they resemble the basic tuffs of the Love Cove sequence, they can be distinguished from the Love Cove rocks by a higher proportion (25 - 30%) of lithic fragments, and more numerous and more varied porphyroblasts. Quartz, albite, calcite, chlorite and epidote patches are common in the Bull Arm tuffs but only epidote and chlorite patches have been observed in the Love Cove volcanics.

The field observations given above appear to hold true for the area studied by the writer; however, exposures of basic tuffs are relatively rare and more extensive study would be needed before generally valid criteria for distinguishing Bull Arm and Love Cove basic tuffs in the field could be established.

III:3-2-1 Differences between the Love Cove and the Bull Arm Volcanics

The most common rock types in both the Bull Arm Formation and the volcanic unit of the Love Cove Group are felsic flows and/or pyroclastics. As the distinction between the two volcanic units is vital for the solution of stratigraphic problems within the area, the writer paid particular attention to the criteria that can be used to distinguish between Bull Arm and Love Cove acid volcanics in the field.

It was found that the two volcanic units differ in several ways.

Typical felsic rocks of the Bull Arm Formation are massive or flow-banded rhyolite flows and deep red crystal lithic tuffs, lacking schistosity. They occur along the crest of anticlinal structures and where extensive, are accompanied by the highly distinctive black

Cannings Cove conglomerate. Thin section and X-ray diffractometer study show that the Bull Arm Formation is characterized by the presence of triclinic K-feldspar (microcline).

In contrast, most of the Love Cove volcanics are highly schistose and contain little or no K-feldspar. They occur in a fault-bounded belt and consist predominantly of ash-flow tuffs. A few of the Love Cove tuffs lack schistosity, but may be recognized as Love Cove volcanics because of their intimate association with the schistose varieties and their lack of K-feldspar.

The overall lack of K-feldspar in the Love Cove volcanics may be explained by the simple assumption that there was little or no K-feldspar originally, or at least no K-feldspar phenocrysts. The presence of sericite in the volcanics of the Love Cove belt suggests that there may have been some K-feldspar in the groundmass, which was later destroyed by greenschist metamorphism and penetrative deformation producing the schistosity. Table V-2 shows that the lack of visible K-feldspar has a chemical, not merely mineralogical, basis; the average K_2O value for Love Cove acid and intermediate volcanics is roughly half that of the Bull Arm volcanics.

The distinguishing features given above are considered reliable and are substantiated by chemical differences observed between the Bull Arm and the Love Cove volcanics (Chapter V). However, a group of volcanic rocks in the SW part of the map area is more ambiguous. The rocks are physically similar to the Bull Arm volcanics, chemically similar to the Love Cove volcanics and mineralogically are intermediate between the two.

These volcanics consist of grey flow-banded rhyolite (Plate 10) and deep red crystal lithic tuffs containing relatively higher amounts of Fe oxides. They lie along the crest of an anticlinal structure and are associated with the black Cannings Cove conglomerate. The anticlinal structure is flanked by the Rocky Harbour Formation. Thus physically and stratigraphically these rocks should be classified as Bull Arm volcanics.

X-ray diffractometer shows that the rhyolites of this group contain K-feldspar but the crystal lithic tuffs do not. These deep red tuffs contain a large amount of plagioclase (An 0-5) phenocrysts. However, similar deep red crystal lithic tuffs outside this corner of the map area, again contain microcline.

Thus the assignment of these rocks either to the Love Cove or to the Bull Arm volcanic unit is somewhat problematical. Physical appearance and stratigraphic position demand that they be placed in the Bull Arm Formation. Mineralogically, the rhyolite shows characteristics of the Bull Arm Formation while the crystal lithic tuffs fit the Love Cove volcanics to a greater degree. It will be shown later that the trace element content of the volcanics is similar to that of the Love Cove rocks. The rhyolite major elements resemble those of the Bull Arm volcanics, and the major elements of the crystal lithic tuffs display characteristics of both.

Of the four criteria used (physical appearance, stratigraphic position, chemistry and mineralogy), the first two are the least ambiguous and therefore these rocks will be assigned to the Bull Arm Formation. However, they will be distinguished by a separate symbol on subsequent diagrams.

III:3-3 Rocky Harbour Formation

Jenness (1963) described the Rocky Harbour Formation as consisting of a series of yellow-green cross-bedded sandstones found stratigraphically below the Crown Hill Formation and above the Cannings Cove Formation. The type locality lies at Rocky Harbour near the east end of Random Sound, 75 km SSE of Glovertown. The estimated thickness of the formation is 300 meters.

The Rocky Harbour Formation is the most abundant rock type in the area. It consists of sandstone (laminated and non-laminated), siltstone, conglomerate and epiclastic volcanic rock. The sandstones and siltstones are the dominant members of the formation; epiclastic volcanic sediments are relatively minor and the conglomerate, rare.

The typical sandstone is found just west of Glovertown (Plates 14 and 15). It varies from massive to laminated; the irregular laminae, alternating yellow and green, vary in width from 5 mm to 10 mm. The rock is well sorted and has a uniform grain size. Most grains have well-rounded edges but are not, generally, spherical in appearance. They consist of plagioclase, K-feldspar, quartz and devitrified acid volcanic fragments. The devitrified fragments show both anhedral, massive appearance and spherulitic textures. Secondary minerals include chlorite, epidote, calcite and sericite, chlorite being the most abundant.

The most striking feature of the sandstone is the intense cross-stratification that is evident in outcrops. The foreset beds of the wedge-shaped cross-bedding dip in opposite directions and are found in both the plane of the strike and the plane of the dip. The size of the cross-stratification is small, varying from ¼ m to 2 m in length. This type of cross-bedding, is characteristic of aeolian deposits. The opposite dips of foreset beds and the variation in size of the cross-stratification features is caused by variations in wind velocity and direction.

The Rocky Harbour sandstone is found along the entire western edge of the map area from the Glovertown region to the Terra Nova town road. In the town of Glovertown proper, the lithology of the Rocky Harbour Formation changes from the intensely cross-bedded sandstone to a well laminated sandstone with less distinct cross-bedding (Plate 16). The laminae are sharply defined, regular, alternating grey and dark grey-green bands, varying in width from 1 mm to 1 cm. The grain size is slightly smaller and individual grains more angular than in the equivalent facies to the west. The composition of the grains is the same as in the westerly sandstones, predominantly feldspar, quartz and acid volcanic fragments. The secondary minerals are also the same as in the "western" facies, although the amount of chlorite is much less, suggesting a decrease in "silt" content in the original matrix material. Cross-bedding is still present but the angle of dip of the foreset beds has decreased.

The increasingly laminar nature of the rock plus the disappearance of intense cross-bedding suggests a change in environment from west to east, from subaerial to a subaqueous type of sedimentation.

Towards the east, the grain dimensions of the sediment gradually decrease to silt size, cross-bedding almost disappears and laminations become less distinct. Color of the alternating bands in the siltstone changes from dark grey to grey (Plate 19). The color along with the regularity and small scale of the layering in the siltstone is suggestive of varve deposition. Thus, the environment of the Rocky Harbour Formation can be summarized as being one of subaerial aeolian deposits facies changing to a subaqueous environment of beach and basin. The presence of a restricted basin, probably a fresh water lake, is supported by trace element data which will be discussed in Chapter V. The well-laminated sandstone and siltstone are cut off to the south by the western fault of the Love Cove horst, but continue to the north beyond the present map area.

Besides sandstone and siltstone, the area also contains sedimentary rock formed solely from the accumulation of little reworked detritus of rhyolite and/or tuffeceous origin (Plate 17). These sediments are interbedded with the siltstones but not with the intensely cross-bedded subaerial sediment west of Glovertown. This, along with evidence of cross-bedding in these epiclastic volcanic sediments, indicates that their deposition is entirely associated with water. Current direction determined from cross-stratification features was from east to west. In view of the scarcity of data, this determination may not be statistically significant, although it is supported by evidence found to the north of the map area, where an outcrop shows volcanic detrital material interfingering with underlying siltstone in a manner pointing to eastward derivation of the epiclastic volcanic sediments. The direction of origin of the other sediments comprising the Rocky Harbour Formation is unknown.

The grain size of the epiclastic volcanic rock ranges from very fine (1/64 mm - 1/32 mm) to relatively coarse (8 mm - 16 mm). The siltstone and the fine grained sediment of volcanic origin can be distinguished in hand specimen by the appearance of their weathered surfaces. The siltstone weathers white and the laminae are more distinct; the epiclastic volcanic rocks weather to a brown or dark grey color and lack the distinct laminations. Bedding is not visible in the fine-grained volcanic sediments but can be recognized in the siltstones. On a fresh surface, the siltstone is smooth and uniform while the epiclastic volcanic rock displays a wisp-like texture and a ragged surface. Further, the epiclastic volcanic sediments are characterized by the presence of pyrite, in cubes up to 5 mm in size, while no crystalline pyrite has been observed in the siltstones.

The coarser units are much easier to identify, many of these epiclastic volcanic sediments are composed almost entirely of light pink rhyolite fragments while others contain a larger percentage of dark rhyolitic clasts. Analyses done on epiclastic volcanic rocks containing a very high proportion of rhyolite fragments show that the trace element values for these rocks are similar to those of the acid volcanics of the Bull Arm Formation in the area (Appendix II).

A different type of epiclastic volcanic sediment is found in the

Rosedale region, north of Traytown. This consists of flow-banded rhyolite clasts, ranging in size from 1 cm by 1 cm to 10 cm by 20 cm, derived from the Bull Arm rhyolites of the locality (Plate 18). The clasts are generally unsorted and form a small proportion of the rock compared to the dark grey matrix. The angularity of the rhyolite fragments and the small areal extent of the rock type would indicate rather limited transportation prior to deposition. It appears that this rock was quickly deposited in local depressions about the rhyolite bodies.

III:3-4 Crown Hill Formation

The "Crown Hill Formation" was introduced and described by Jenness (1963). It is composed of red and green conglomerates, sandstones and shales occurring stratigraphically above the Rocky Harbour Formation and underlying the Random Formation. The type section is located at the village of Crown Hill in the Random Sound area 65 km SSE of the map area. The estimated thickness of the formation is 800 meters.

In the study area, the Crown Hill sediments conformably overlie the Rocky Harbour cross-bedded sandstones. The top of the formation is not exposed in the map area. The sedimentary rock of the Crown Hill Formation is usually well bedded, displaying sharply defined bedding planes (Plates 20-21). Compared to the Cannings Cove conglomerate, the conglomerates of the Crown Hill Formation are relatively finer-grained; maximum size of the pebbles does not exceed 2 cm by 3 cm and on the average reaches only ½ cm by 1 cm. The pebbles in the conglomerate include red, pink and black rhyolite, red and green sandstone and quartz. The presence of distinctive Crown Hill sandstone and shale in the conglomerate indicate that some beds may represent intraformational units. This is indicated by the varying amount of sedimentary detritus in the conglomerates. At the three localities where Crown Hill conglomerate occurs, the following percentages are found:

1.	Newman Sound	5%
2.	Terra Nova River	25%
3.	East of Cary Cove	30%

The matrix of the sandstones and shales, as well as the conglomerates, may be either red or green. This may reflect oxidizing and reducing environments, although the red-colored volcanic pebbles also contribute greatly to the overall color effect. The shales are strongly fissile. The sandstones generally display limited cross-bedding but to a much leeser extent than the Rocky Harbour Formation.

In thin section, the finer units of the formation are fairly uniform in composition throughout the map area. The grains making up the sandstones, include devitrified volcanic fragments, rock fragments heavily impregnated with hematite, rhyolitic grains displaying spherulitic textures, quartz, sodic plagioclase and microcline.

III:3-5 Source of Clastic Grains

The Bull Arm Formation is the most probable source for the variety of clasts composing the sedimentary units of the Musgravetown Group. All the minerals and rock types forming detrital grains are found in the volcanics of the Bull Arm, except for albite. Plagioclase (An 0-5) crystal fragments are common everywhere in the sediments and form a major component of the rocks. However, only 6% of thin sections of the Bull Arm volcanics revealed any amount of plagioclase phenocrysts. The mineral may come from the Love Cove volcanics, which contain large percentages of albite phenocrysts, but the fact that no clasts of a schistose nature are found in the sandstones of the map area would seem to cast doubt on the Love Cove Formation as a possible source, as the Love Cove volcanics are dominantly schistose. Thus, no source within the study area can be found for the plagioclase grains. It is possible that the mineral is derived from some parts of the Bull Arm Formation (not exposed in the study area) that are of a different composition from the typical rhyolites, perhaps crystal lithic tuffs.

III:4 Intrusive Rocks

III:4-1 Granite

The Traytown leucogranite is found two km east of the town of Traytown. The exposure has an approximate surface area of 15 sq. km. The contact between the granite and country rock is sharp, the intrusion displays no evidence of chill margin and no contact aureole is apparent. Pegmatitic patches indicate that it is a high-level intrusion.

Thin sections show that the granite is composed of perthite, microcline, quartz and riebeckite. The riebeckite shows only slight chlorite alteration about the grain edges, indicating that the rock is relatively fresh.

Two thin apophyses of the peralkaline granite were discovered during field work, both within two km of the main body. One intrudes the Cannings Cove conglomerate, the other the Connecting Point shales. The grain size of these apophyses is relatively coarse, only slightly finer than the granite proper. The mineralogy of the dykes is similar to the main intrusion. The apophyses do not contain any fresh riebeckite but show an increased percentage of chlorite which may be the result of complete alteration of riebeckite. The widths of the dykes are ½ m and 1½ m respectively. The dyke which intrudes the conglomerate has sharp contacts while the other contains partly granitized shale xenoliths along the edges.

III:4-2 Gabbro

Two gabbroic bodies were found in the map area. The largest lies four km east of Traytown. It is 1 3/4 km long and ½ km wide, elongated in the north-south direction. The gabbro separates the Connecting Point Group shales from the Cannings Cove conglomerate; it may mark the trace of a northerly trending fault separating the two rock units. The mineral assemblage in the gabbro includes actinolite, tremolite, chlorite, sodic plagioclase and idocrase.

The second gabbro has a surface area of only 300 sq. meters and is located in the SW Arm area. The rock is medium grained, finer than the intrusion described above. In thin section the gabbro is seen to consist of augite and plagioclase in various stages of alteration. Secondary minerals include actinolite, chlorite, scapolite, epidote, quartz and very small colourless isotropic grains that may be spessartite garnet, although their identification is not definite.

III:4-3 Dykes

Both basic and felsic dykes are found in the region, the basic type being much more common. Basic dykes intrude nearly all rock types in the map area and most are completely altered to greenschist-facies assemblage. Some are highly schistose; the development of a schistosity is dependent on the orientation of the dyke to the trend of the regional schistosity, (NNE).

Although the dykes were probably emplaced at different periods over a long span of time, their sequence is difficult to establish. Evidence of dykes cutting dykes can be seen at several points, and a number of dykes cutting the Connecting Point Group rocks of the map area are surprisingly fresh suggesting a lack of general metamorphic alteration which affects all other dykes. Thus, there were at least three different periods of emplacement, but this is undoubtedly a minimum estimate.

Two types of felsic dykes are found in the area. The most prominent is the variety associated with the fault zones of the Love Cove volcanic belt. This "felsite", rhyolitic in composition, is in most places difficult to distinguish from the tuffs, but the felsite dykes lack schistosity and usually have a brecciated appearance. The color of this intrusive rock is reddish brown, similar to the tuffs. As some of the more competent tuffs may also have no schistosity, the second feature is the more reliable.

The second type of felsic dyke occurs at various points and is not restricted to the fault zones. This type of felsite dyke is light pink to light brown in color, in most places flow-banded and usually no more than two meters wide.

Along with rhyolitic felsite dykes, light-red dyke rock of intermediate composition is also associated with the faults marking the boundaries of the Love Cove horst. The intermediate rocks are medium grained; composed of sodic plagioclase, microcline, hornblende, and minor quartz; small amounts of secondary minerals include chlorite, epidote, actinolite and calcite.

CHAPTER IV

STRUCTURE AND METAMORPHISM

IV:1 Folding and Cleavage

IV:1-1 Love Cove Group

The Love Cove rocks of the map area show very tight folding and a prominent schistosity. Folds, as deduced from bedding attitudes, have interlimb angles of 0° to 20°. The penetrative fabric which cuts the Love Cove volcanics is characterized by the growth of sericite and/or chlorite, depending on the chemical composition of the rock affected.

The Love Cove Group represents the only typically schistose belt in the Avalon zone. The schistosity was used by previous workers to distinguish the Love Cove Group from other rocks of similar appearance. The most common trend is NNE, similar to observed bedding; dips are vertical or near vertical, either to the NNW of the SSE, in most placed paralleling bedding and masking it. Direction of "younging" in the Love Cove belt can generally be determined only by intersection of bedding and cleavage, where bedding is not vertical.

Minor structures observed in the Love Cove are all the result of faulting. Of those that were seen none seemed to be related to the large scale folding. The horst faults are responsible for minor folding and crenulation cleavage. Both are best exposed at the Newman Sound Campgrounds. Bedding in close proximity of the faults is disrupted and attitudes affected in such a manner as to cause an increase in the angle of dip and a distortion in strike direction. This is best seen in the Crown Hill sediments in the Newman Sound Campground area.

IV:1-2 Connecting Point Group

At most of the observed localities the Connecting Point Group is moderately folded; interlimb angles vary from 40° to 50°. No minor folds were visible in the Connecting Point strata of the map area. The uniform nature of the shale and the cleavage cutting it makes bedding difficult to decipher. The cleavage strikes approximately NE-SW and dips steeply, much like the dominant fabric in the Love Cove rocks. Due to lack of outcrop near the assumed contact between the Love Cove and the Connecting Point Groups, the cleavage cannot be traced from one group to the other with reasonable certainty.

IV:1-3 Musgravetown Group

The Musgravetown Group displays moderate folding, with the exception of the Rocky Harbour Formation, in which the folding becomes tighter from west to east. In the west the formation is composed of moderately folded sandstone. Bedding attitudes indicate interlimb angles of 80° to 100°, and "younging" direction is easily noted from the numerous cross-bedding features. In the east, the Rocky Harbour siltstone is isoclinally folded. Bedding attitudes and minor folds show interlimb angles of 15° to 30° for these folds. This change in style of folding is gradual over a distance of eight kilometers. The tightening of folds to the east may be caused by a change in competence of the rock rather than by increasing intensity of deformation.

The majority of fold axes in the Musgravetown Group and probably of the entire map area trend northeasterly and plunge from 0° to as much as 50°. The direction of plunge is predominantly to the NE but some minor folds were observed to have a SW plunge direction.

Cleavage is usually not easily discernible in the coarser sediments but there is one notable exception. In the sediments of the Crown Hill Formation along the Terra Nova River, there is a highly schistose band (approximately 100 m wide) of green conglomerate flanked by non-schistose red siltstone. Jenness (1963) mapped this conglomerate as part of the Love Cove Group. The conglomerate forms the core of a tight anticlinal structure, the conformable red siltstone forming the limbs. This appears to be an isolated case; other conglomerates in the same vicinity do not display any schistosity.

In the finer-grained rock types of the Musgravetown Group zones of intense penetrating deformation (Plate 23) are the norm. These are usually no more than a meter wide, and are best seen in the Rocky Harbour sediments east of Glovertown. Sericite and chlorite growth is evident along cleavage planes.

The volcanics of the Bull Arm Formation have no penetrative cleavage except for the basic rocks which display a weak schistosity striking NNE and dipping at a high angle.

Minor folds related to regional deformation are rare in the Musgravetown Group within the map area, although minor folds related to faulting are fairly common. Fault-related minor folds are identifiable by the fact that they decrease in amplitude and eventually die out (usually a short distance, 50 m - 200 m) away from the fault-zone. The best example is found in the sediments of the Crown Hill Formation east of Cary Cove, where green finely laminated shales exhibit a variety of fold styles, such as isometric, asymmetric, box and chevron folding.

In summary, the three main stratigraphic units of the map area each show a unique style of folding, although all apparently display the same dominant penetrative fabric which seems to have overprinted any previous fabric to a degree that makes identification difficult. The upright folding and the steeply dipping cleavage are characteristic of the Acadian orogeny in the region (Williams, et al., 1972; Kennedy, 1975). Evidence for an earlier Precambrian orogeny will be discussed later.

IV:2 Faults

IV:2-1 Love Cove Horst

The most prominent faults in the map area are those which flank the Love Cove volcanics. As stated earlier, the volcanics are found in a NNE-trending horst structure, bringing older Love Cove rock into contact with the Musgravetown and Connecting Point sediments. The width of the western fault, in the north, can be seen in the village of Culls Harbour, NNE of Traytown, where it is approximately sixteen meters wide. The presence of the fault is indicated by a felsic dyke and large quartz veins which separate Love Cove acid tuffs from sediments of the Rocky Harbour Formation (Plate 27). In the south, near the entrance to Newman Sound Campgrounds and in the Terra Nova road area, the eastern and western fault zones are exposed in road cuts. They are represented by rust-colored brecciated rock, intensely altered yellow-green rock (albite, chlorite, actinolite and epidote) and intermediate dykes (sodic plagioclase, microcline and hornblende). The original nature of the altered and brecciated country rocks is unknown. The width of the zones is estimated to be 150 to 200 meters. The difference in zone widths may reflect a variation in the degree of movement from north to south. In addition, the width of the horst structure diminishes northwards. These two points suggest the possibility that the structure dies out to the north, thus ending the continuous belt of exposures of the Love Cove Group.

A group of three high-angle faults is located in the Rocky Harbour siltstones and epiclastic volcanic sediments between Glovertown and Traytown. The movement of the largest of these faults as deduced from the orientation of chlorite porphyroblasts, a direct result of the movement, is a combination of strike-slip and dip-slip. The elongated spots are at an angle of 55° - 60° to the horizontal, inclined to the south. This attitude indicates that the dip-slip movement was greater than that of the strike-slip, with the east side moving upwards relative to the west. The strike-slip movement was one of the east side moving northwards relative to the west half. The amount of movement for both the dip-slip and the strike-slip components is impossible to determine accurately.

The fault zones are characterized by chlorite and quartz veins and grey-brown altered rock which contains the porphyroblasts. The original sedimentary nature of the rock is still recognizable.

IV:2-2 Cary Cove Faults

The Cary Cove faults form a graben structure east of Cary Cove, preserving Crown Hill Formation siltstone and conglomerate within the Love Cove volcanics. The faults are shown by rusted, brecciated zones which have a maximum observed width of ten meters (Plate 28).

IV:2-3 Rosedale Fault

The most visible result of this fault is the cutting of the large rhyolite exposure in the Rosedale area. The fault appears to have had only lateral movement and is therefore classified as a wrench fault. The total displacement is in the order of 1.25 km, with the east side having moved northwards relative to the west side.

IV:3 Metamorphism

The metamorphic minerals of the map area include chlorite, biotite, actinolite, tremolite, calcite, epidote, albite and quartz. This assemblage is characteristic of the greenschist facies. The biotite found in small amounts, is brown to green and is not easily detectable microscopically, although X-ray diffraction patterns clearly show its presence. It is distributed sparsely throughout the area; thus it would seem that pressure-temperature conditions of metamorphism in the entire map area straddle the boundary between the quartz-albite-epidotite-chlorite subfacies and the quartz-albite-epidote-biotite subfacies of the greenschist facies.

In order to determine the metamorphic grade of rocks within the study area, it was necessary to study in detail the metamorphic mineralogy of the basic rocks. The mineral assemblages of the more siliceous rocks are usually not diagnostic under low-grade metamorphic conditions, and thus are of limited use for the determination of metamorphic facies and subfacies.

The typical basic tuff of the Love Cove Group, found in the area between Traytown and SW Arm, consists of a fine grained anhedral mosaic of chlorite, epidote, leucoxene, muscovite, actinolite and subhedral albite, with coarser aggregates of epidote and chlorite forming patches, aligned with schistosity. Epidote and calcite also occur in veinlets. The tuff is completely recrystallized, no original mineralogy remains and there are no recognizable pseudomorph outlines.

A typical Bull Arm basic tuff (west of Norton Cove) has a coarser texture than the Love Cove rocks. Lithic fragments are common and there are numerous cavities, now filled by albite. Like the Love Cove basic rocks the Bull Arm tuffs are totally recrystallized. All secondary minerals identified in the Love Cove rocks are also present in the Bull Arm basic units. In addition, green biotite is found in the basic rocks, usually associated with chlorite, locally with epidote. Albite does not dominate the groundmass; the fine grains in these basic rocks consist of leucoxene and epidote.

The common basic rock of the Connecting Point Group from the Newman Sound area is usually somewhat brecciated. These rocks are not as completely recrystallized as the Bull Arm and Love Cove basic tuffs; original phenocrysts of plagioclase, now albite in composition, are still noticeable although somewhat masked by secondary calcite and epidote. The mineral assemblage in the basic rocks of the Connecting Point Group include actinolite, calcite, leucoxene, epidote, chlorite and brown biotite. As with the Bull Arm basic tuffs, leucoxene and epidotite are the dominant minerals in the groundmass. Actinolite forms relatively coarse prismatic crystals and chlorite is found as anhedral porphyroblastic growth.

The basic dykes of the area which intrude the Love Cove belt, the Connecting Point Group, the Rocky Harbour and Cannings Cove Formations, all display secondary minerals similar to those found in the extrusive basic rocks described above, i.e. actinolite, albite, chlorite, epidote, calcite and occasionally green biotite. Most are fine-grained, completely altered; some are schistose, some amygdaloidal.

As all the stratigraphic units of the map area display similar assemblages of secondary minerals characteristic of the greenschist facies, it is clear that the main period of metamorphism was post-Rocky Harbour and probably post-Precambrian. In the schistose basic rocks, it can be seen that the chlorite which defines the fabric is in contact with the other secondary minerals, indicating equilibrium conditions. Thus, the metamorphic recrystallization is probably related to the tectonic event which caused the development of the penetrative fabric. This event, as stated earlier in this chapter, is most probably the Acadian orogeny of the Devonian period.

CHAPTER V

PETROCHEMISTRY

V:1 Introduction

The data presented in this chapter and the analyses in Appendix II, represent the first information on the petrochemistry of the study area and of the Love Cove volcanic belt as a whole. A total of fifty-seven specimens were analysed for major, minor and trace elements; a further six specimens were analysed for trace elements alone. Nineteen of the analysed specimens are from the Love Cove belt, fourteen from the Bull Arm Formation, two from the Connecting Point Group, fifteen from the Rocky Harbour Formation, two from the Traytown granite, eleven represent various basic and acid dykes and three are from small stocks or sills of gabbro.

The chemical study was undertaken not only to provide basic data not previously available for this major volcanic belt in the western part of the Avalon zone, but also to attempt to solve the problem first posed by the suggestion of Younce (1970) that the Love Cove belt is merely a sheared equivalent of volcanic rocks of the Musgravetown Group. Although chemical data alone may not provide the final answer, it is obvious that a discovery of significant and persistent chemical differences between the Love Cove and other rocks would be a major factor in the controversy.

V:2 Metasomatism

Before the chemical data given in Appendix II can be used to compare the various rock types and to draw conclusions about the origin and tectonic setting of the stratigraphic units, on must consider the possibility and extent of metasomatic changes. Few, if any, rocks of Precambrian age have preserved their original composition. In addition, most volcanic rocks are subject to a degree of chemical readjustment during and shortly after extrusion. The question is whether sufficient evidence remains to enable the estimation of their original chemistry.

The first obvious change of original chemistry involves hydration. As revealed in Table V-1, the average loss on ignition (H_2O, CO_2) for the Love Cove basic rocks is 4.01%. This, of course, is to be expected in rocks that are thoroughly recrystallized to the mainly hydrous minerals characteristic of the greenschist facies; however, the high water content should be kept in mind when the rocks recalculated to 100% anhydrous, are plotted on various petrochemical diagrams.

Silicification, a common chemical change in some old volcanic rocks, does not appear to present any significant problems in the study area. Nearly all of the rocks high in SiO_2 lie in the normal rhyolitic range and no physical evidence of extensive silicification has been noted in the field.

Chemical readjustment involving alkalies is potentially a major obstacle in discovering the original chemistry of the rocks.

Love Cove vol.

	$SiO_2 > 70$ 10 anal. avg.	min	max	70 - 60 4 anal. avg.	min	max	< 60 5 anal. avg.	min	max
SiO_2	74.39	71.80	83.50	65.98	62.80	68.60	45.62	42.30	47.60
TiO_2	0.19	0.04	0.40	0.50	0.30	0.66	2.09	1.30	3.10
Al_2O_3	13.08	9.70	14.30	15.15	14.00	16.60	16.10	13.80	17.10
Fe_2O_3	0.86	0.17	1.71	3.75	3.32	3.99	5.64	2.85	6.44
FeO	0.73	0.40	1.51	0.70	0.17	1.13	7.02	5.24	11.99
MnO	0.06	0.03	0.10	0.10	0.09	0.11	0.23	0.18	0.27
MgO	0.27	0.03	1.23	1.55	0.98	2.21	6.92	5.36	8.94
CaO	0.72	0.14	2.56	2.79	1.67	4.64	7.90	4.58	10.28
Na_2O	4.85	2.94	7.10	3.99	1.84	5.67	2.94	2.56	3.09
K_2O	2.44	0.14	5.03	2.72	1.58	3.72	0.37	0.03	0.88
P_2O_5	0.00	.	.	0.11	0.00	0.22	0.31	0.00	0.50
LOI	1.54	0.56	4.49	2.37	0.98	4.06	4.01	2.07	5.46
Tot.	99.13			99.71			99.15		

Bull Arm fm.

	$SiO_2 > 70$ 12 anal. avg.	min	max	70 - 60 2 anal. avg.	min	max
SiO_2	75.63	71.30	79.10	64.30	60.80	67.80
TiO_2	0.24	0.06	0.66	1.19	1.04	1.34
Al_2O_3	11.91	10.80	15.30	15.95	15.00	16.90
Fe_2O_3	2.75	1.05	9.25	5.91	5.19	6.62
FeO	0.56	0.06	1.18	0.43	0.42	0.44
MnO	0.07	0.00	0.26	0.15	0.10	0.20
MgO	0.24	0.00	1.19	0.55	0.20	0.89
CaO	0.45	0.00	1.46	1.23	0.52	1.94
Na_2O	3.43	1.49	5.65	5.33	5.09	5.57
K_2O	4.53	1.23	7.45	3.83	2.49	5.16
P_2O_5	0.00	.	.	0.12	0.00	0.25
LOI	0.80	0.33	1.45	0.78	0.54	1.55
Tot.	100.61			99.89		

table (V-1)

average major and minor element values

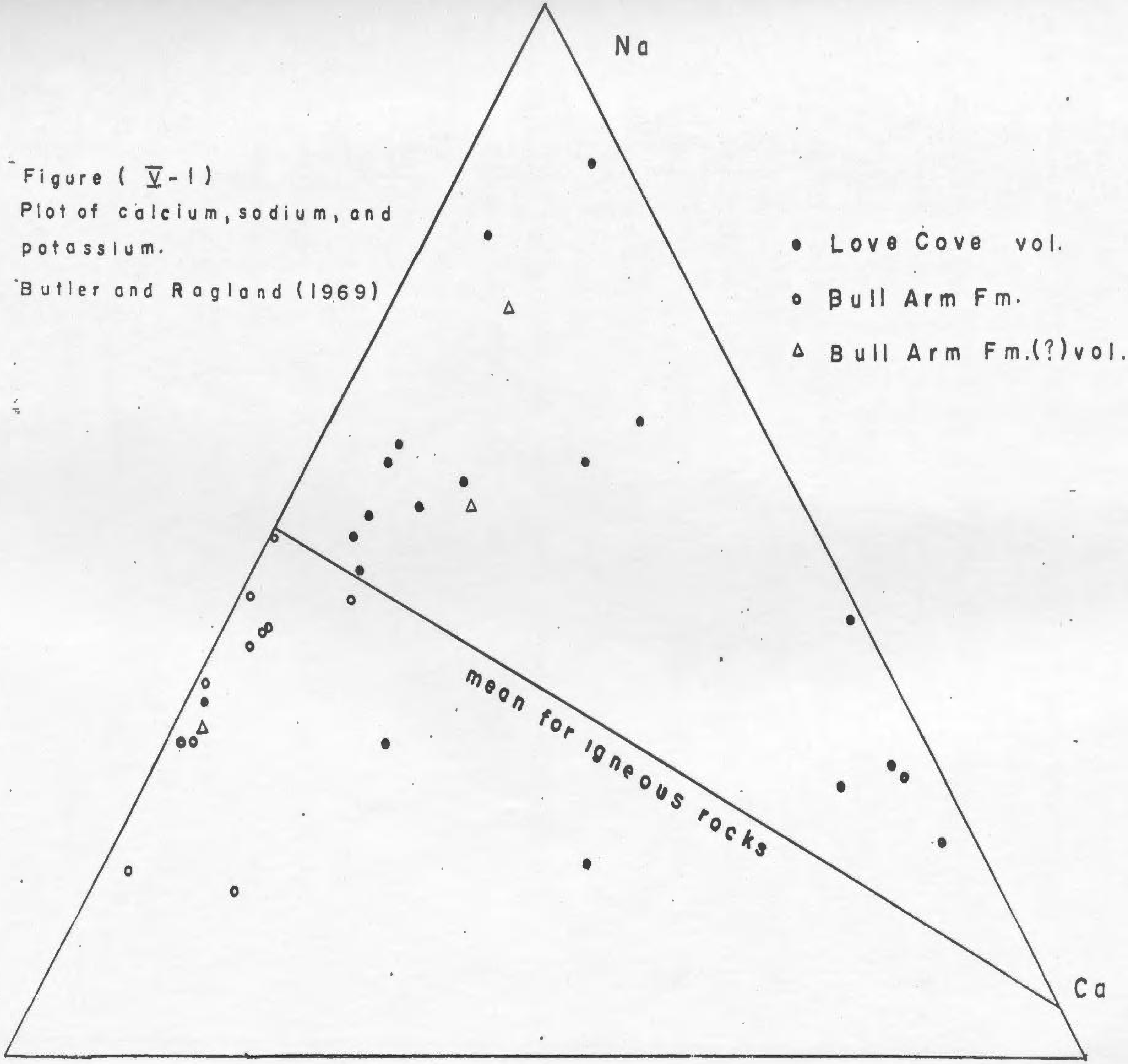


Figure (V - 1)
Plot of calcium, sodium, and potassium.
Butler and Ragland (1969)

A very similar problem was discussed in detail by Butler and Ragland (1969), who studied "meta-igneous rocks" of "Early Paleozoic and possibly Late Precambrian age", in the Albemarle area of North Carolina. When the volcanic rocks of the Love Cove belt are plotted on the diagram used by Butler et al. (Figure V-1), the pattern appears to be similar to that of the vitric tuffs from North Carolina. Butler et al. concluded that the vitric tuffs were metasomatized because of their higher than normal K:Rb ratio compared to common felsic rocks, higher than the ratios found in related andesitic and basaltic rocks, contrary to what could be expected. It was concluded that sodium had been introduced and potassium removed.

The Love Cove rocks present a more complex situation. The K:Rb ratio of the Love Cove volcanics is lower than that of the related basic volcanics which agrees with the expected trend of differentiation, thus suggesting no loss of potassium in these volcanics. (Figure V-1), seven of the fourteen acid rock analyses fall within a reasonable distance of Butler and Ragland's "mean line", four other analyses display a marked increase in sodium relative to the seven and the remaining three show the opposite effect, an increase in potassium. Therefore, this diagram does not show either a general loss or gain of either of the alkalies in the Love Cove suite as a whole in the study area, but merely local metasomatic effects. The controlling factor for fluctuation of alkalies cannot be locality, physical nature or deformation. Rocks in close proximity, displaying schistosity and appearing to be physically identical show different metasomatic effects.

The Bull Arm volcanics appear to show an enrichment of potassium and a depletion of sodium, (Figure V-1). However, the "mean line", as the name indicates, is merely an average of known igneous rock compositions and therefore cannot be used to denote "alteration" in whole rock suites; only those rocks of a unit which are "abnormal" with respect to the majority can be said to have perhaps undergone chemical alteration. Ten of the fourteen analyses are within a reasonable distance of the "mean line", suggesting that the high potassium values relative to sodium may be a normal feature of the Bull Arm rocks of the map area.

Again as with the Love Cove Group, the obvious chemical changes may trend in either direction. Two of the Bull Arm analyses show potassium enrichment while another Bull Arm (?) rock, (southwest portion of map area, discussed in Chapter III and later in this chapter), displays sodium enrichment. Thus, there again seems to be no universal chemical alteration pattern. Malpas (1972) noted that in the Bull Arm rocks of the Isthmus of Avalon there was a trend to the enrichment of potassium and the depletion of sodium.

Figures V-2 and V-3 support the above conclusions, namely that the soda values in the Love Cove rocks and the potassium values in the Bull Arm volcanics for the most part have not been greatly affected. No overall metasomatic change involving alkalies has occurred in these volcanic units. Local chemical alteration has caused opposite effects in both the Love Cove and the Bull Arm rocks. In Figure V-2, plotted according to Irvine and Baragar (1971), most of the Bull Arm rocks lie

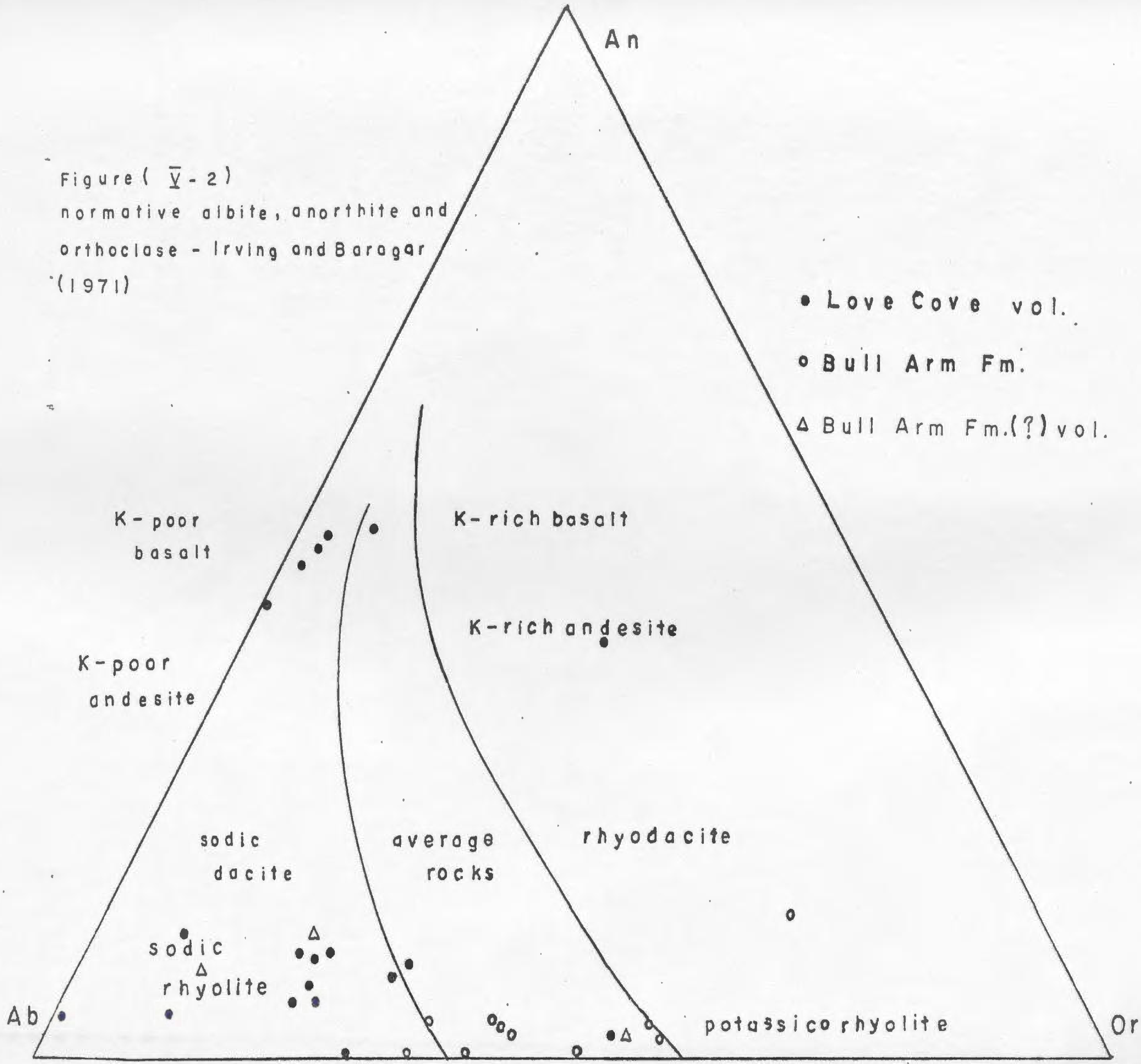


Figure (V-2)
normative albite, anorthite and orthoclase - Irving and Baragar (1971)

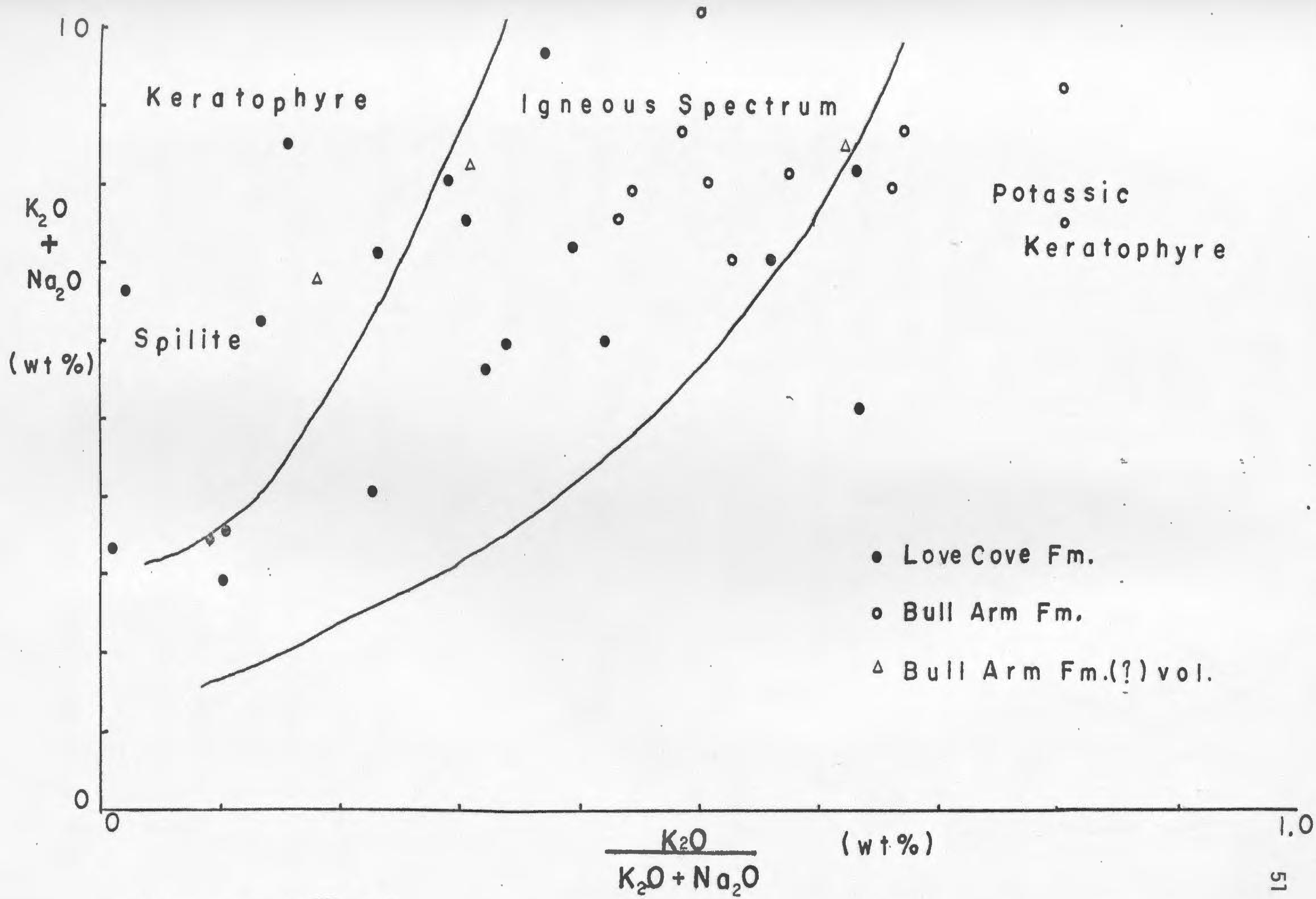


Figure ($\overline{V}$-3)
Igneous Spectrum Plot- Love Cove vol. & Bull Arm Fm.

within the zone of "average rocks", while the Love Cove specimens plot in the field of sodic rhyolite. This probably reflects an original chemical difference between the two suites rather than a simple metasomatic effect.

A somewhat similar diagram, (Figure V-3) was devised by Hughes (1972) to separate rocks of "normal" igneous composition (the "igneous spectrum") from those that have presumably undergone alkali metasomatism. In plots of interpretation only those points falling within the "igneous spectrum" zone will be used; although the fact that a rock composition falls within this zone does not indicate that it has retained its original composition, and a rock falling outside the zone is not necessarily altered. Fresh rock types such as hawaiites and mugearites plot outside the zone, (Papezik, pers. comm.). However, since Figure V-3 supports Figures V-2 and V-1, it may be said that the compositions of the rocks used for petrogenic interpretation do not differ greatly from their original compositions.

V:3 Volcanic Rocks

Within the limitations noted above, the chemical data in Appendix II provide a good deal of useful information on the chemical composition of volcanic rocks of the Love Cove Group and Bull Arm Formation, information which has so far been completely lacking.

Average compositions for the Love Cove and Bull Arm volcanic rocks are given in Table V-1. The range of silica in the volcanic rocks reflects to some extent a sampling bias. The predominance of acid rocks is shown clearly in Figure V-4, which also illustrates the scarcity of basic volcanics in the Bull Arm and the apparent bimodality of the Love Cove suite. Whether the bimodality is real is impossible to state because much of the Love Cove volcanic belt is poorly exposed. Silicification does not appear to be a serious problem; only three out of fourteen Bull Arm and two out of nineteen Love Cove rocks exceed 77% SiO_2. The distribution of the remaining major elements is shown in Figure V-5 by using Harker diagrams. Rocks falling outside the limits of the "igneous spectrum" of Hughes (1972) are included but represented by separate symbols.

In the acid volcanics of the Love Cove belt and the Bull Arm formation TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO and CaO display negative slopes, that is, their values decrease with increasing silica. Values of FeO are all low while K_2O and Na_2O are scattered; the lack of a consistent pattern is probably the effect of localized alkali exchange. The Bull Arm acid volcanics show the same negative slopes as are exhibited by the Love Cove oxides. However, TiO_2, Al_2O_3 and MnO in the Bull Arm rocks are higher than those of the Love Cove volcanics at any given point along slope. CaO shows the opposite effect; Love Cove compositions display higher CaO values along slope than the Bull Arm volcanics. Na_2O and K_2O in the Bull Arm Formation show a more consistent pattern than in the Love Cove Group. Bull Arm compositions concentrate in the range of 3% to 5% for both oxides with K_2O values being generally higher than those found in the Love Cove volcanics of the map area.

The oxides Al_2O_3, MnO, Na_2O and K_2O of the basic rocks can be

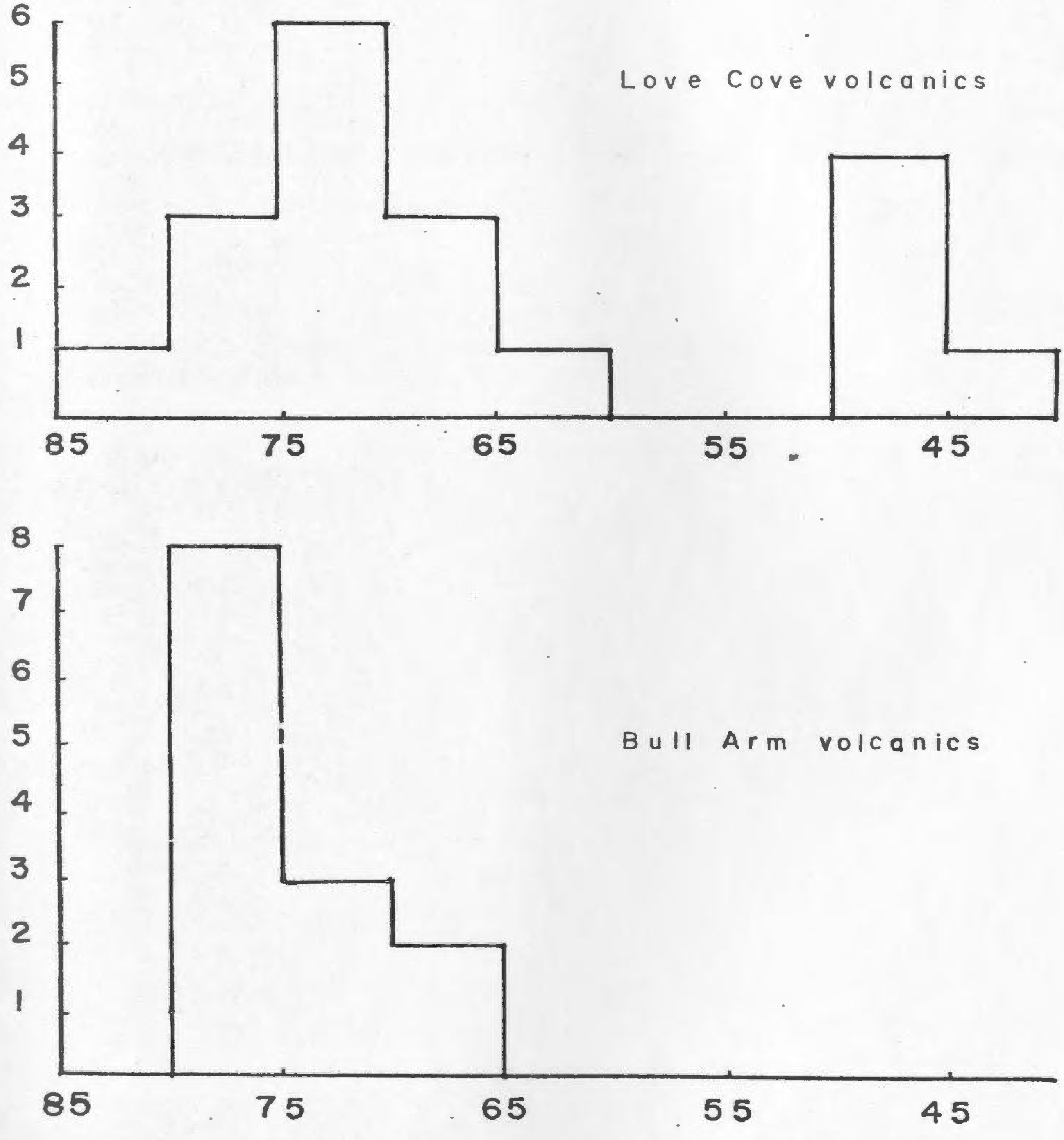


Figure (V-4)

histograms, frequency vs SiO_2

Figure (V - 5)
Harker diagrams
major, minor, and trace elements versus SiO_2
- Love Cove vol. & Bull Arm Fm. - All plots are anhydrous and in weight percent.

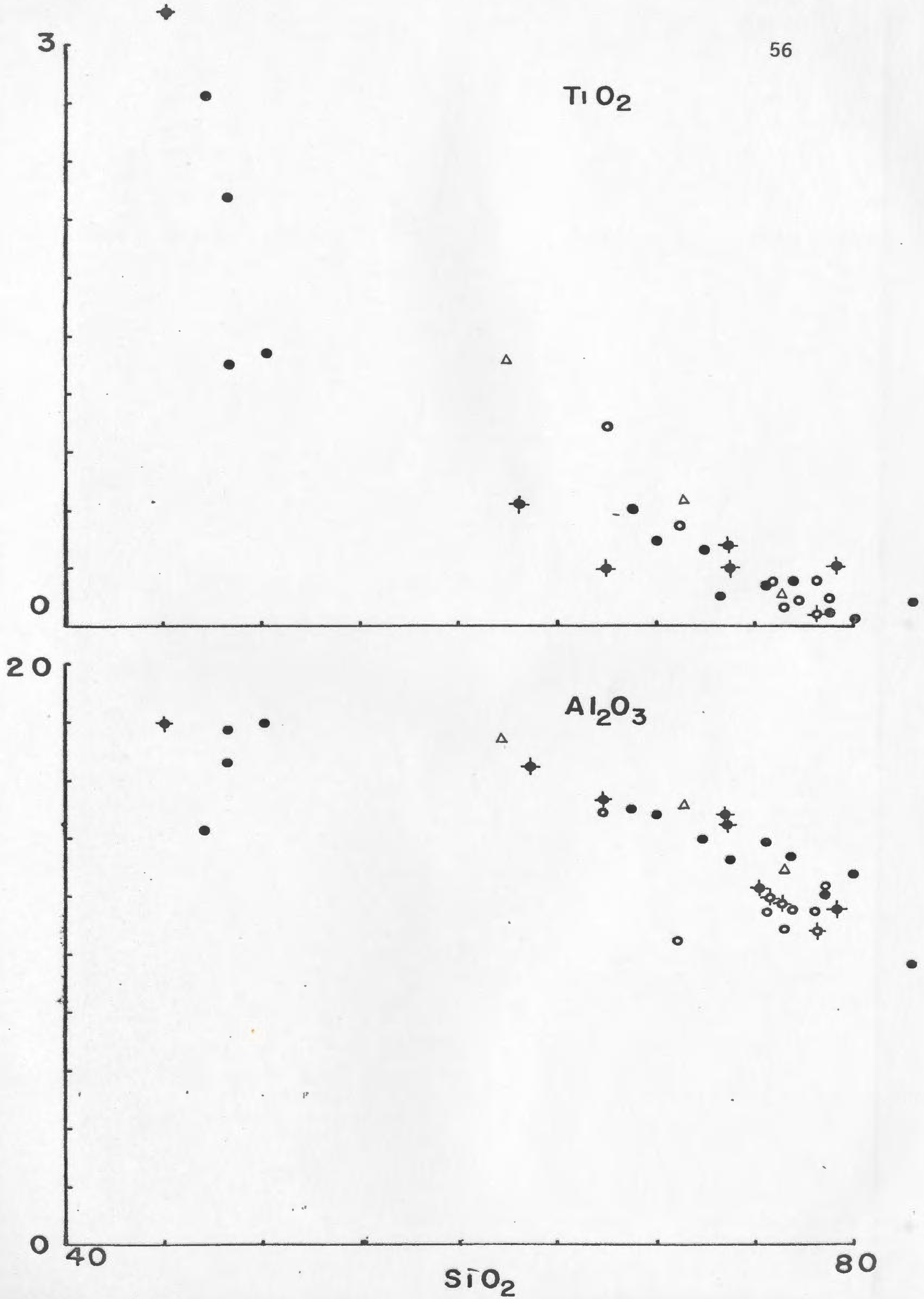
● Love Cove vol.

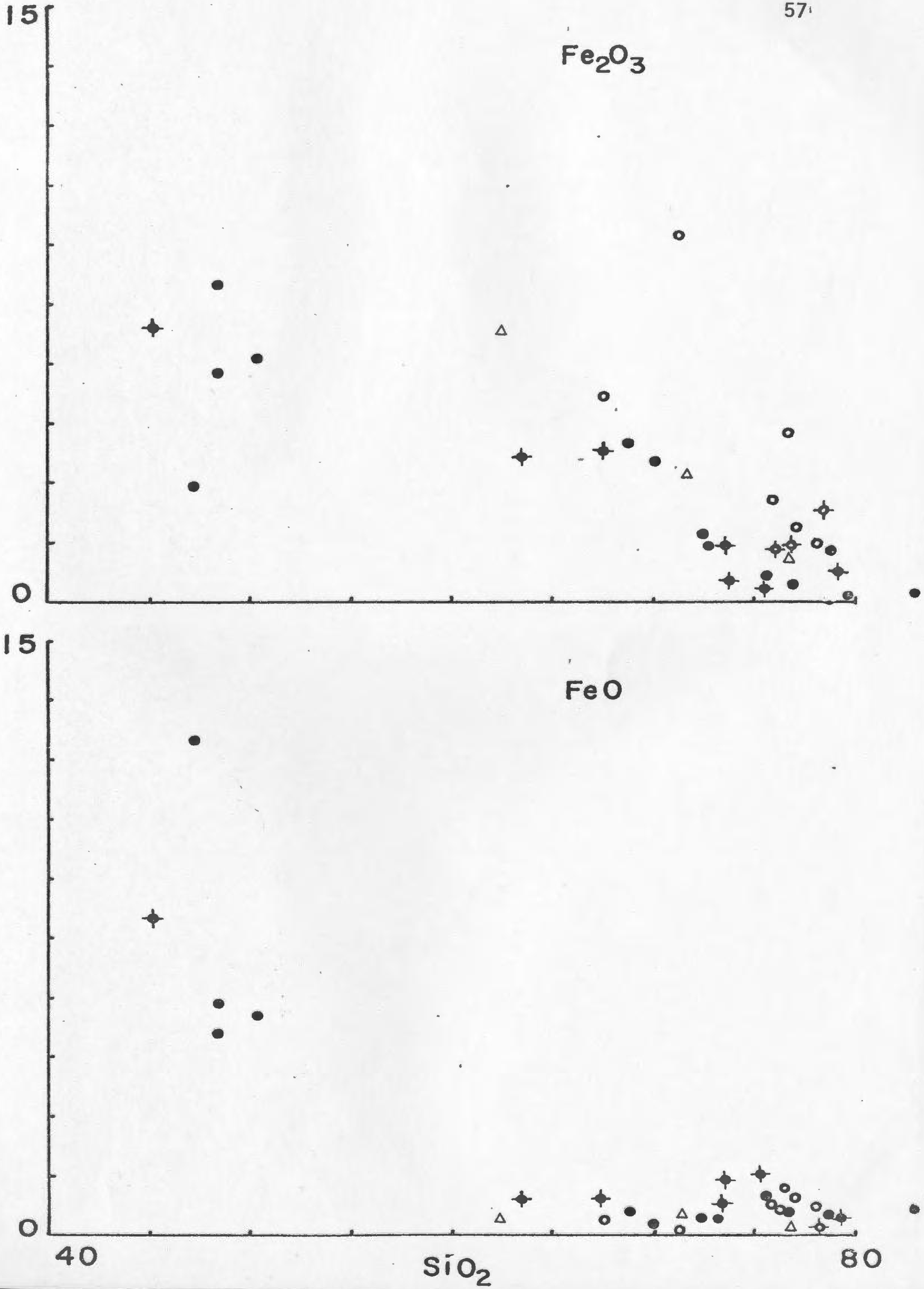
○ Bull Arm Fm.

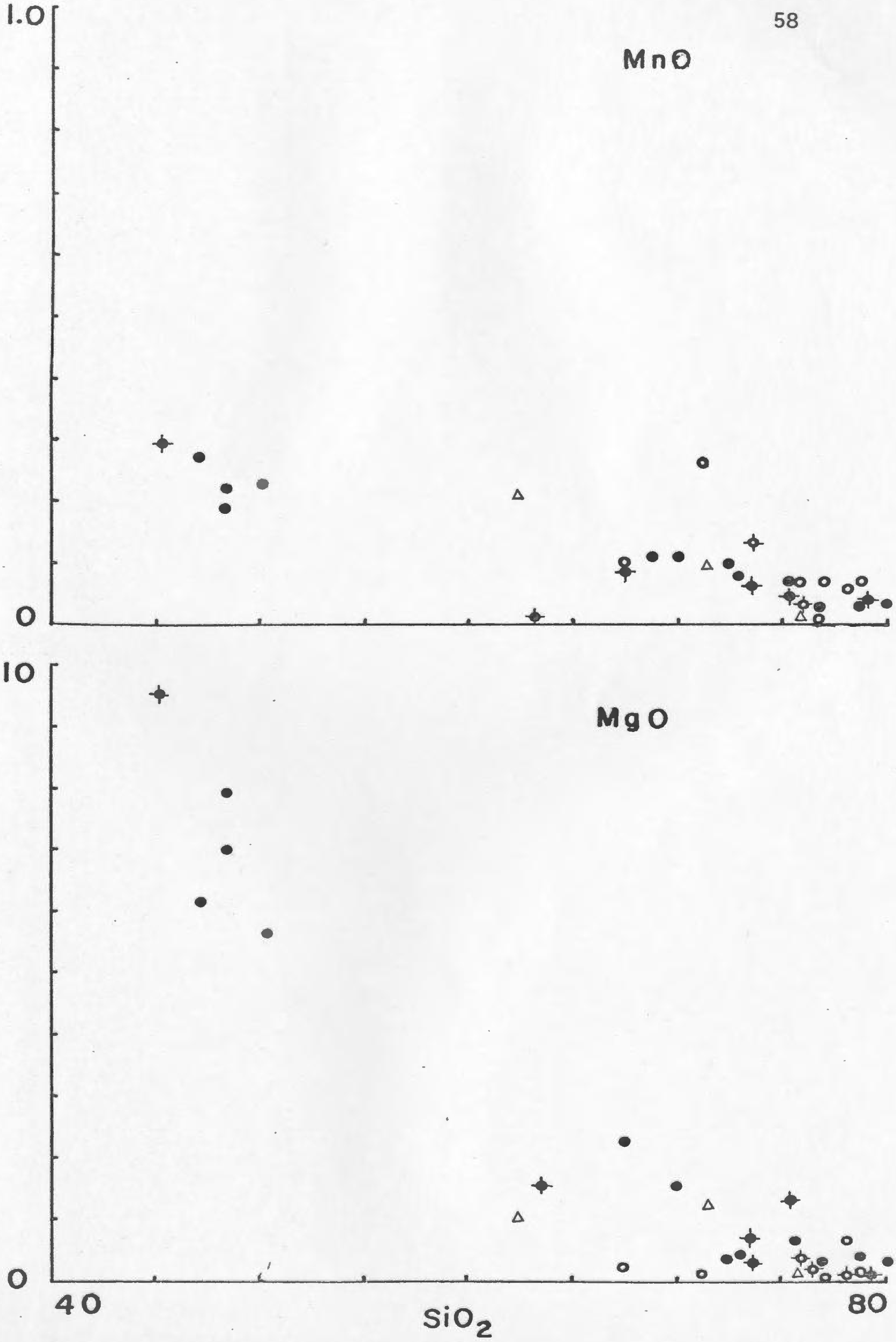
✦ Love Cove vol. -outside "Igneous Spectrum" (Hughes, 1972)

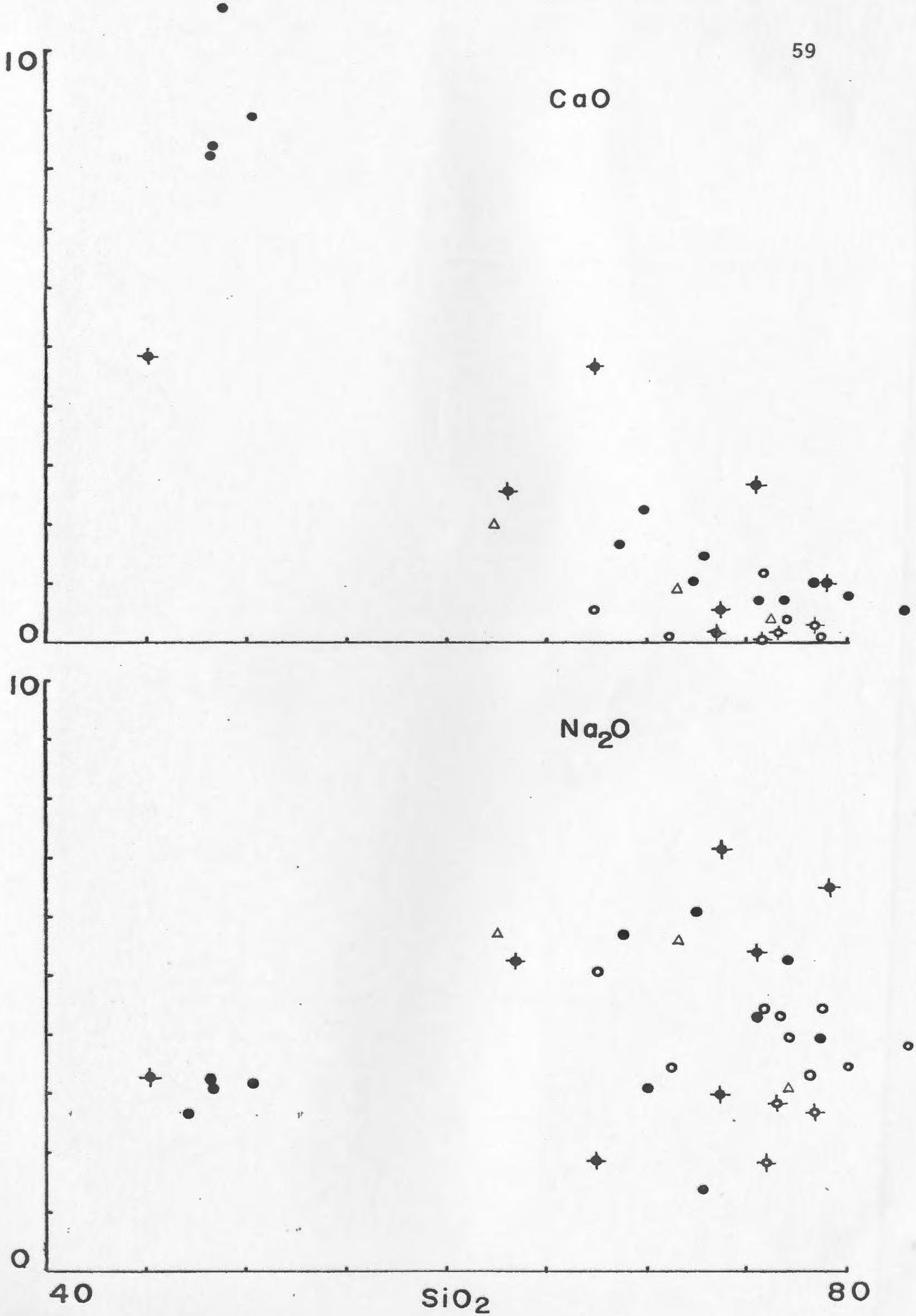
✧ Bull Arm Fm. outside "Igneous Spectrum" (Hughes, 1972)

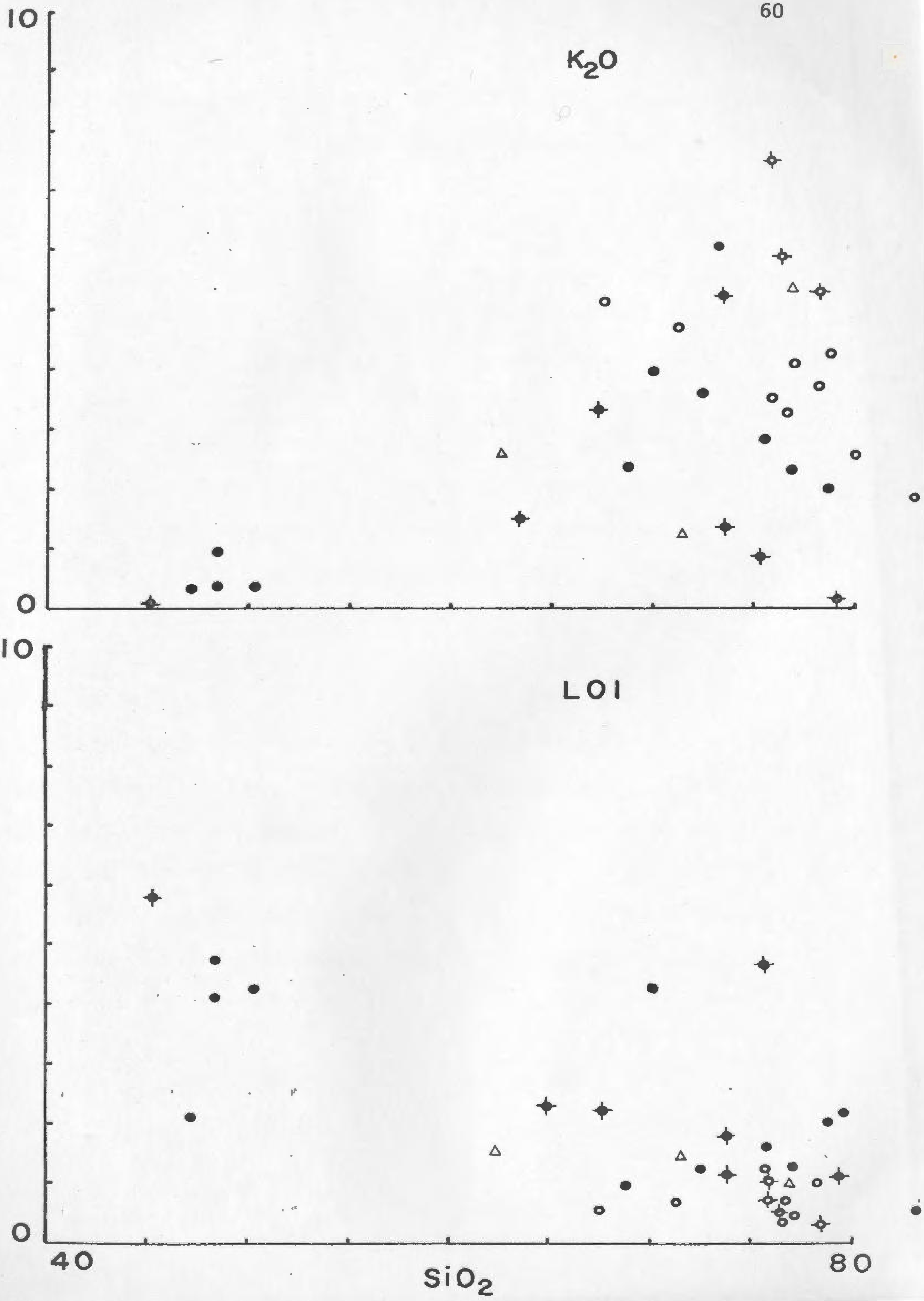
△ Bull Arm Fm.(?) vol SW corner of map area


3
Ti O2
0
20
Al2O3
0
40
80
SiO2


15
Fe_2O_3
0
15
FeO
0
40
SiO_2
80


MnO
1.0
0
MgO
10
0
40
80
SiO_2


10
CaO
0
10
Na2O
0
40
SiO2
80


10
K_2O
0
10
LOI
0
40
80
SiO_2

seen to cluster in their corresponding Harker diagrams. The remainder display a degree of scatter; TiO_2 showing the largest, which makes it doubtful whether titanium can be utilized as a petrogenic indicator in the case of the Love Cove basic tuffs. The high Fe_2O_3 values relative to those of FeO, in both basic and acid volcanics of the Love Cove Group and the Bull Arm Formation, are clearly affected by oxidation of these subaerial volcanics. The practice of reducing the Fe_2O_3 value for C I P W norm calculation was not used here, which may cause a shift to higher quartz content. However, since normative values are not used in petrogenic interpretation, they have no effect on conclusions reached.

The mobile oxides Na_2O and K_2O show very good clustering in the basic tuffs, suggesting either uniformity in alternation or very little alternation effect. CaO on the other hand shows scattering, indicating both local loss and gain of calcium.

The basic volcanics, as expected, show high "loss on ignition" values and on the whole the Love Cove volcanics display higher values than the Bull Arm volcanics. Figure V-6 shows relative position, anhydrous and hydrous for the Love Cove basic rocks. The shift of position undoubtedly has some influence on petrochemical diagrams (Figure V-6). However, Fig. V-7 shows that this effect is not of major importance. The shift causes very little change in alkali-lime index value.

V:4 Petrochemical Classification of the Love Cove Volcanics, using Major Elements

An alkali-lime index value of 60 was found for the Love Cove volcanics (Figure V-7), indicating a calc-alkaline affinity. The scatter of points makes the exact figure somewhat unreliable, but the classification itself is probably correct.

A good evidence of a calc-alkaline affinity of the Love Cove volcanics can be found by using the statistical method of Ragland et al. (1968). "The method used here is to compare the composition of the primary dike magma with the composition of other basalts from areas of different geologic characteristic in order to determine the condition of the North Carolina area at the time the dykes were formed", (Ragland et al., 1968, p. 72-73). In this study the compositions of both the Love Cove acid and basic tuffs are compared with acid and basic rocks from other areas, in an attempt to determine the chemical affinity of the volcanics of the Love Cove Group. The advantage of this method is that it utilises the complete chemical analysis, including both immobile and mobile elements, thereby negating to a degree any chemical alteration that has occurred.

The format involves the calculation of the following two equations:

1. The sum, for all oxides, of the quantity:

$$\frac{(\%\ X - \%\ LC)^2}{\%\ LC}$$

2. The sum, for all oxides, of the quantity:

$$\frac{|\%\ X - \%\ LC|}{\%\ LC}$$

where % X is the percentage of a particular oxide in the comparison rock and % LC is the percentage of the same oxide in the Love Cove volcanics. The smaller the values for the sums of the above equations, the closer the compositions of the two rocks involved. The larger the values the more unlike the compositions are.

A typical acid tuff composition (P-47) was compared to fifteen others of varied chemical affinities from various areas (Table V-2). The three smallest values correspond to the calc-alkaline suites of Mt. Jefferson in the Cascades, of the Santorini Group of Greece and of Crater Lake in the Cascades.

The basic tuff composition (DB - 381 and DB - 414) compared to the basaltic compositions shown by Ragland et al. (1968) may be seen in Table V-3. The three lowest ranks and therefore most similar in composition to the Love Cove basic volcanics are those of Picture Gorge type of Columbia River basalt, those of Japanese high-alumina basalts and those of the high-alumina basalts of the Cascade Range and Oregon plateaus.

In both the comparison of acid and basic rocks, Cascade rock types are involved. It would therefore appear that the condition of formation of the Love Cove volcanics was one similar to that of the Cascades, a continental calc-alkaline environment. Figure V-8 adapted

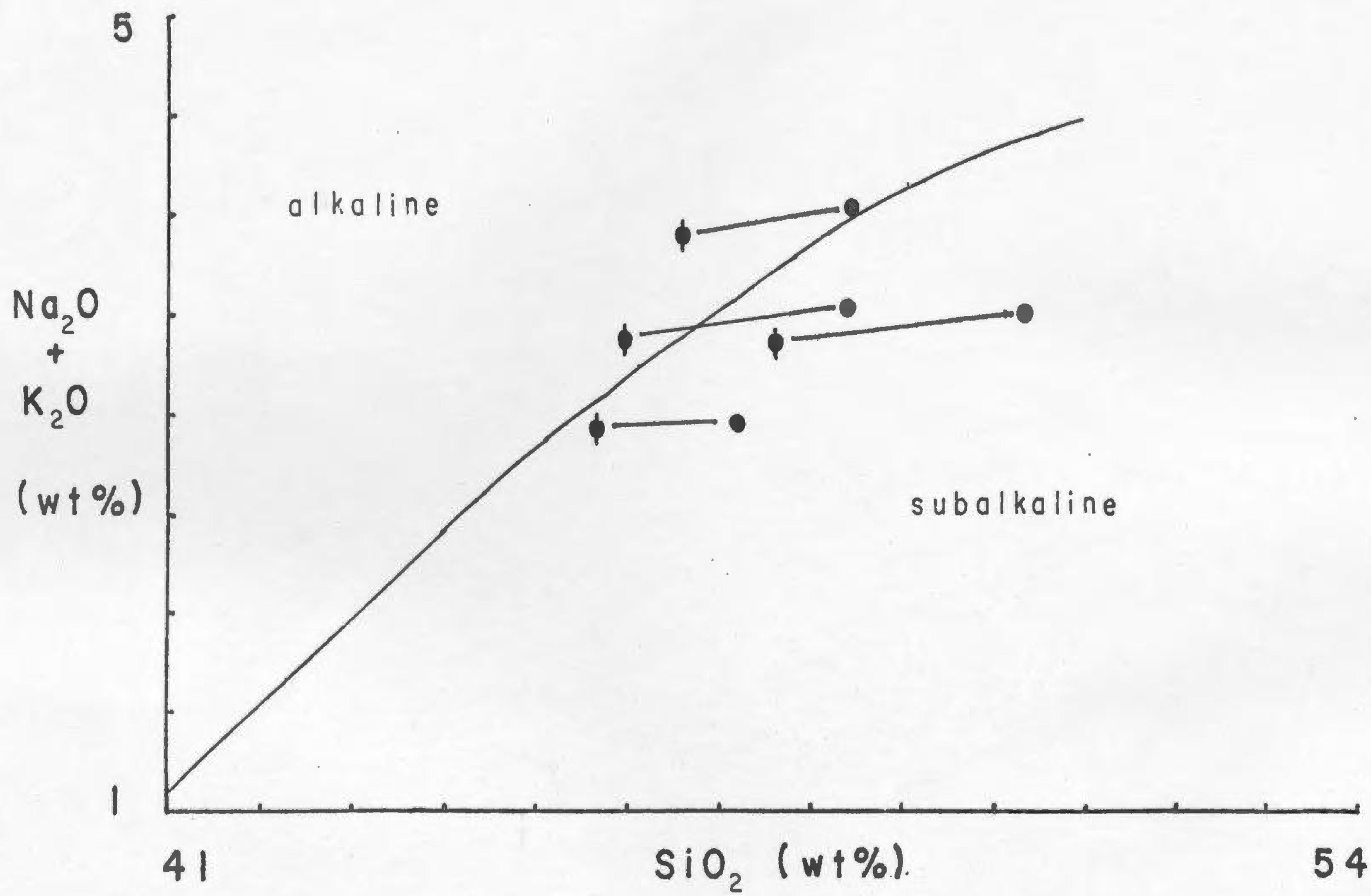


Figure (V-6)

total alkalies vs SiO_2 (Irvine & Baragar, 1971)

⸸ hydrous • anhydrous Love Cove volcanics

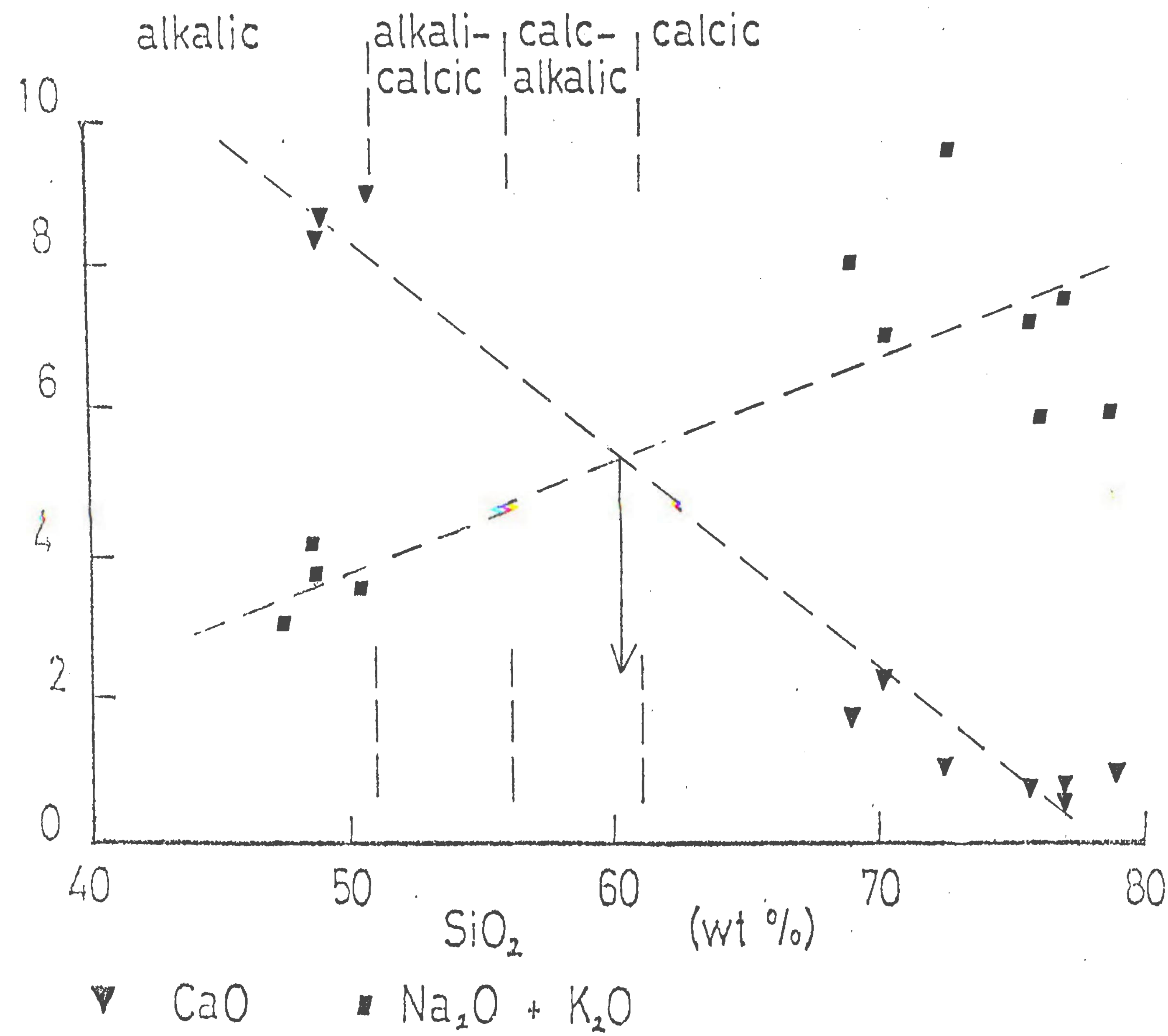


Figure ($\underline{V}$-7) Alkali Lime Index — Love Cove volcanics

COMPARISON OF ASH-FLOW COMPOSITIONS

No.	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	anal.
1	76.62	12.78	0.09	0.91	0.61	0.19	0.89	3.49	4.39	14
2	68.81	15.48	0.56	2.85	0.53	1.13	3.37	3.35	3.58	16
3	74.82	13.69	0.21	1.27	0.08	0.30	1.03	4.04	4.52	5
4	68.37	15.21	0.64	0.90	3.22	1.13	2.86	4.97	2.67	4
5	68.45	15.66	0.54	2.31	0.94	1.02	2.77	5.17	2.47	1
6	68.94	15.77	0.71	0.69	2.89	0.86	1.89	5.95	2.24	1
7	67.51	15.34	1.28	1.53	2.64	0.49	1.97	5.77	3.43	2
8	68.98	9.84	0.42	8.78			0.67	6.30	4.60	25
9	73.00	12.00	0.40	3.50		0.30	0.50	4.70	4.20	1
10	72.00	10.40	0.40	5.20		0.30	0.80	5.60	4.20	1
11	68.51	13.33	0.90	4.68	0.64	0.45	1.14	5.80	4.51	10
12	64.07	16.77	0.66	2.19	1.71	2.90	4.36	4.40	2.90	2
13	76.30	12.35	0.13	1.10	0.46	0.12	0.49	3.54	5.46	2
14	70.88	15.27	0.34		2.42	0.32	0.73	5.46	4.23	5
15	74.27	13.51	0.44	1.61	1.04	0.48	0.59	5.35	2.66	4

TABLE V-2 (CONTINUED)

No.	Equation 1	Rank	Equation 2	Rank
1	7.253	9	4.301	13
2	7.372	10	2.576	4
3	9.522	12	3.601	11
4	1.039	2	1.296	2
5	1.218	3	1.306	3
6	0.364	1	0.789	1
7	1.621	4	2.584	5
8	10.754	14	3.222	10
9	4.074	5	3.176	9
10	4.089	6	2.818	6
11	7.034	8	3.099	8
12	9.663	13	4.440	14
13	11.184	15	6.091	15
14	7.894	11	3.604	12
15	4.788	7	2.923	7

Equation 1 $\frac{(X\ \% - LC\%)^2}{LC\%}$ Equation 2 $\frac{|X\% - LC\%|}{LC\%}$

TABLE V-2 (CONTINUED)

No.

1. Northern Chile--ignimbrite (Pichler, tubingen and Zeil, 1972, p. 203).
2. Northern Chile--ignimbrite (Guest, 1969, p. 353).
3. Peru--ignimbrite (Jenks and Goldich, 1956).
4. Greece--ignimbrite (Pichler, Kufsmaul and Tubingen, 1972, p. 287).
5. Cascades, U.S.A., Crater Lake--ignimbrite (Williams, 1942, p. 151).
6. Cascades, U.S.A., Mt. Jefferson-- (McBirney, 1968, p. 101).
7. Oregon, U.S.A., Newberry Volcano--welded tuff (Higgins, 1973, p. 473).
8. Ethiopia--pantelleritic welded ash-flow tuff (Gibson, 1970, pp. 104-106).
9. Ethiopia--plateau ignimbrites (Mohr, 1971, p. 1974).
10. Ethiopia--rift ignimbrites (Mohr, 1971, p. 1974).
11. Canary Islands--ash-flow tuffs (Schmincke and Swanson, 1967, p. 659).
12. Papua--(Jakes and Smith, 1970).
13. Wyoming, U.S.A.--welded tuffs (Boyd, 1961, p. 408).
14. Canada, Nfld., Bull Arm Fm.--ignimbrite (Malpas unpub. M.Sc. Thesis, M.U.N. St. John's, Nfld.).
15. Canada, Nfld., Harbour Main Group--ignimbrite (Papezik, 1970, p. 1488).

TABLE V-3

COMPARISON OF BASALT COMPOSITIONS, AFTER RAGLAND, ROGERS AND JUSTUS (1968)

No.	Equation 1	Rank	Equation 2	Rank
1	2.426	7	1.579	4
2	1.917	4	1.345	1
3	2.832	9	2.136	8
4	3.768	15	2.704	11
5	1.926	5	2.681	10
6	5.245	24	4.558	25
7	2.361	6	1.814	6
8	3.143	11	1.807	5
9	3.219	13	2.561	9
10	5.061	23	4.339	23
11	8.066	28	7.075	36
12	2.525	8	2.947	14
13	4.924	22	4.657	26
14	8.933	30	6.279	30
15	7.160	27	5.698	29
16	1.034	2	1.474	3
17	1.132	3	2.069	7
18	4.672	20	4.224	22
19	3.566	14	3.207	15
20	4.529	19	3.998	19
21	9.643	32	6.870	34
22	3.170	12	4.443	24
23	10.248	33	3.726	18
24	31.233	37	12.176	37
25	10.405	34	6.855	33
26	10.410	35	6.714	32
27	3.127	10	3.650	17
28	10.895	36	6.889	35
29	4.349	18	4.139	21

TABLE V-3 (CONTINUED)

No.	Equation 1	Rank	Equation 2	Rank
30	4.119	16	3.215	16
31	6.417	26	5.121	27
32	3.972	15	2.726	12
33	8.077	29	5.684	28
34	0.812	1	1.370	2
35	9.514	31	6.294	31
36	5.416	25	2.798	13
37	4.831	21	4.037	20

	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Number[a]
1	49.19	14.61	1.69	2.60	8.99	8.49	11.42	1.90	0.34	7
2	49.94	17.25	1.51	2.01	6.90	7.28	11.86	2.76	0.16	10
3	49.36	13.94	2.50	3.03	8.53	8.44	10.30	2.13	0.38	181
4	51.08	13.27	2.80	2.04	9.15	8.05	10.60	2.18	0.43	32
5	51.17	17.24	0.94	3.63	7.34	5.13	10.78	2.60	0.72	7
6	46.61	15.47	2.94	5.37	6.29	7.32	11.32	2.89	1.06	8
7	52.3	14.5	1.1	3.8	10.2	5.1	10.0	2.1	0.4	11
8	49.78	15.69	0.68	2.73	9.20	7.79	11.93	1.21	0.29	3
9	49.15	13.23	2.87	4.68	9.09	5.50	9.79	2.87	0.49	10
10	52.64	15.16	1.64	4.92	7.29	4.07	8.70	3.49	1.23	2
11	46.0	18.5	1.4	6.1	5.0	5.4	11.9	2.6	1.6	1
12	49.95	17.65	1.42	4.44	5.80	6.05	11.43	2.38	0.87	9
13	47.26	14.91	2.48	2.53	9.59	8.05	9.98	3.13	1.20	5
14	48.18	16.10	2.31	6.02	8.71	3.90	9.89	3.49	1.56	19
15	49.14	15.71	3.17	3.64	8.17	6.03	8.38	3.69	1.39	14
16	50.19	17.58	0.75	2.84	7.19	7.39	10.50	2.75	0.40	11
17	49.47	17.85	1.53	2.78	7.25	6.96	9.97	2.90	0.72	21
18	48.11	15.55	1.72	2.99	7.19	9.31	10.43	2.85	1.13	7
19	46.87	13.98	2.72	2.61	9.60	9.82	10.47	2.84	0.68	7
20	47.04	14.82	3.05	3.31	9.22	8.29	10.40	2.96	0.85	28
21	48.16	18.31	2.91	4.24	5.89	4.87	8.79	4.05	1.09	10
22	46.54	15.36	2.23	4.26	7.63	9.12	9.54	3.46	1.27	7
23	43.1	13.1	4.1	5.5	8.5	9.0	12.4	2.7	1.6	3
24	46.7	17.3	3.6	3.8	7.1	4.7	9.7	4.1	3.0	10
25	47.7	15.2	3.2	2.3	8.7	9.7	8.9	2.7	1.6	2
26	47.09	16.92	3.78	2.66	8.52	5.78	9.43	3.28	1.56	4
27	51.63	15.87	0.93	2.18	8.30	7.15	10.32	1.76	0.95	4
28	51.71	12.50	3.01	4.23	8.19	7.15	8.42	2.45	1.08	29
29	49.86	14.35	1.62	4.21	7.02	8.25	8.45	2.80	1.23	16
30	50.35	13.55	2.51	3.11	11.25	5.27	10.42	2.57	0.64	15
31	50.90	13.07	2.10	4.28	9.25	4.96	9.47	2.79	1.31	8
32	46.05	15.24	3.10	3.53	10.52	8.23	8.74	2.62	0.46	3
33	54.5	14.1	2.0	2.6	9.4	4.1	8.0	3.0	1.5	8
34	50.2	15.9	1.6	3.6	7.9	6.6	10.5	2.7	0.5	16
35	50.5	13.6	3.2	1.9	12.6	4.4	8.4	2.9	1.4	4
36	51.19	15.75	0.45	1.01	7.95	10.77	11.04	1.44	0.38	1
37	53.36	16.45	0.59	0.52	8.32	6.72	11.49	1.60	0.91	6

[a] Number of analyses involved in calculating the average.

1. Pacific tholeiites; (KUNO, 1966, p. 202).
2. Pacific and Atlantic thoeliites (dredged); ENGEL *et al.*, 1965, No. 1, Table 3, p. 723)
3. Hawaiian tholeiites and olivine tholeiites; (MACDONALD and KATSURA, 1964, No. 8, Table 9; water-free calculation taken from ENGEL *et al.*, 1965, No. 2, Table 3, p. 723).
4. Hawaiian tholeiites; (KUNO *et al.*, 1957; No. 1, Table 10, p. 213).
5. Northern Marianas Islands tholeiites; (SCHMIDT, 1957, No. 11, Table 6, p. 157).
6. Azores plagioclase basalts and olivine basalts; (ESENWEIN, 1929, No. 7—10 and 13—16).
7. Izu Peninsula, Japan, basalts; (KUNO, 1950, No. VI, Table 5, p. 1000)
8. Japanese tholeiites; (KUNO, 1960; Table 6, p. 141).
9. Thingmuli volcano, Iceland, basalts; (CARMICHAEL, 1964, No. 1—10, Table 9, p. 454).
10. Northeastern Umnak Island, Aleutians, aphyric basalts; (BYERS, 1961, Table 7, p. 109).
11. Bogoslof Island basalt; (BYERS, 1961, No. 34, Table 1).
12. Nicaraguan basalts; (WILLIAMS, 1952, No. 2—10, Table 2, p. 41).
13. Basalts of peripheral district of South Island, New Zealand; (BENSON, 1941, No. E, Table I, p. 541).
14. Basalts of inner district of South Island, New Zealand; (BENSON, 1941, No. F, Table I, p. 541).
15. Banks Peninsula, New Zealand, post-rhyolite basalts; (BENSON, 1941, No. D, Table I, p. 541).
16. Japanese high-alumina basalts; (KUNO, 1960, Table 6, p. 141).
17. High-alumina basalts of Cascade Range and Oregon plateaus; (WATERS, 1962, Table 5, p. 165)
18. Japanese alkali-olivine basalts; (KUNO, 1960, Table 6, p. 141).
19. Hawaiian alkali-olivine basalts; (KUNO *et al.*, 1957, No. 2, Table 10, p. 213).
20. Hawaiian alkali-olivine basalts; (MACDONALD and KATSURA, 1964, No. 4, Table 10, p. 124). (Sum of major oxides recalculated to 100%.)
21. Pacific alkali basalts; (ENGEL *et al.*, 1965, No, 3, Table 3, p. 723).
22. Pribilof Islands alkali basalts; (BARTH, 1956, average of Table 6, p. 148). (Includes one sample with SiO_2 of 41.70%).
23. Tristan da Cunha alkali basalts; (BAKER *et al.*, 1964, No. 1, Table 8, p. 531).
24. Tristan da Cunha trachybasalts; (BAKER *et al.*, 1964, No. 2, Table 8, p. 531).
25. Gough Island basalts; (LE MAITRE, 1962, No. 5, Table 13, p. 1335).
26. Marquesas Islands trachybasalts; (CHUBB, 1930, No. 1 and 3, Table 2, p. 25, and No. 1 and 2, Table 4, p. 32).
27. Drakensberg basalts of Stormberg series of South Africa; (WALKER and POLDERVAART, 1949, No. b—o. Table 27, p. 694)
28. Southern African Karroo basalts (northern Province); COX *et al.*, 1967, No. A, B, C, D_1, D_2, D_3, Table 3), p. 1462). (Unweighted averages of six separate types with a total of 29 individual analyses).
29. Central Victoria, Australia, labradorite basalts; (EDWARDS, 1938, No. 12, Table XV, p. 309).
30. Indian Deccan basalts; (SUKHESWALA and POLDERVAART, 1958, No. 10, Table 3, p. 1487).
31. Non-porphyritic central basalts of Mull; (BAILEY, *et al.*, 1924, No. I—VIII, Table II, p. 17). (One rock shows total iron, and FeO/Fe_2O_3 is calculated as the average ratio of the other seven analyses; only seven TiO_2 analyses).
32. Plateau basalts of Mull; (BALEY *et al.*, 1924, No. I—III, Table I, p. 15).
33. Yakima type of Columbia River basalt; (WATERS, 1962; Table 2, p. 162).
34. Picture Gorge type of Columbia River basalt; (WATERS, 1962, Table 2, p. 162).
35. Late Yakima-Ellensberg type of Columbia River basalt; (WATERS, 1962, Table 2, p. 162).
36. Antarctic Ferrar dolerite; (GUNN, 1966, olivine tholeiite No. 26903, Table 2, p. 908).
37. Tasmanian undifferentiated diabases; (EDWARDS, 1942, No. 1, Table 3, p. 465).

1. the sum, for all oxides, of the quantity:

$$\frac{(\%X - \%LC)^2}{\%LC}$$

2. the sum, for all oxides, of the quantity:

$$|\%X - \%LC|$$

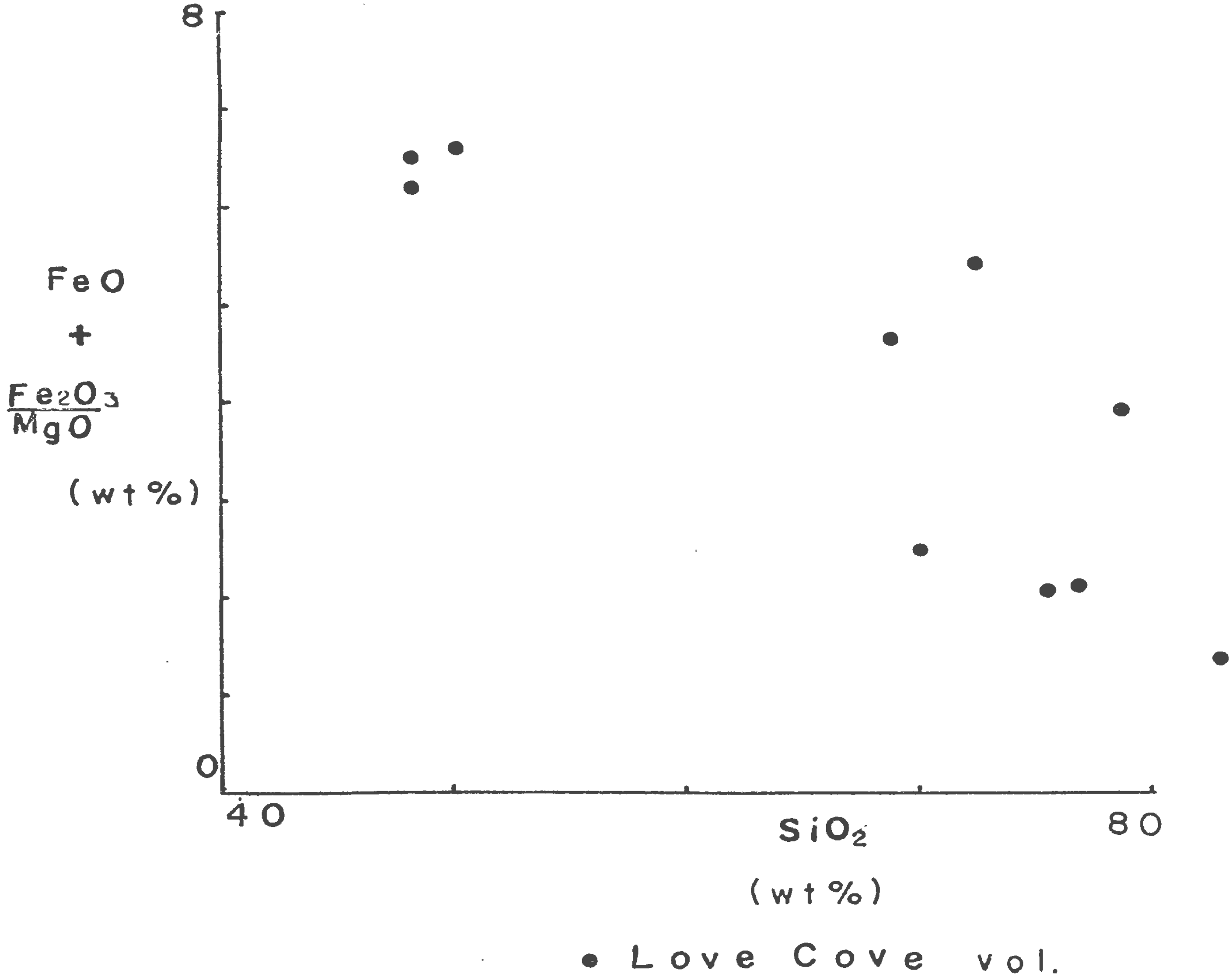


Figure ($\overline{V}$- 8)
Continental versus Island Arc calc-alkaline volcanism.

from Jakes and White (1972) was undertaken to separate the calc-alkaline volcanics into one of two categories, continental, as is suggested above, or island arc. According to Jakes and White, continental calc-alkaline rocks display ($FeO + Fe_2O_3/MgO$) values of greater than two, and their SiO_2 content varies from 56% to 75% while the SiO_2 range in island arc volcanics extends from 50% to 66%. As can be seen in the diagram, most of the analyses fall into the field of a continental calc-alkaline affinity for the Love Cove volcanics; this is in agreement with the Cascade model.

V:5 Trace Elements of the Love Cove and Bull Arm Volcanics

Trace element analyses are given in Appendix II and summarized in Table V-4. The trends of trace elements with increasing amounts of SiO_2 are shown in Harker diagrams (Figure V-5).

The Love Cove acid volcanics contain typically low Pb, and Ni, more variable Zn, Rb and Sr while Ga, Zr and Y are fairly constant at moderate levels. Overall trends for Ga, Zr and Y define a weak negative slope. The scattered plots of Rb and Sr closely correspond with the major oxides K_2O and CaO, respectively, signifying that the chemical alteration which affected these two major elements similarly affected Rb and Sr.

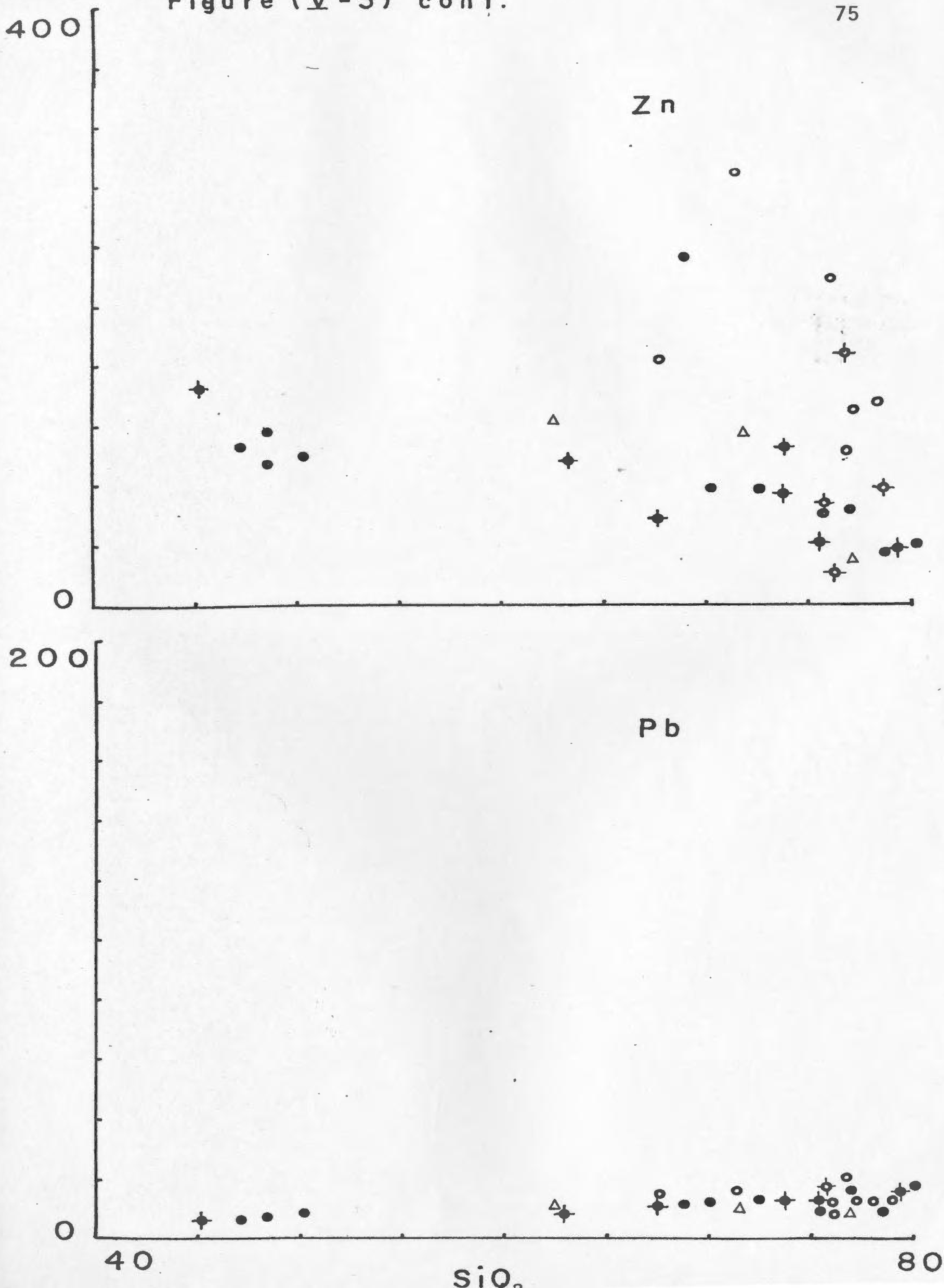
The basic tuffs of the Love Cove Group show uniform clustering of Zn, Pb, Rb, Ga, Zr and Y, while Cu, Ni and Sr are highly variable. Again a close correspondence can be seen between K_2O and Rb and CaO and Sr.

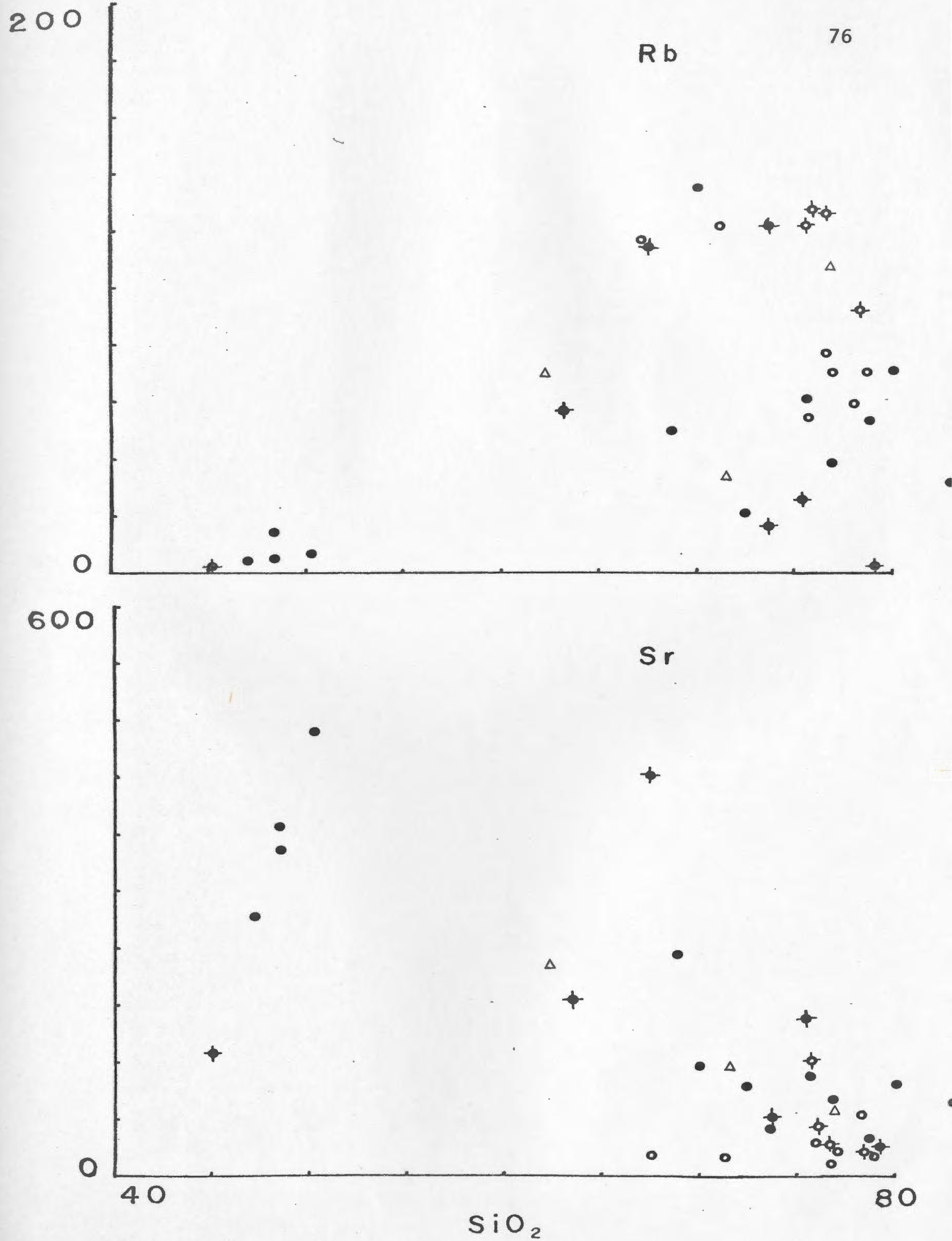
	Love Cove vol.			Bull Arm vol.		
	$SiO_2 > 70$	10 anal.		$SiO_2 > 70$	12 anal.	
	average	min.	max.	average	min	max
Sr	80	30	167	59	13	121
Rb	45	2	123	89	34	127
Zn	57	34	105	151	20	290
Cu	4	1	6	5	3	7
Pb	13	10	17	13	9	20
Ni	5	3	8	5	2	8
Ga	15	11	22	25	6	37
Zr	131	63	200	584	125	1562
Y	19	9	29	56	22	99
	70 - 60	4 anal.		70 - 60	2 anal.	
Sr	236	116	422	122	22	223
Rb	89	50	136	78	70	116
Zn	118	57	233	144	124	164
Cu	12	6	19	7	4	10
Pb	11	11	12	12	10	14
Ni	11	4	25	5	5	5
Ga	18	18	18	29	22	36
Zr	202	170	223	606	186	1026
Y	27	25	28	46	29	63
	$SiO_2 < 60$	5 anal.				
Sr	317	129	469			
Rb	6	1	14			
Zn	112	94	145			
Cu	72	31	119			
Pb	7	6	8			
Ni	56	13	111			
Ga	22	20	25			
Zr	165	134	192			
Y	21	18	23			

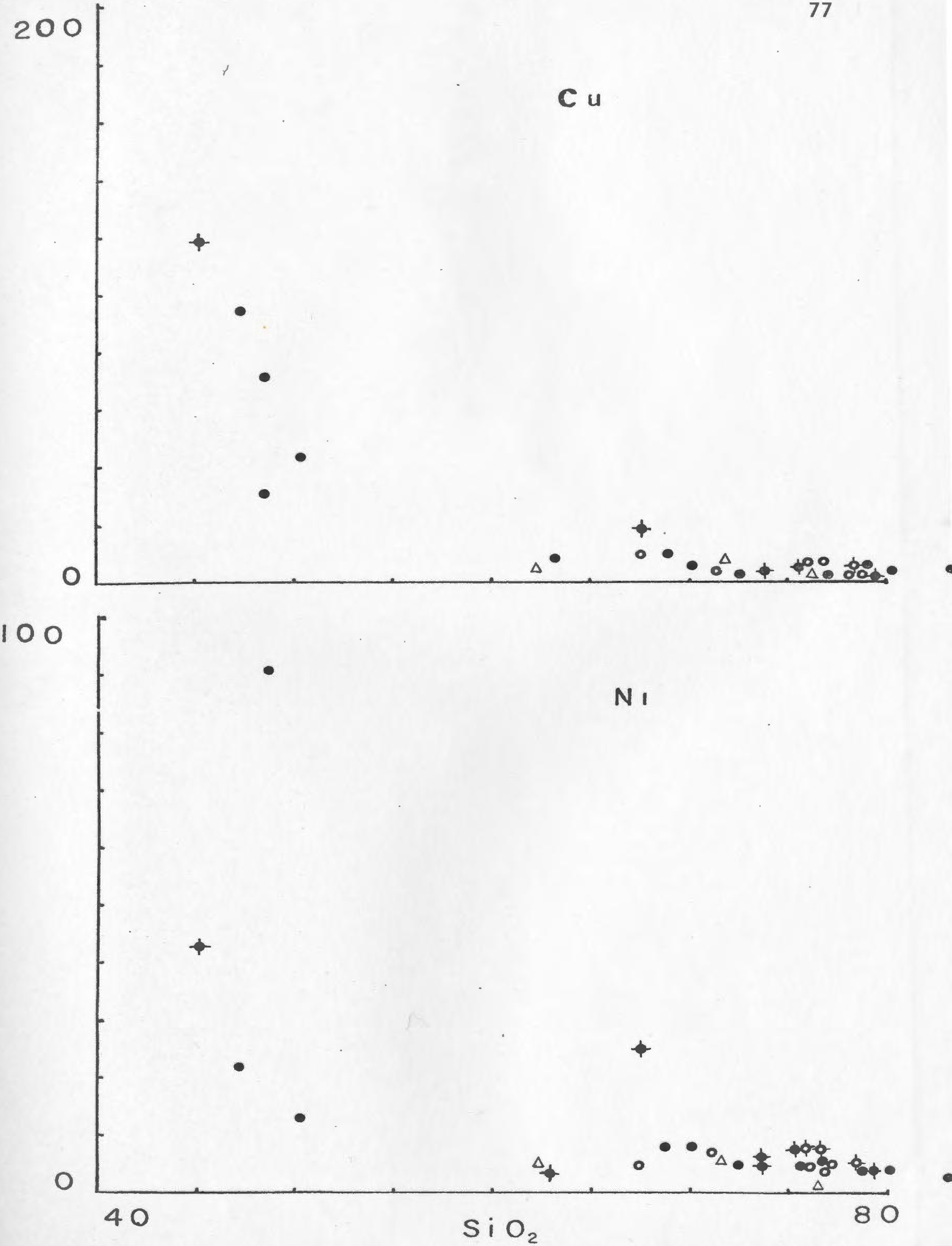
table (V - 4)

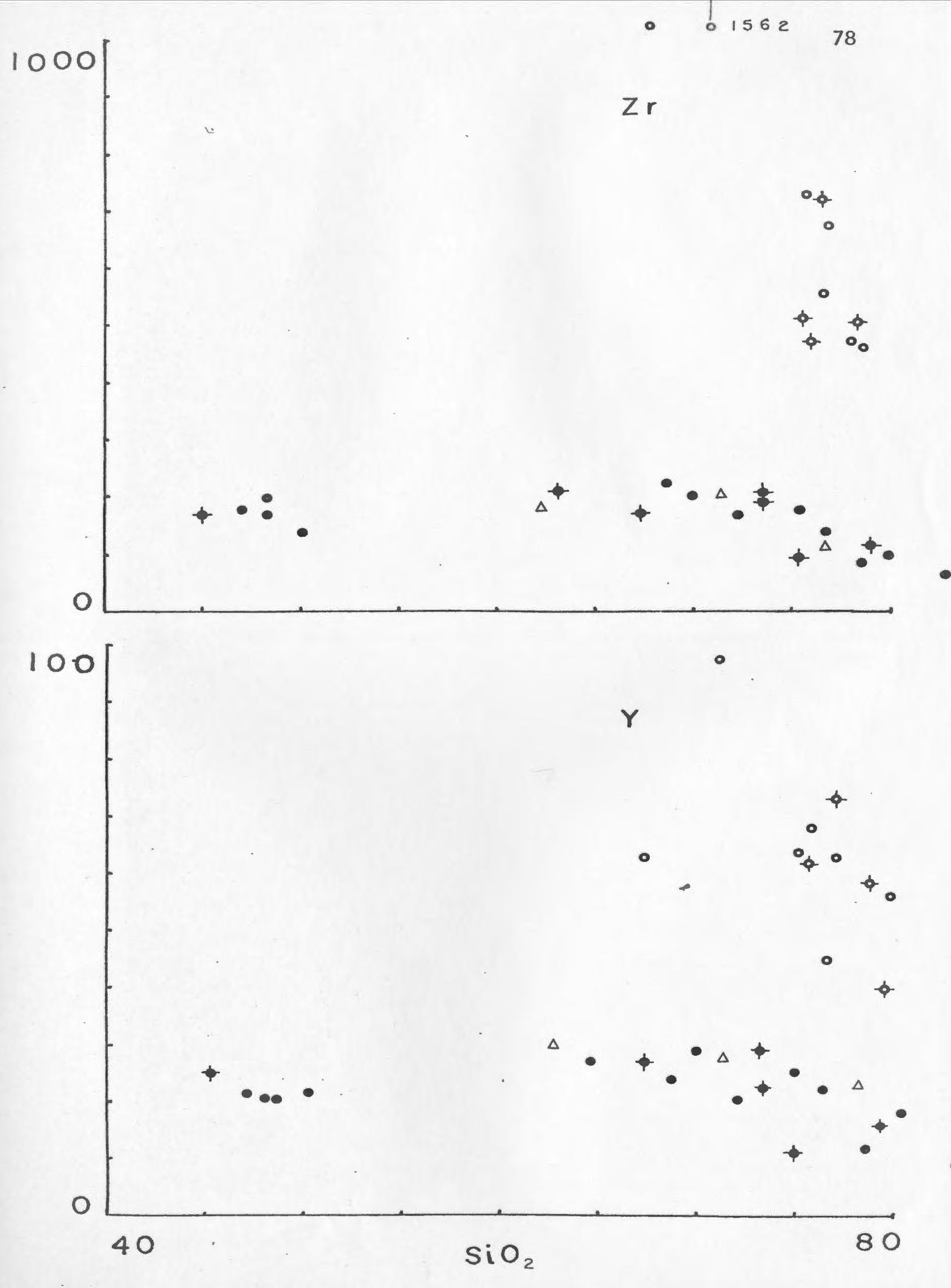
average trace element values

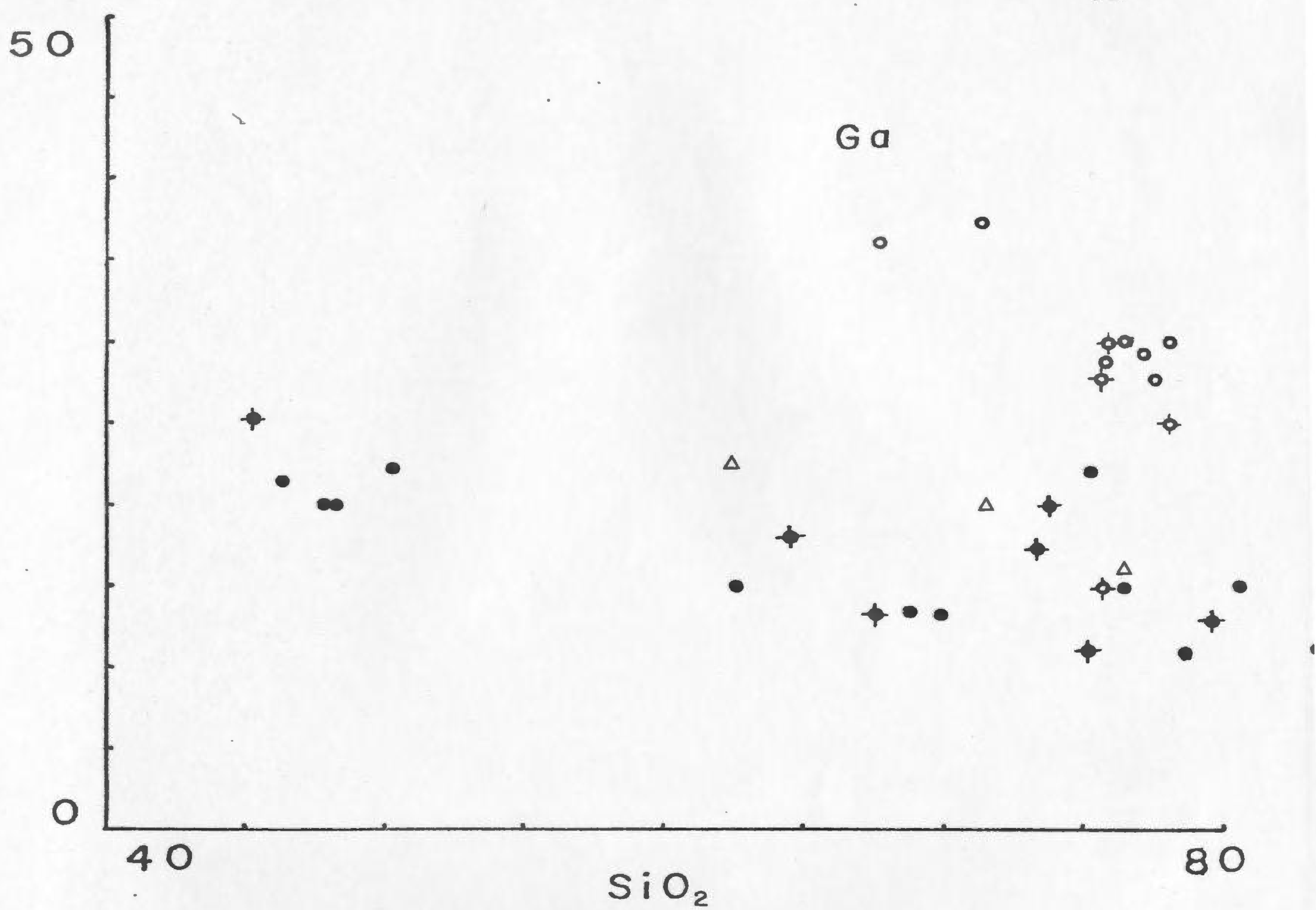
Figure ($\overline{V}$-5) cont.




200
Rb
0
600
Sr
0
40
80
SiO2


200
Cu
0
100
Ni
0
40
80
SiO_2


1562
1000
Zr
0
100
Y
0
40
80
SiO2


50
Ga
0
40
80
SiO2

Intermediate and Acid vol.	average values Zr	Y
Alkaline Suites	570	42
Calc-Alkaline Suites	140	24
Tholeiite Suites	111	29
Love Cove vol. 14 analyses	152	21
Bull Arm Fm. 14 analyses	587	53

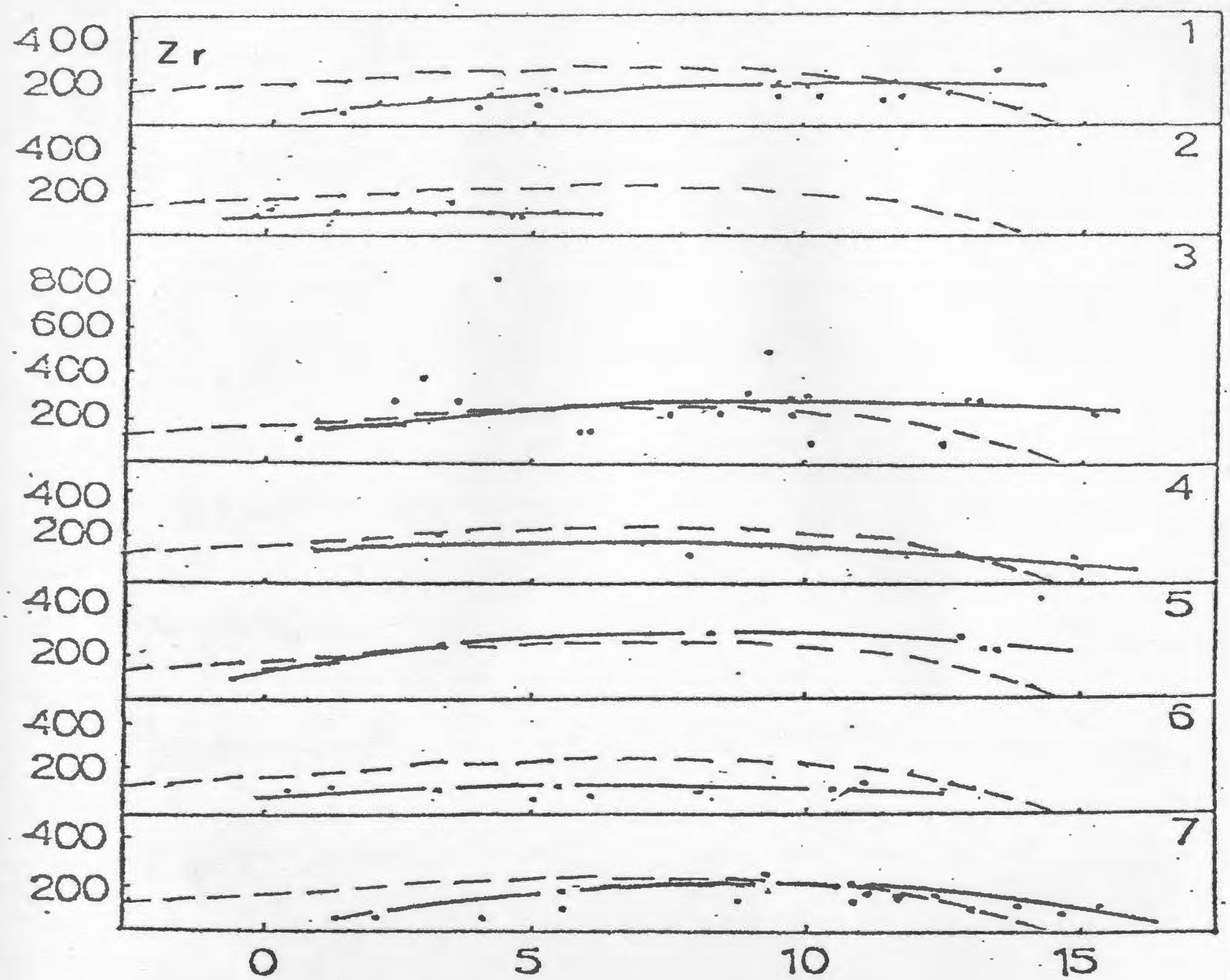
Table ($\overline{\underline{V}}$-5)
comparison of Zr and Y values
(ppm)

The Bull Arm volcanics, as the Love Cove rocks, show low values of Pb, Cu and Ni. Steep negative slopes are apparent in dealing with Y, Zr and Ga. The values of Zr, Y and Ga in the Bull Arm rocks are on the whole much higher than those found in the Love Cove volcanics, with the exception of the anomalous group of Bull Arm (?) volcanics which have been discussed in Chapter III. Rb, Sr and Zn are scattered; Rb and Sr display the same correlation with K_2O and CaO as that found in the Love Cove rocks.

V:6 Petrochemical Classification of the Love Cove and Bull Arm Volcanics, using Trace Elements

Trace element data proved most valuable in determining the chemical affinity of the volcanics in the study area, especially zirconium and yttrium which are not affected by greenschist metamorphism, (Winchester and Floyd, 1976). The average values for zirconium and yttrium for alkaline, calc-alkaline and tholeiitic volcanics may be seen in Table V-5, (Nockolds, 1953, 1954, 1956). Along with these are given the average values from the Love Cove and Bull Arm rocks of the map area.

The Love Cove values closely resemble those of the calc-alkaline provinces. The calc-alkaline affinity of the Love Cove volcanics is further supported by Figure V-9, involving plots of zirconium versus differentiation index of various alkaline and calc-alkaline provinces (Nockolds, 1953, 1954). The dashed line representing the Love Cove volcanics can be seen to correspond strongly to the graphs of the

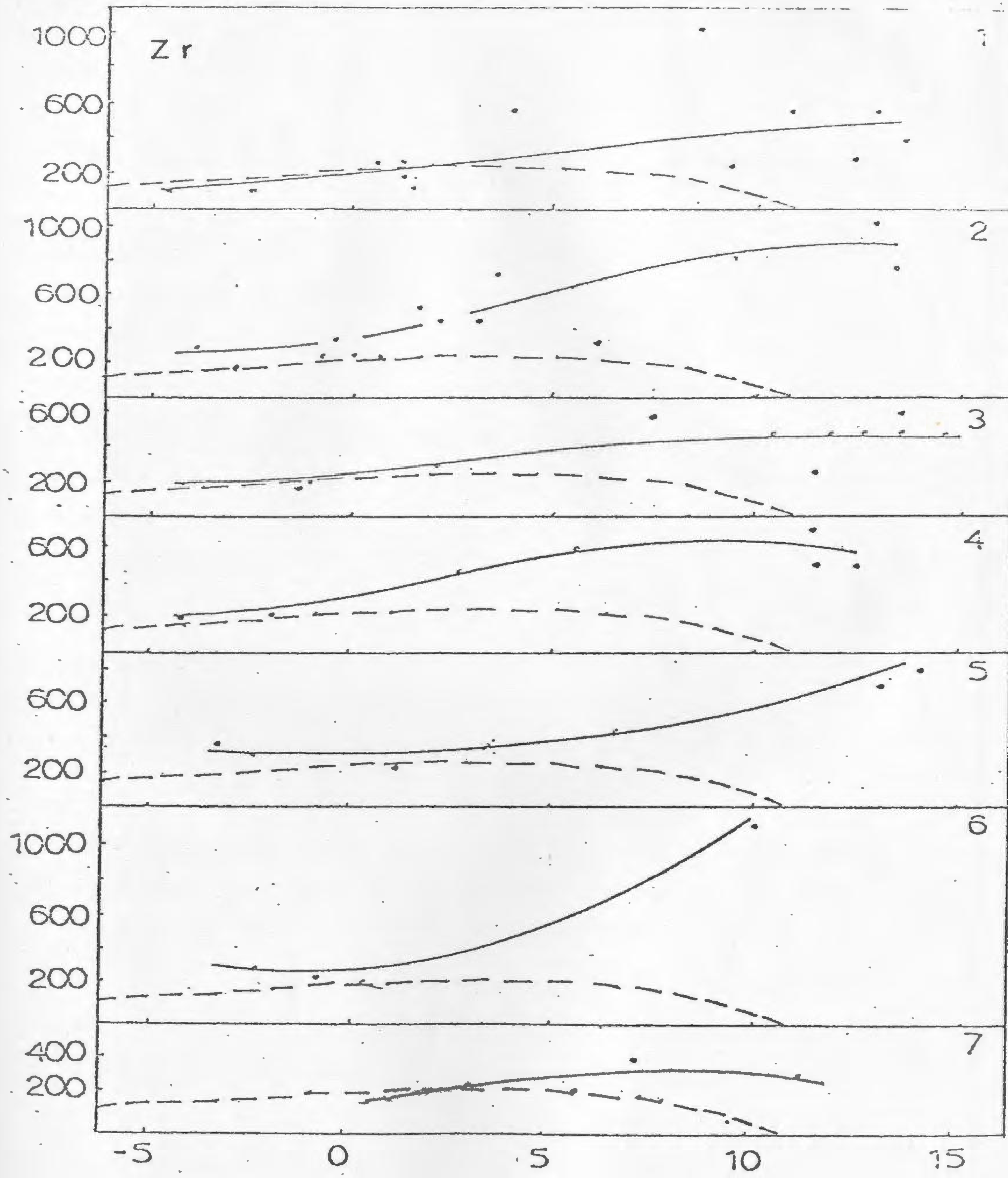


- - - Dashed line represents Love Cove volcanics.

Figure V-9

Zircon vs Differentiation Index

Calc-Alkaline Suites	Alkaline Suites
1. Crater Lake	1. Scottish Tertiary
2. Lesser Antilles	2. Hawaii
3. Scottish Caledonian	3. Polynesia I
4. E. Central Sierra Nevada	4. Polynesia II
5. Medicine Lake Highlands	5. Easter Island
6. Lassen Peak	6. Braefoot
7. S. California Batholith	7. Nevada Latite Series



D.I. = (1/3 Si + K) − (Ca + Mg)

Alkaline suites

calc-alkaline regions.

The use of Ti, Zr, Y, Sr discrimination diagrams (Pearce and Cann, 1973) to decipher the chemical affinity of the Love Cove basic tuffs proved inconclusive. In the three diagrams of Figure V-10, the points representing the compositions of the tuffs do not fall in the same representative area in each plot. Therefore no conclusion can be reached using the basic tuff data in this manner.

As was stated earlier, the purpose of analysing Bull Arm Formation volcanics was to compare their compositions with those of the Love Cove rocks and so endeavor to distinguish the two on the basis of chemical evidence.

The trace elements proved the most helpful in establishing a dividing line between the Love Cove and Bull Arm volcanics, particularly zirconium and yttrium (Figure V-11). The average zirconium and yttrium values for the Bull Arm Formation are much higher than those of the Love Cove rocks, resembling the values typical of alkaline suites, (Table V-4). In Figure V-12, a strong correlation can be seen between the dashed line representing the Bull Arm Formation and the solid line graphs of the alkaline provinces.

The two trace elements, zirconium and yttrium, show a definite difference between Love Cove and the main belt of the Bull Arm volcanic rocks in the study area. This proves conclusively that Younce's idea of stratigraphic equivalence of Love Cove Group and Bull Arm Formation (Musgravetown Group) is incorrect. The one remaining ambiguity concerns a group of analyses from the western part of the area. Although

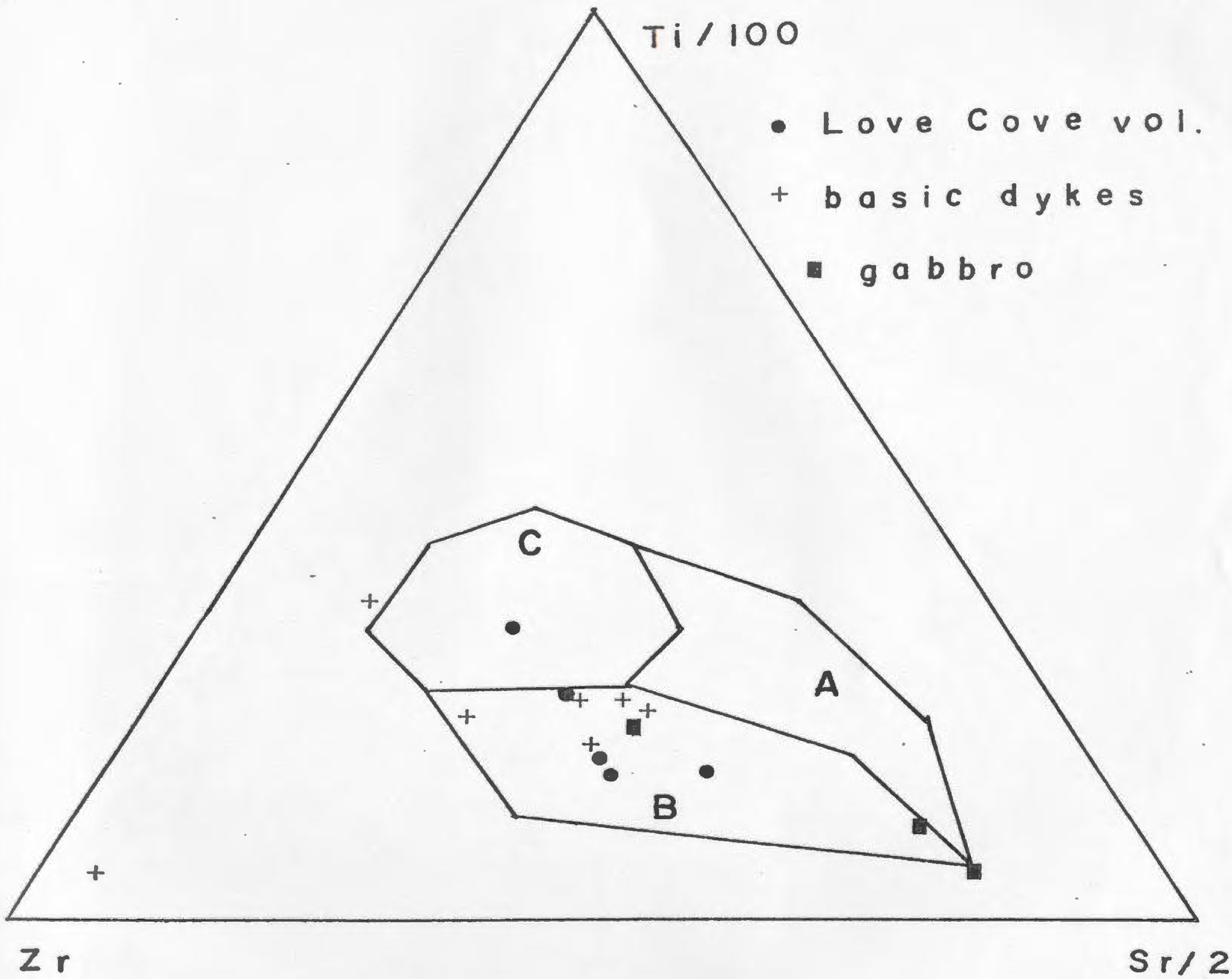
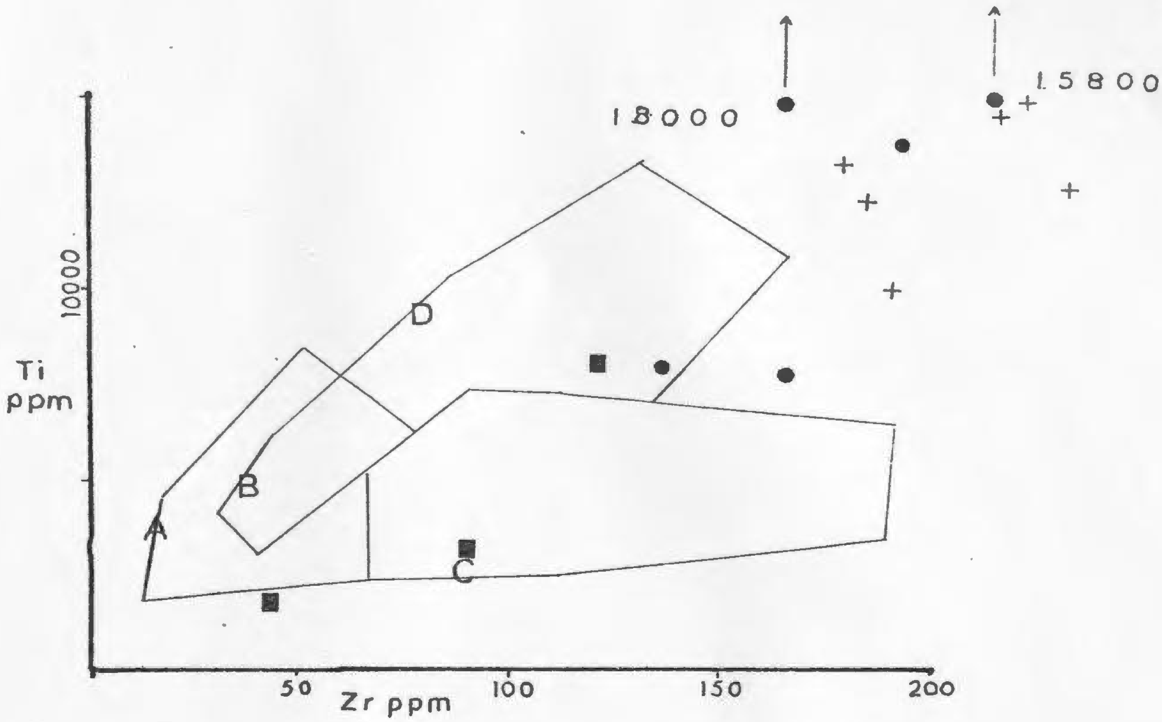


Figure (V-10)
Ti, Zr, Y, and Sr discrimination diagrams
Pearce and Cann (1973)

A - low-potassium tholeiite
B - calc-alkali basalt
C - ocean-floor basalt



A and B - low-K tholeiite

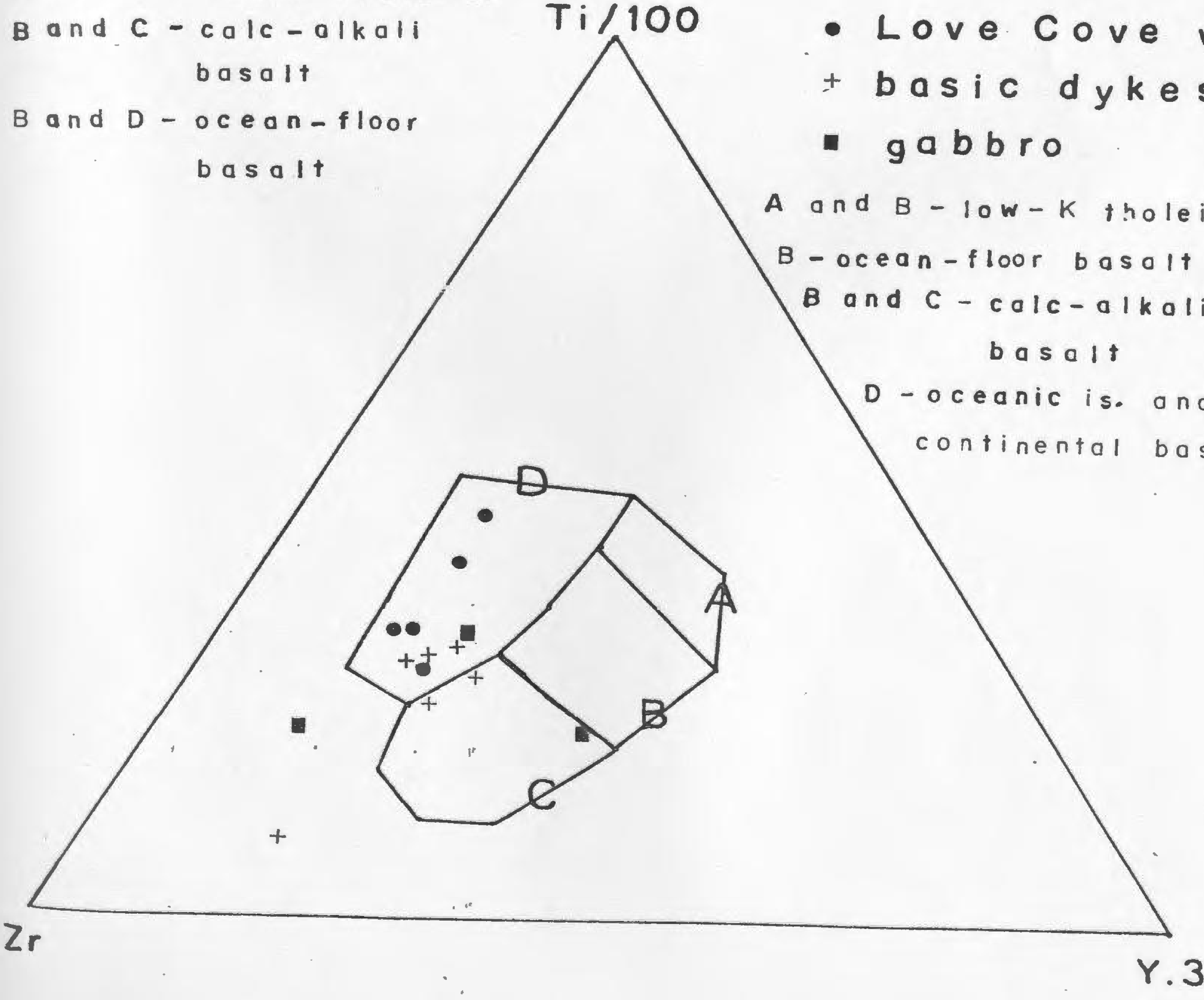
B and C - calc-alkali basalt

B and D - ocean-floor basalt

• Love Cove vol.

+ basic dykes

■ gabbro



A and B - low-K tholeiite

B - ocean-floor basalt

B and C - calc-alkali basalt

D - oceanic is. and continental basalt

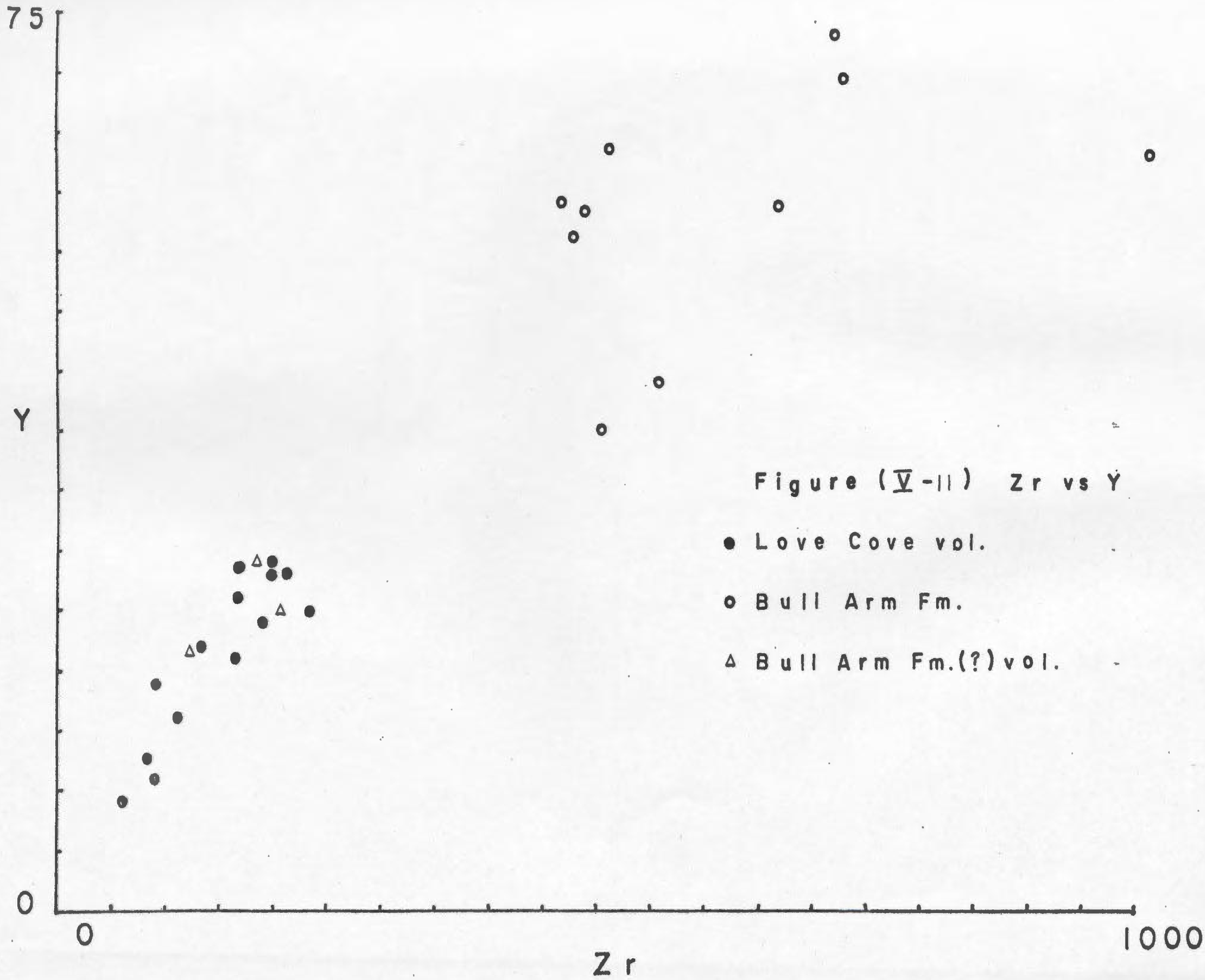
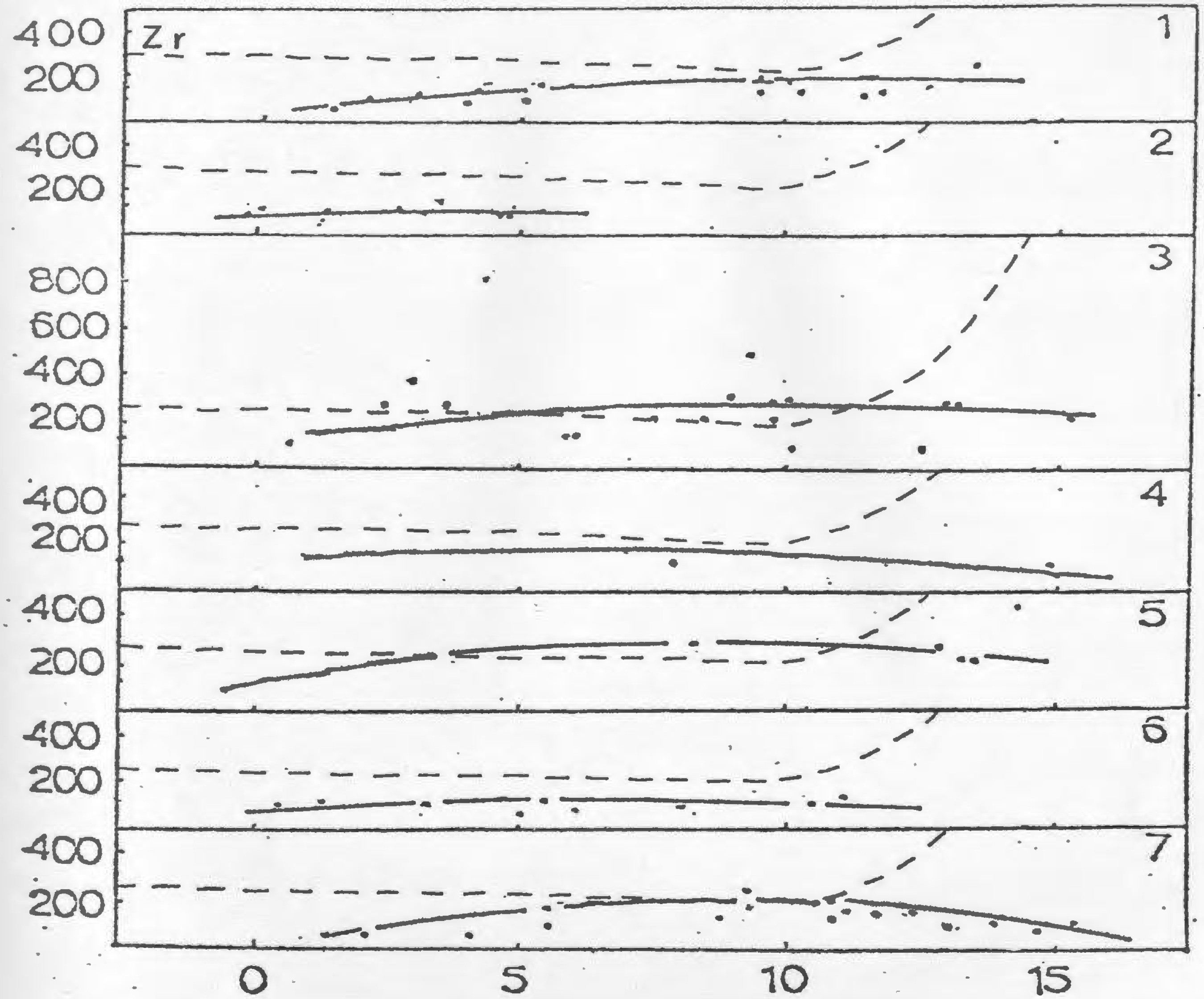


Figure (V-11) Zr vs Y



- - - Dashed line represents Bull Arm Formation

Figure V-12

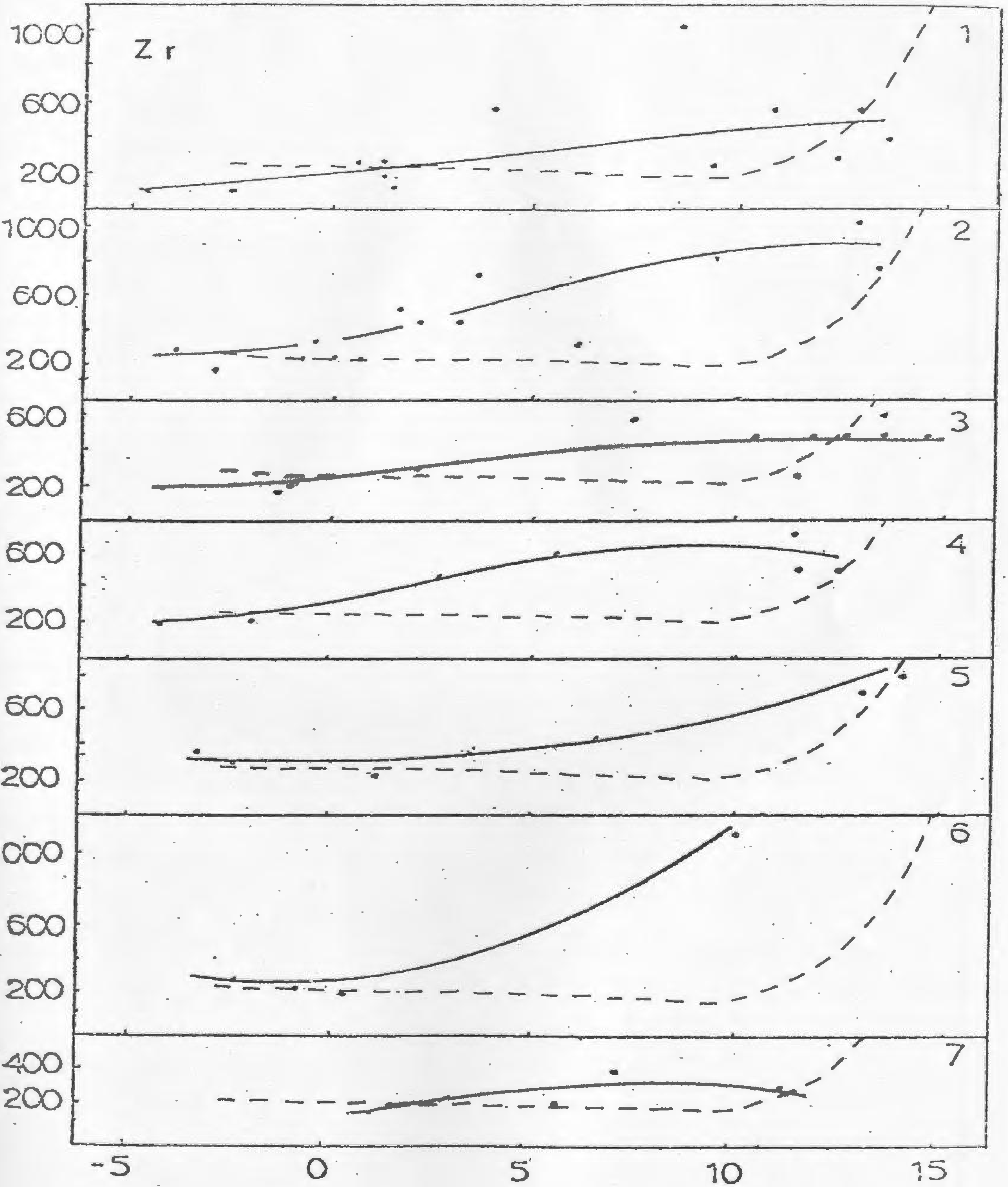
Zircon vs Differentiation Index

Calc Alkaline Suites

1. Crater Lake
2. Lesser Antilles
3. Scottish Caledonian
4. E. Central Sierra Nevada
5. Medicine Lake Highlands
6. Lassen Peak
7. S. California Batholith

Alkaline Suites

1. Scottish Tertiary
2. Hawaii
3. Polynesia I
4. Polynesia II
5. Easter Island
6. Braefoot
7. Nevada Latite Series



D. I. = (1/3 Si + K) – (Ca + Mg)

Alkaline suites

the rocks resemble Bull Arm volcanics, their trace element chemistry is closer to Love Cove rocks. These rocks may have been erupted from a different center, or at a different time. However, the time difference, if any, was not long enough to produce a major change in the relative stratigraphic position of these rocks; stratigraphically, they appear to be part of the Bull Arm Formation of the map area.

V:7 Acid and Basic Intrusive Rocks

V:7-1 Traytown Granite

A plot of agpaitic indices versus SiO_2 for the various granitic bodies of eastern Newfoundland shows the Traytown granite to be chemically peralkaline, (Figure V-13). Strong et al. (1974) concluded that the Traytown pluton bore a "strong similarity" to the granite bodies at St. Lawrence on the Burin Peninsula 210 km to the SW of Traytown. This conclusion was based on a similarity of their major element chemistry, as shown by Figure V-13 and on similar trace element values for strontium and zinc. The St. Lawrence granites are dated as Carboniferous in age (315 ± 10 my). In view of the similarity between the two granites and their unique mineralogy, it is possible that the Traytown pluton may also have been intruded in the Carboniferous period.

V:2 Basic Intrusive Rocks (Dykes and Gabbroic stocks)

In attempting to decipher the number of periods of dyke intrusions, the chemical compositions were of no real assistance. The analysis of various dykes in the area, are given in Appendix II.

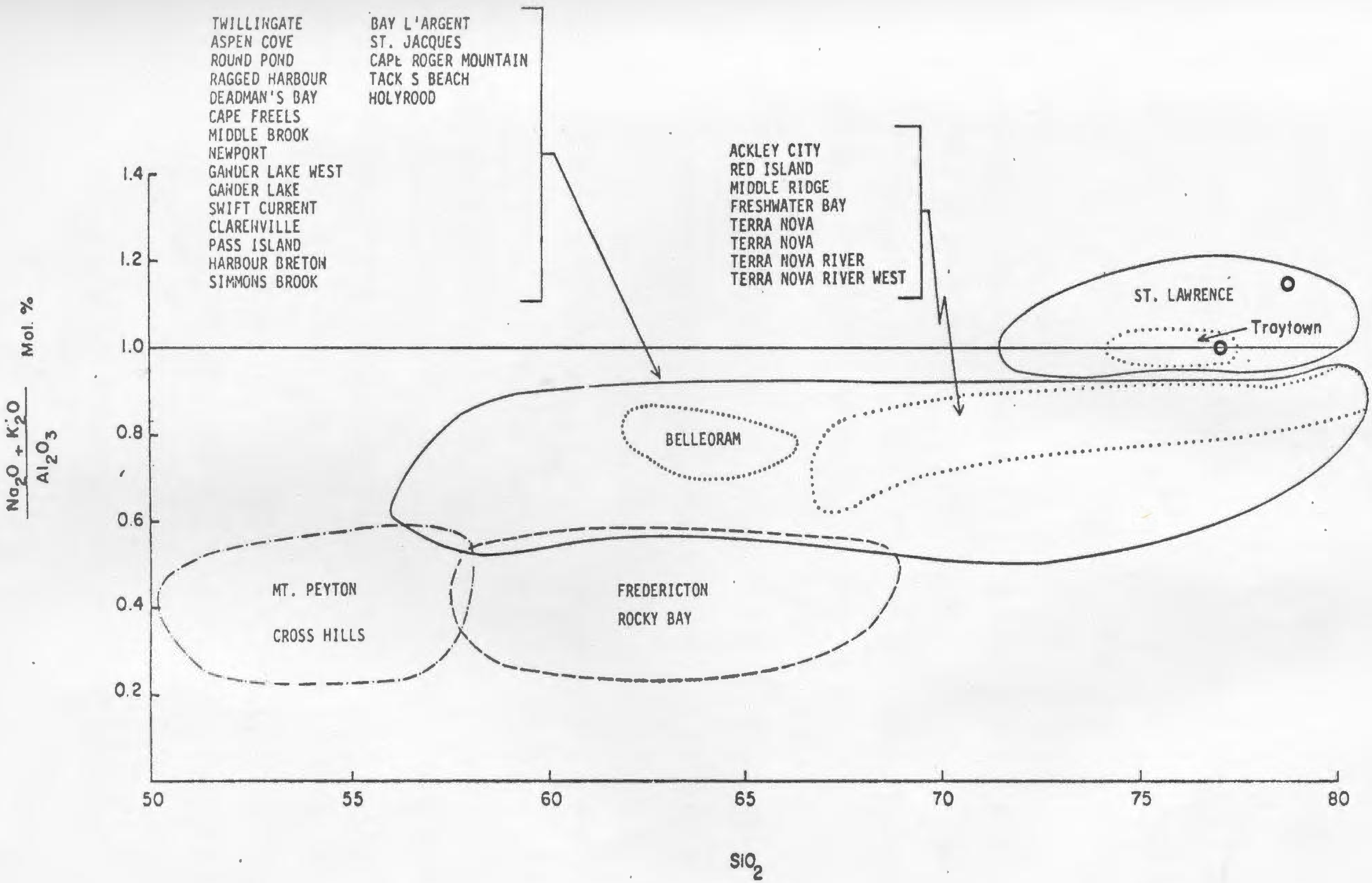


Figure (V-13)

agpaitic indices of eastern Newfoundland - Strong et al (1974)

open circles represent analyses done during this study

DB-103 and DB-97 intrude the Love Cove belt, the others intrude the sediments of the Musgravetown Group, except for DB-255 which cuts Connecting Point strata.

Figure V-10 reveals the close similarity between the basic dykes and the Love Cove calc-alkaline basic tuffs; as with the tuffs, the dyke compositions plot in different fields in the various diagrams. The gabbroic stocks of the map area show no strong chemical affinity although there appears to be a slight calc-alkaline bias (Figure V-10).

The significance of the possible "calc-alkaline" nature of the basic intrusions is unknown. Genetically, they are not related to the Love Cove or Bull Arm volcanics in the map area.

V:8 Sedimentary Rock

Chemical analysis was carried out on a number of sedimentary rocks in an effort to provide supporting data for the conclusions evolved from field work and petrology (Appendix II).

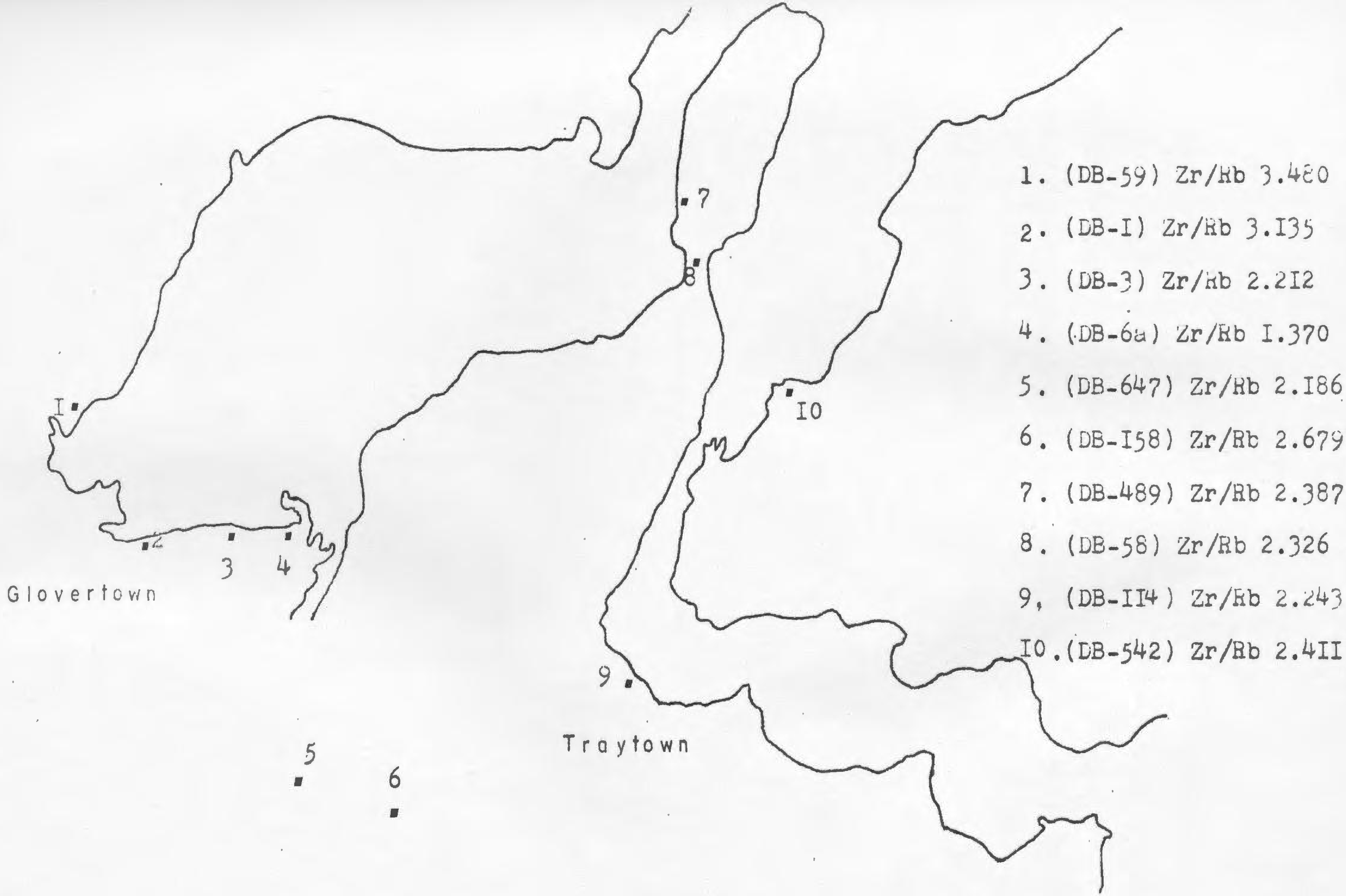
As stated in Chapter III, the dominant source of detritus for the Musgravetown Group sediments is believed to be the Bull Arm Formation. This conclusion has been substantiated chemically by analysis of pebbles and sediments with a high percentage of clasts, such as DB-141, DB-46 and DB-456. The high Zr and Y valves associated with the majority of Bull Arm volcanics in the map area are also found, to a degree, in these epiclastic sediments. The major and minor element chemistry cannot be relied on to define the main source of detritus; the sediments show considerable fluctuation in all major and minor elements, within a formation.

Recent studies (Taylor, 1965) have indicated that zirconium in sediments is mostly found in the detrital fraction, rubidium in the non-detrital phases of the rocks. Therefore Zr/Rb values will indicate the proportion of detrital to non-detrital material. As stated by Taylor (1965), "Zr/Rb ratio should, in the ideal case, decrease from the margins of a basin toward the centre." This, of course, must remain only a crude estimate, in view of the complications involved here. However, Zr/Rb values for a number of rocks support the idea of a sedimentary basin in the Rocky Harbour Formation to the east of Glovertown, presented earlier (Figure V-14).

Degens et al. (1957) undertook a study to attempt to distinguish between Carboniferous marine and freshwater shales geochemically. They found that Rb was generally lower and Ga higher in freshwater shales as compared to shales deposited in a marine environment. The average values of Rb and Ga adapted from their paper are as follows:

	fresh	brackish	marine
Rb	139	186	281
Ga	17	14	8

The average Rb and Ga values for the Rocky Harbour siltstones east of Glovertown are 73 and 21 respectively. The low value for Rb and the high value for Ga correspond to those found in freshwater sediments, indicating that the siltstone were deposited in a fresh water, perhaps lacustrine, environment.



Figure(V-14) sample locations for basin study

scale 1: 50,000

However, Potter et al. (1963) found that Ga is higher in marine argillaceous sediments (>20 ppm) than in freshwater sediments (<20 ppm). In relation to the trace elements determined in this study, they found no appreciable difference with Cu and Pb but were able to discriminate between the two sediment types by means of nickel content. Marine shales on the whole have greater than 25 ppm Ni while fresh water sediments generally have less than 25 ppm. The highest nickel content of the Rocky Harbour siltstone is 13 ppm.

The answer to the question whether the basin siltstone east of Glovertown was deposited in a freshwater or marine envrionment is not easily obtainable. Of the three trace elements mentioned, there is disagreement on the role of gallium, leaving only Rb and Ni, which indicate a freshwater environment for the Rocky Harbour siltstones. However, a good deal more work would have to be done before a final decision can be reached. In both papers mentioned, boron is indicated as the best discriminator of the type of deposition; unfortunately, the facilities for boron analysis were not available to the author at the time of this study.

CHAPTER VI

CONCLUSION

VI:1 Age and Relationship of the Love Cove Volcanics

The Love Cove volcanics show only faulted contacts with adjacent rock units; therefore their exact stratigraphic position remains unknown. The field work of the author supports the conclusion of Jenness (1963) and others that the Love Cove rocks are the oldest in the region. The following points support this statement.

1. Acid volcanic pebbles found in the Cannings Cove Formation have similar physical (schistose), mineralogical (lack of K-feldspar) and chemical (low Zr and Y) properties as the Love Cove volcanics. This suggests that the Love Cove rocks are at least older than the Musgravetown Group in which the Cannings Cove Formation forms in part the basal unit.

2. The Love Cove rocks are more tightly folded than those of the Connecting Point Group. The folding exhibited by the volcanics of the Love Cove Group is isoclinal, having interlimb angles of 0° - 20°, while the folds in the shales of the Connecting Point, judging from bedding attitudes, have interlimb angles in the range of 40°. Since the Love Cove volcanics are more competent than the sediments of the Connecting Point Group, it appears that the Love Cove rocks have suffered at least one previous deformation not shown by the other rocks of the region. This suggests an older age for the Love Cove Group.

VI:2 Petrochemistry and Relationship of the Volcanic and Sedimentary Rocks

1. The Love Cove Group in the study area consists solely of volcanic rock. The sedimentary rock originally included in the group is part of the Rocky Harbour Formation of the Musgravetown Group.

2. The Love Cove volcanics chemically display a continental calc-alkaline affinity. These volcanics have an overall chemical similarity to those of the Cascades in the northwestern United States.

3. The Love Cove and Bull Arm volcanics are different in physical appearance, in petrology and in chemistry. In outcrop the Bull Arm acid volcanics do not have a cleavage while the Love Cove volcanics for the most part display a prominent schistosity. In mineralogy, the prominent difference lies in the fact that little or no potassium feldspar is found in the Love Cove volcanics while it is a dominant feldspar in the Bull Arm acid rocks of the map area. Chemical differences are best demonstrated by the high values of Zr, Y, and K_2O in the Bull Arm Formation compared with the low values found in the Love Cove volcanics.

4. The Bull Arm Formation and the Cannings Cove Formation appear to be largely time-equivalent. The Cannings Cove sediments are dominantly composed of detritus from the Bull Arm Formation, but at some localities the Cannings Cove is the basal unit of the Musgravetown Group, clearly overlain by the Bull Arm volcanics.

5. The dominant source of the detritus forming the sedimentary rock of the Musgravetown Group is the Bull Arm Formation. This can be seen both in thin sections of the sediments and in the chemical compositions of the pebbles and cobbles of the conglomerates.

6. The depositional environment of the Rocky Harbour Formation was one of aeolian sands and lake bottom sedimentation.

VI:3 Sequence of Geological Events

The geological history of the map area began with the formation of the oldest rocks, those of the Love Cove Group. These volcanics were erupted at the edge of a continent, possibly forming a line of high volcanoes, an environment similar to that of the present Cascades in the northwestern United States. Farther inland (to the east) at approximately the same time, a more alkaline, terrestrial volcanism, was involved in the formation of the Harbour Main Group of the Avalon Peninsula.

The area, judging from the highly deformed nature of the Love Cove volcanics, suffered a deformational period of limited intensity and extent. Subsidence of the area, most likely related to the later stage of the deformation, caused a submergence, with the Love Cove and Harbour Main rock types now becoming islands in this newly formed sea.

Erosion and deposition of shales and greywackes of the Connecting Point and Conception Groups about the islands occurred over an extended period of time.

General uplift and erosion of the subsided area marked the end of the deposition of the marine sediments. The uplift was accompanied by rifting and rift-related volcanic activity, initiating the development of the Bull Arm Formation.

The rift volcanics form the major detrital component of the Cannings Cove Formation but because the Cannings Cove frequently underlies parts of the Bull Arm Formation, it is considered a facies equivalent. After the volcanism ceased, the Rocky Harbour Formation was deposited, mainly as a crossbedded, dunal sandstone and lake bottom sediment. Later, the first units of the Crown Hill Formation were laid down in a more fluvial environment.

During the Devonian period, the entire area was affected by the Acadian orogeny. This deformational episode is responsible for the present fold structures, the prominent axial-planar cleavage found in the pre-Devonian rocks of the map area, and the formation of the Love Cove horst.

Present day surface topography has been dominantly molded by Pleistocene glaciation.

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APPENDIX I

Plates

Plates 1 and 2

Love Cove Vol. crystal lithic tuffs,
7 km E.S.E. of Glovertown--note
diversity in size of fragments

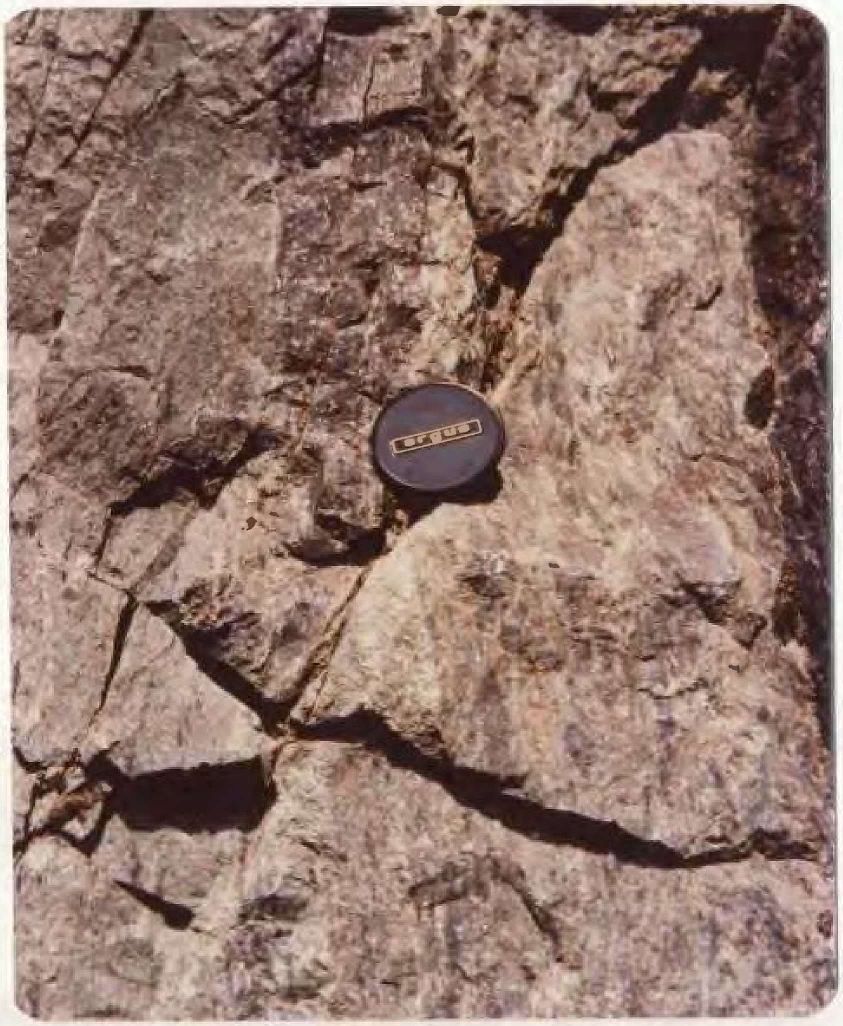
argus

Plate 3

Love Cove Vol. basic tuff, 6.5 km east of Glovertown--note acid tuff fragments (grey coloration)

Plate 4

Embayment feature in plagioclase--Love Cove tuff (DB-62), taken in transmitted light, under crossed nicols

Scale: 1 cm. = 0.25 mm

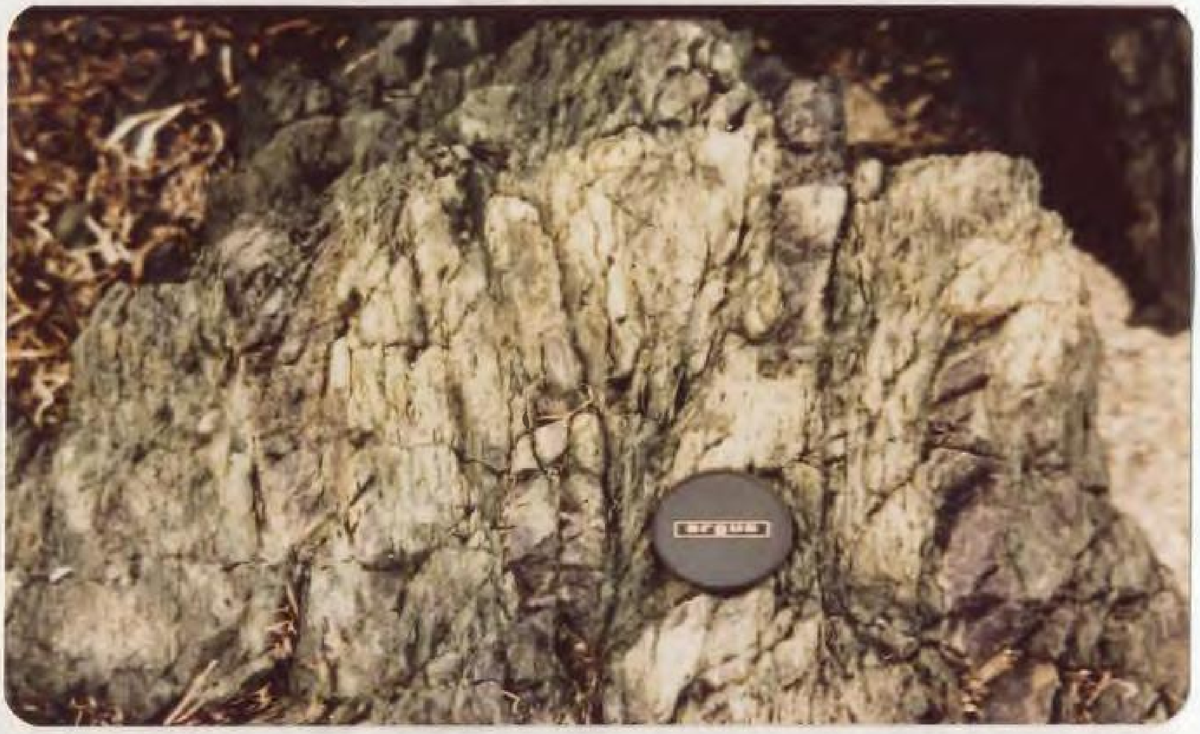
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Plate 5

Bent plagioclase phenocryst--Love Cove tuff,
taken in transmitted light,
under crossed nicols

Scale: 1 cm = 0.25 mm

Plate 6

Broken plagioclase phenocryst--Love Cove tuff
(P-47), taken in transmitted light, under
crossed nicols

Scale: 1 cm = 0.25 mm

Plate 7

Broken plagioclase phenocryst--Love Cove tuff (DB-397), taken in transmitted light, under crossed nicols

Scale: 1 cm = 0.25 mm

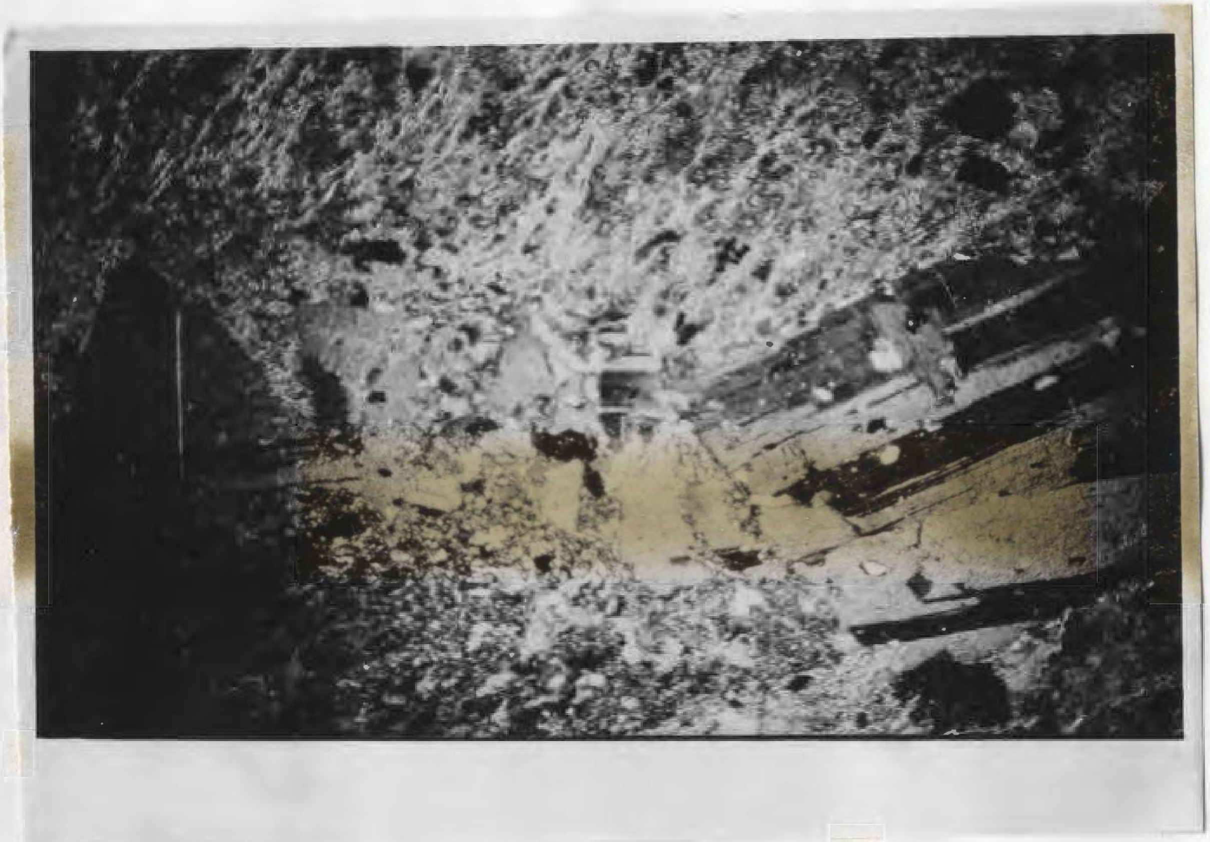


Plate 8

Black shales and greywacke--Connecting Point Group, 11 km east of Glovertown

Plate 9

Breccia formed of basic volcanic fragments--Connecting Point Group, 9 km ESE of Glovertown

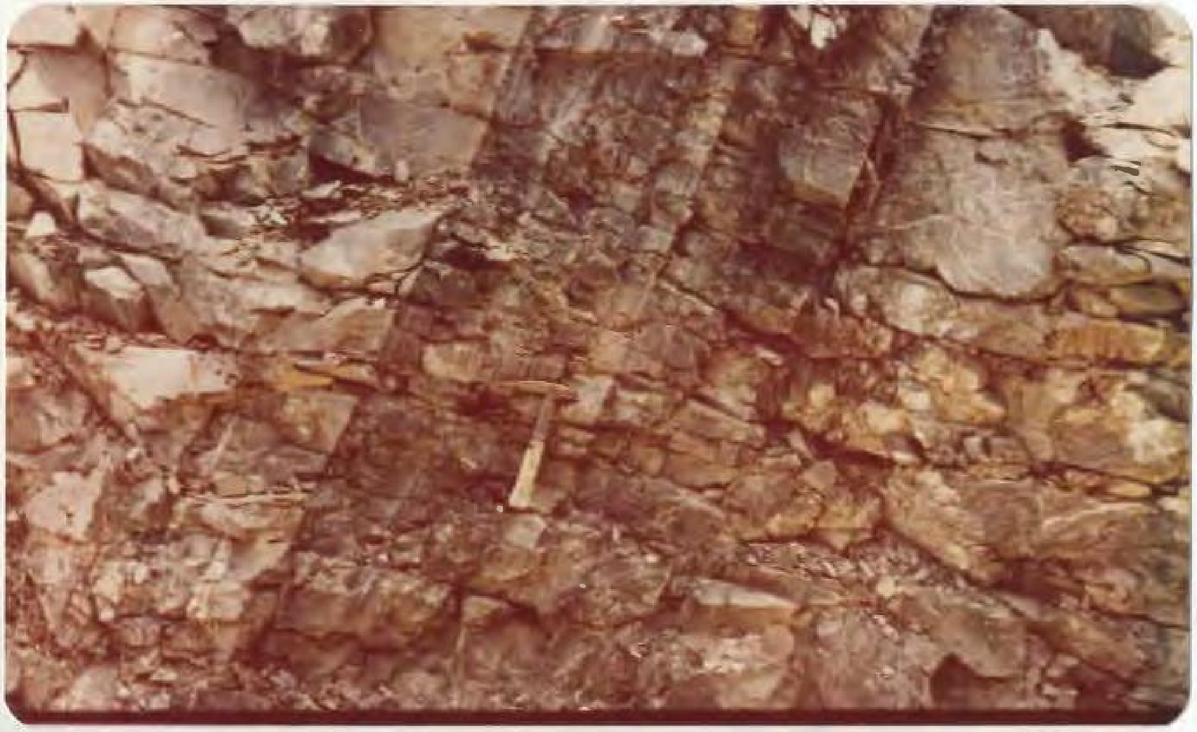


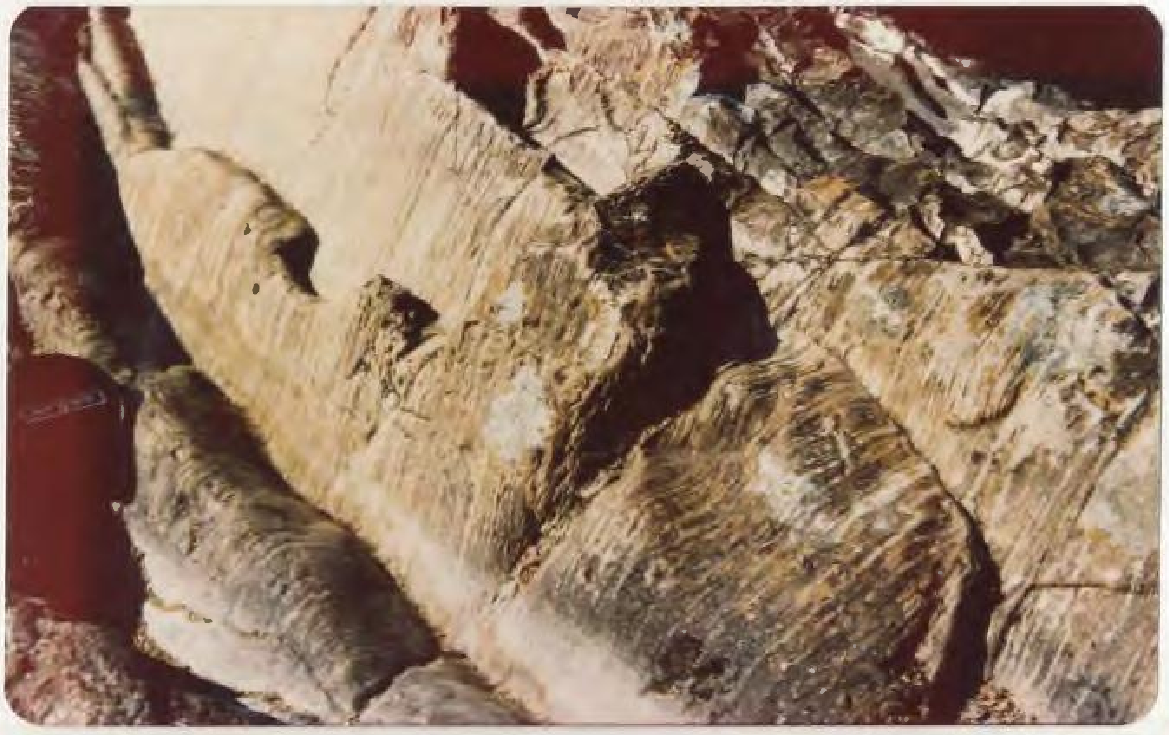
Plate 10

Flow banded rhyolite--Bull Arm Fm.,
8.5 km SSW of Glovertown (DB-599)

Plate 11

Embayment feature in plagioclase--Bull Arm
crystal lithic tuff (DB-538), taken in
transmitted light, under crossed nicols

Scale: 1 cm = 0.25 mm



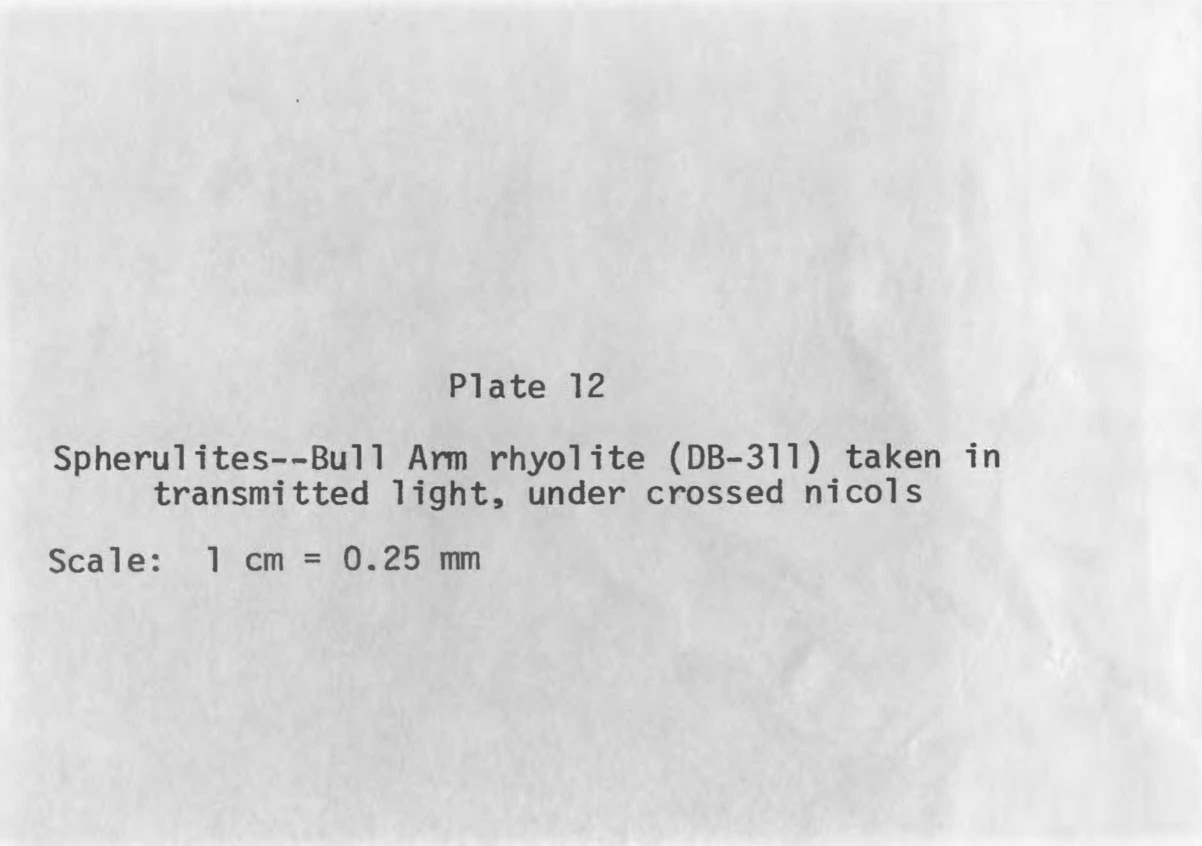


Plate 12

Spherulites--Bull Arm rhyolite (DB-311) taken in transmitted light, under crossed nicols

Scale: 1 cm = 0.25 mm

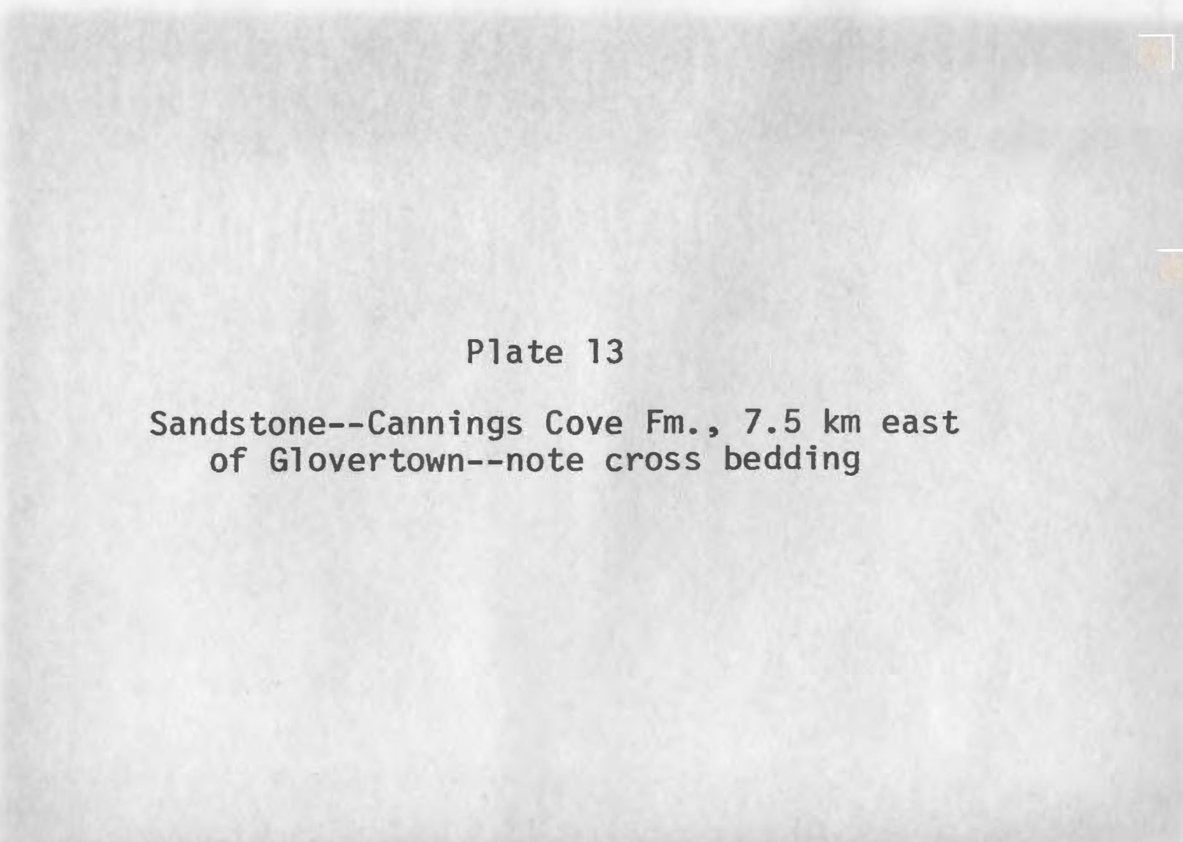


Plate 13

Sandstone--Cannings Cove Fm., 7.5 km east of Glovertown--note cross bedding

Plate 14 and 15

Crossbedded sandstones--Rocky Harbour
Fm., 2 km west of Glovertown

Plate 16

Laminated sandstone--Rocky Harbour Fm., 3 km north of Glovertown--note acute nature of the laminae and shallow cross-bedding

Plate 17

Epiclastic volcanic sediments--Rocky Harbour Fm., Glovertown--note abrupt transition from fine to coarse detritus

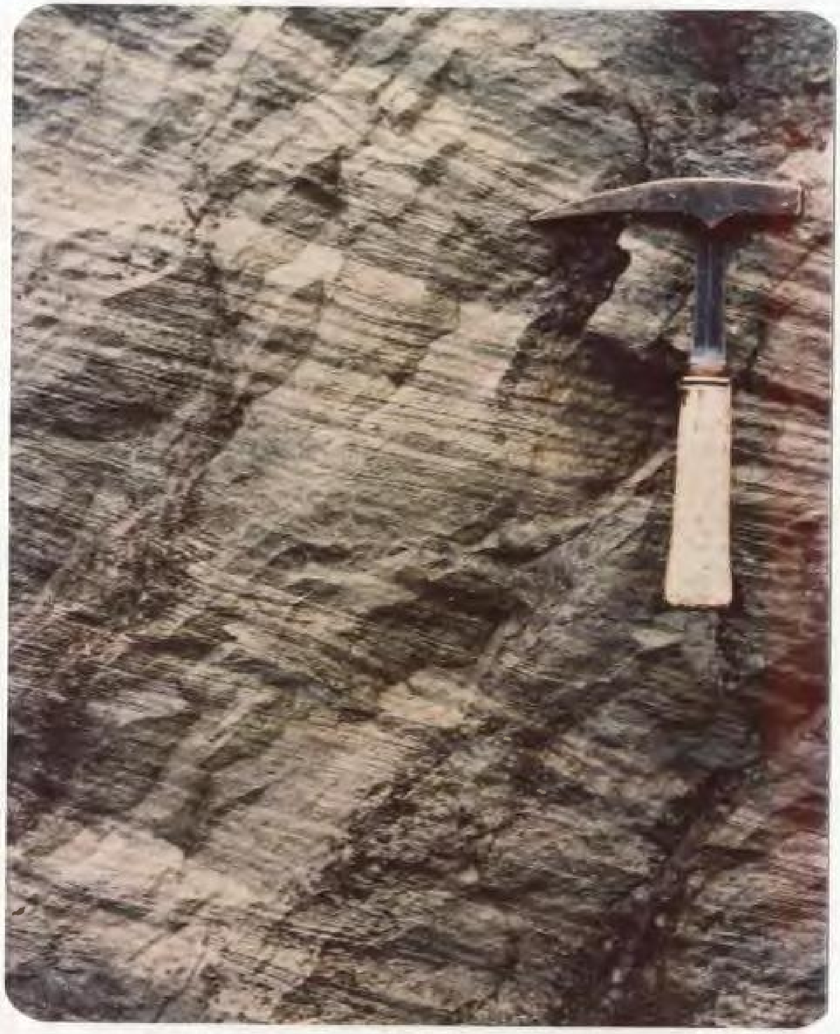


Plate 18

Conglomerate--Rocky Harbour Fm., 5.5 km ENE of Glovertown--note flow banding in the rhyolite fragment in the top left hand corner

Plate 19

Siltstone--Rocky Harbour Fm., 6 km NE of Glovertown--note laminated nature

Plate 20

Red beds, shale and sandstone--Crown Hill Fm., 2.5 km NW of Glovertown

Plate 21

Red conglomerate and shale--Crown Hill Fm., 13.5 km SE of Glovertown--note sharp contact

Plate 22

Minor fold--Rocky Harbour siltstone,
9 km SSW of Glovertown

Plate 23

Schistose zone (½ m wide)--Rocky Harbour laminated
sandstone, 1.5 km east of Glovertown

Plate 24

Kink banding--Rocky Harbour siltstone,
9 km SSW of Glovertown


argus

Plate 25

Love Cove horst, fault zones, intermediate
dykes (pink) and altered country rock,
6.5 km east of Glovertown

Plate 26

Love Cove horst, fault zones, intermediate
dykes (pink) and altered country rock,
8.5 km SE of Glovertown

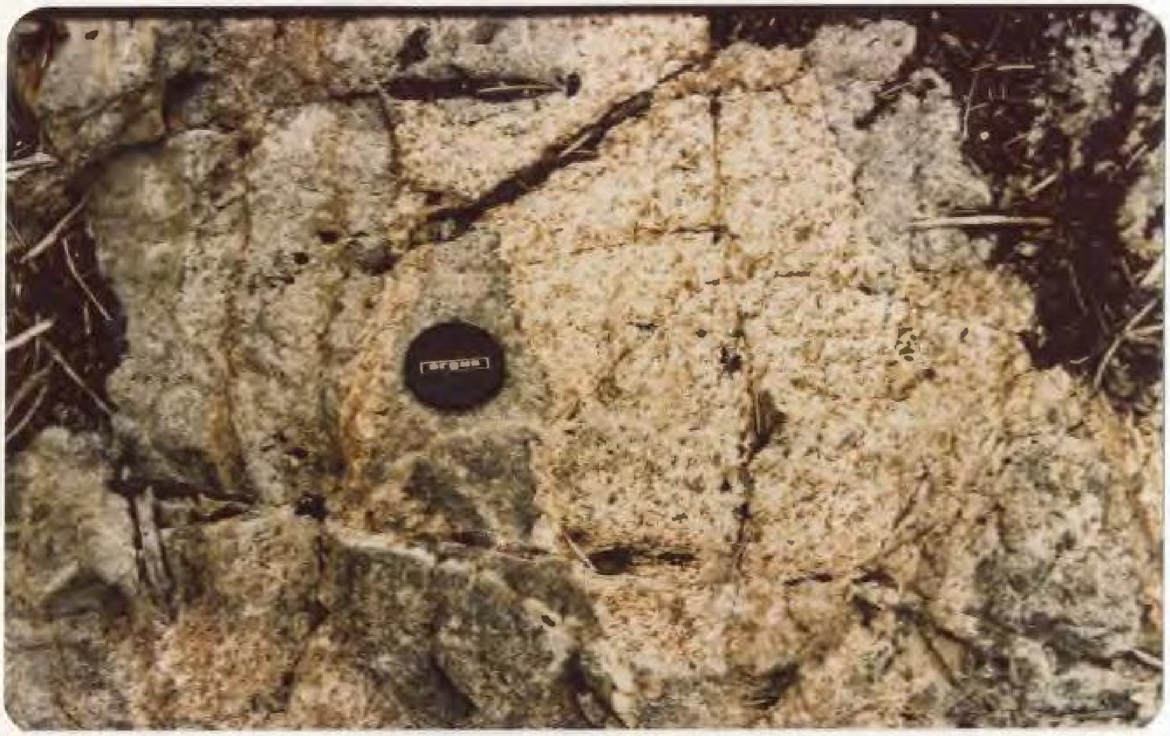


Plate 27

Love Cove horst fault zones, felsite dyke and quartz veins, 7 km ENE of Glovertown

Plate 28

Cary Cove graben fault zones, rusted lithology, 10 km ENE of Glovertown

Plate 29

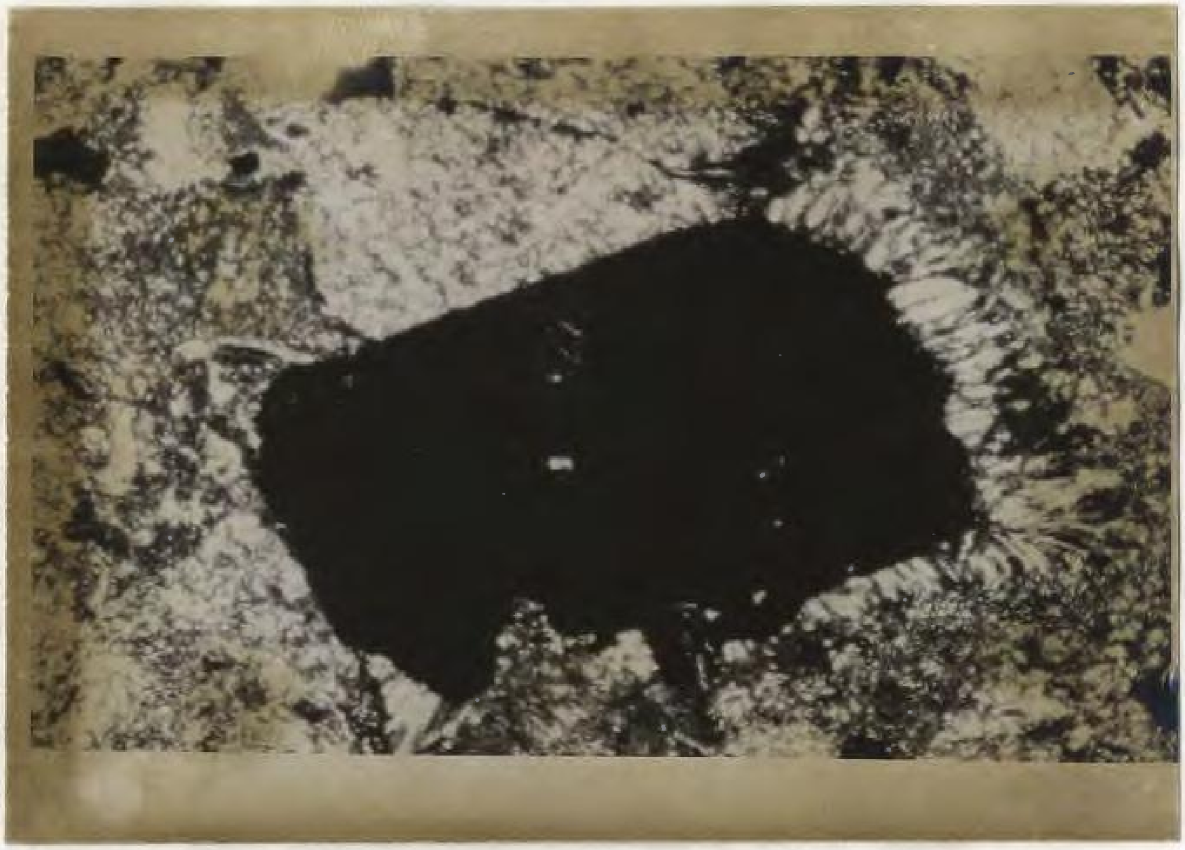
Albite growth infilling void caused by alteration of pyrite cube--Rocky Harbour sandstone, taken in transmitted light, under crossed nicols

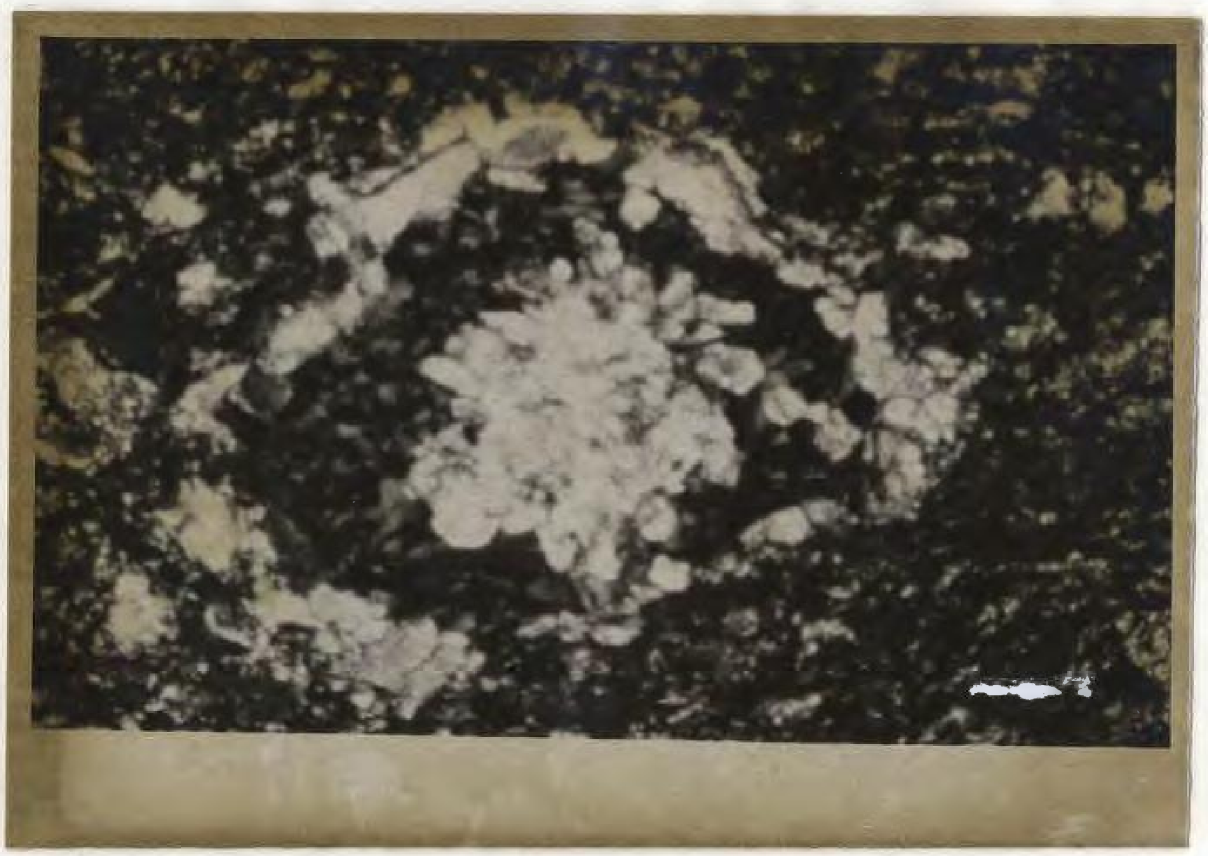
Scale: 1 cm = 0.25 mm

Plate 30

Epidote (light center and outer rim) and chlorite (dark inner circle) alteration--Bull Arm basic tuff, taken in transmitted light, under crossed nicols

Scale: 1 cm = 0.25 mm





APPENDIX II

Analyses

LOVE COVE VOLCANICS

SAMPLE	DB 62	DB 709	DB 397	DB 410	DB 407
SIO2	83.50	77.60	76.70	76.60	74.50
TIO2	0.12	0.30	0.04	0.08	0.22
AL2O3	9.70	11.40	12.20	11.80	12.90
FE2O3	0.17	0.71	0.73	1.26	0.44
FEO	0.66	0.48	0.0	0.49	0.53
MNO	0.04	0.03	0.03	0.03	0.03
MGO	0.24	0.03	0.30	0.37	0.28
CAO	0.52	0.94	0.78	0.94	0.70
NA2O	3.84	6.40	3.33	3.82	5.07
K2O	1.83	0.14	2.42	1.95	2.24
P2O5	0.0	0.0	0.0	0.0	0.0
LOI	0.56	1.13	2.14	2.01	1.28
TOTAL	101.18	99.36	98.67	99.35	98.19
ZR	63	113	97	84	134
SR	77	30	97	38	80
RB	32	2	71	54	39
ZN	43	36	39	34	62
CU	4	1	4	6	3
GA	11	13	15	12	15
PB	10	15	17	11	15
NI	3	4	4	4	5
Y	9	16	18	13	22
Q	51.93	39.25	47.96	45.56	35.48
OR	10.75	0.84	14.93	11.84	13.66
AB	32.29	55.13	29.41	33.21	44.27
AN	2.56	2.00	4.04	4.79	3.58
COR	0.45	0.0	2.80	1.74	0.89
DIO	0.0	0.16	0.0	0.0	0.0
HY	1.54	0.0	0.78	0.95	1.03
OL	0.0	0.0	0.0	0.0	0.0
MAG	0.24	0.79	0.0	1.48	0.66
ILM	0.23	0.58	0.07	0.16	0.43
HM	0.0	0.18	0.0	0.27	0.0
AP	0.0	0.0	0.0	0.0	0.0

LOVE COVE VOLCANICS

SAMPLE	P 51	P 49	DB 104	DB 399	DB 415
SIO2	74.20	73.10	72.80	72.00	71.80
TIO2	0.21	0.30	0.40	0.22	0.40
AL2O3	13.62	14.44	14.00	11.60	14.30
FE2O3	0.68	0.51	1.71	0.30	1.34
FEO	0.95	1.42	0.40	1.51	0.84
MNO	0.07	0.13	0.10	0.04	0.06
MGO	0.63	0.28	0.34	1.23	0.67
CAO	0.69	0.56	1.02	2.56	0.14
NA2O	4.27	7.10	6.09	5.15	2.94
K2O	2.79	1.33	3.60	0.80	5.03
P2O5	0.0	0.0	0.0	0.0	0.0
LOI	1.61	1.14	1.27	4.49	1.77
TOTAL	99.72	100.31	101.73	99.90	99.29
ZR	174	189	166	91	200
SR	103	62	95	167	51
RB	61	17	21	26	123
ZN	60	105	76	41	73
CU	4	4	3	5	4
GA	22	20	15	11	17
PB	10	13	13	12	13
NI	5	5	5	8	6
Y	26	24	21	11	29
Q	36.52	24.41	21.85	33.60	35.02
OR	16.81	7.93	21.18	4.96	30.48
AB	36.03	60.58	51.30	45.67	25.51
AN	3.49	2.80	0.23	6.47	0.71
COR	2.37	0.31	0.0	0.0	3.86
DIO	0.0	0.0	1.82	5.60	0.0
HY	2.58	2.65	0.0	2.81	1.71
OL	0.0	0.0	0.0	0.0	0.0
MAG	1.00	0.75	0.45	0.46	1.79
ILM	0.41	0.57	0.76	0.44	0.78
HM	0.0	0.0	1.39	0.0	0.14
AP	0.0	0.0	0.0	0.0	0.0

LOVE COVE VOLCANICS

SAMPLE	*	P 47	P 53	*	DB 396	*	DB 144	*
SIO2	*	68.60	66.40	*	66.10	*	62.80	*
TIO2	*	0.60	0.30	*	0.42	*	0.66	*
AL2O3	*	14.97	15.04	*	14.00	*	16.60	*
FE2O3	*	3.98	3.71	*	3.32	*	3.99	*
FEO	*	0.57	0.93	*	0.17	*	1.13	*
MNO	*	0.11	0.09	*	0.10	*	0.10	*
MGO	*	0.98	2.21	*	1.44	*	1.58	*
CAO	*	1.67	4.64	*	2.14	*	2.70	*
NA2O	*	5.67	1.64	*	2.92	*	5.52	*
K2O	*	2.35	3.21	*	3.72	*	1.58	*
P2O5	*	0.20	0.0	*	0.0	*	0.22	*
LOI	*	0.98	2.21	*	4.06	*	2.24	*
TOTAL	*	100.68	100.58	*	98.39	*	99.12	*
ZR	*	223	170	*	200	*	214	*
SR	*	233	422	*	116	*	173	*
RB	*	50	116	*	136	*	54	*
ZN	*	233	57	*	77	*	104	*
CU	*	10	19	*	6	*	14	*
GA	*	18	18	*	18	*	18	*
PB	*	11	11	*	12	*	11	*
NI	*	8	25	*	8	*	4	*
Y	*	25	27	*	28	*	27	*
Q	*	22.21	30.67	*	29.84	*	17.67	*
OR	*	13.93	19.28	*	23.31	*	9.64	*
AB	*	48.12	15.83	*	26.19	*	48.21	*
AN	*	7.01	23.40	*	11.25	*	12.36	*
COR	*	0.54	0.10	*	1.36	*	1.47	*
DIO	*	0.0	0.0	*	0.0	*	0.0	*
HY	*	2.45	5.59	*	3.80	*	4.06	*
OL	*	0.0	0.0	*	0.0	*	0.0	*
MAG	*	0.46	2.46	*	0.0	*	2.12	*
ILM	*	1.14	0.58	*	0.61	*	1.29	*
HM	*	3.68	2.07	*	3.52	*	2.66	*
AP	*	0.0	0.0	*	0.0	*	0.53	*

LOVE COVE VOLCANICS

SAMPLE	DB 414	DB 381	DB 656	DB 676	DB 318
SIO2	47.60	46.60	46.00	45.60	42.30
TIO2	1.33	1.30	2.10	2.64	3.10
AL2O3	17.00	17.10	15.80	13.80	16.80
FE2O3	5.81	5.53	7.58	2.85	6.44
FEO	5.24	5.57	4.82	11.99	7.48
MNO	0.22	0.18	0.21	0.26	0.27
MGO	5.36	7.62	6.68	5.98	8.94
CAO	8.50	8.14	7.98	10.28	4.58
NA2O	3.02	3.02	3.02	2.56	3.09
K2O	0.30	0.88	0.35	0.29	0.03
P2O5	0.18	0.20	0.46	0.38	0.50
LOI	4.04	4.59	3.91	2.07	5.46
TOTAL	98.60	100.73	98.91	98.70	98.99
ZR	134	164	192	172	163
SR	469	344	368	273	129
RB	7	14	5	4	1
ZN	100	94	115	106	145
CU	44	72	31	95	119
GA	22	20	20	21	25
PB	8	7	7	6	6
NI	13	91	111	22	43
Y	18	19	21	23	22
Q	3.97	0.0	3.23	0.0	0.79
OR	1.87	5.41	2.18	1.77	0.19
AB	27.02	26.58	26.90	22.42	27.95
AN	33.78	31.73	30.02	26.19	20.83
COR	0.0	0.0	0.0	0.0	4.86
DIO	7.62	7.09	6.63	19.93	0.0
HY	13.71	11.42	14.44	12.18	27.86
OL	0.0	6.39	0.0	7.14	0.0
MAG	8.91	8.34	10.66	0.0	9.98
ILM	2.67	2.57	4.20	5.19	6.29
HM	0.0	0.0	0.62	0.0	0.0
AP	0.44	0.48	0.0	0.0	1.24

BULL ARM Fm.

SAMPLE	DB 311	DB 111	DB 198	DB 200	DB 214
SIO2	79.10	78.40	78.20	76.50	76.40
TIO2	0.12	0.06	0.24	0.24	0.24
AL2O3	11.30	10.80	11.50	11.70	12.00
FE2O3	4.35	2.31	1.49	1.27	1.31
FEO	0.59	0.23	0.74	1.18	0.90
MNO	0.0	0.05	0.06	0.03	0.03
MGO	0.02	0.0	0.62	0.18	0.34
CAO	0.0	0.26	0.26	0.20	0.34
NA2O	4.42	2.69	3.31	2.84	1.84
K2O	3.39	5.25	3.71	5.82	7.45
P2O5	0.0	0.0	0.0	0.0	0.0
LOI	0.72	0.33	1.02	0.47	0.74
TOTAL	104.01	100.38	101.17	100.43	101.59
ZR	558	507	475	723	471
SR	13	25	64	32	51
RB	77	93	60	127	127
ZN	102	77	135	167	20
CU	7	5	3	4	5
GA	30	25	30	30	15
PB	20	9	10	14	9
NI	2	5	5	7	5
Y	44	40	56	73	58
Q	39.10	42.08	43.16	36.67	35.54
OR	19.40	31.01	21.89	34.41	43.66
AB	36.21	22.75	27.97	24.04	15.44
AN	0.0	1.29	1.39	0.99	1.67
COR	0.35	0.22	1.53	0.37	0.29
DIO	0.0	0.0	0.0	0.0	0.0
HY	0.05	0.0	1.54	1.23	1.07
OL	0.0	0.0	0.0	0.0	0.0
MAG	1.50	0.73	1.88	1.84	1.88
ILM	0.22	0.11	0.46	0.46	0.45
HM	3.17	1.81	0.19	0.0	0.0
AP	0.0	0.0	0.0	0.0	0.0

BULL ARM FM.

SAMPLE	DB 110	DB 599	DB 668	DB 33	DB 488
SIO2	75.70	75.40	75.40	75.30	73.80
TIO2	0.14	0.14	0.14	0.12	0.20
AL2O3	11.40	12.80	11.70	12.70	11.20
FE2O3	1.86	1.05	2.69	1.64	2.49
FEO	0.88	0.06	0.0	0.39	0.78
MNO	0.07	0.01	0.07	0.08	0.07
MGO	0.06	0.19	0.08	0.36	0.03
CAO	0.36	0.28	0.08	1.46	1.10
NA2O	3.87	3.05	4.24	1.49	4.27
K2O	4.00	5.22	4.06	6.09	3.42
P2O5	0.0	0.0	0.0	0.0	0.0
LOI	0.46	1.00	0.40	1.26	1.03
TOTAL	98.80	99.20	98.86	100.89	98.39
ZR	678	125	469	513	731
SR	27	68	21	121	34
RB	71	108	71	123	55
ZN	130	29	122	65	219
CU	4	5	3	6	4
GA	29	6	28	27	29
PB	12	(9	13	17	11
NI	5	4	5	8	5
Y	59	22	58	63	69
Q	37.64	37.47	36.45	39.81	35.30
OR	24.04	31.41	25.05	36.12	20.76
AB	33.30	26.28	37.46	12.65	37.11
AN	1.82	1.41	0.41	7.27	1.33
COR	0.05	1.65	0.19	1.01	0.0
DIO	0.0	0.0	0.0	0.0	0.17
HY	0.15	0.48	0.21	0.90	0.0
OL	0.0	0.0	0.0	0.0	0.0
MAG	2.70	0.0	0.0	1.17	2.22
ILM	0.27	0.15	0.16	0.23	0.0
HM	0.03	1.07	0.0	0.84	1.03
AP	0.0	0.0	0.0	0.0	0.0

BULL ARM FM.

SAMPLE	DB 538	DB 417	DB 315	DB 614
SIO2	72.00	71.30	67.80	60.80
TIO2	0.66	0.52	1.04	1.34
AL2O3	15.30	10.50	15.00	16.90
FE2O3	3.26	9.25	5.19	6.62
FEO	0.37	0.07	0.40	0.44
MNO	0.09	0.26	0.10	0.20
MGO	1.19	0.07	0.20	0.89
CAO	0.92	0.08	0.52	1.94
NA2O	5.65	3.44	5.09	5.57
K2O	1.23	4.68	5.16	2.49
P2O5	0.0	0.0	0.0	0.25
LOI	1.45	0.68	0.54	1.55
TOTAL	102.12	100.85	101.04	98.99
ZR	205	1562	1026	186
SR	114	19	22	223
RB	34	123	116	70
ZN	113	290	164	124
CU	6	4	10	4
GA	20	37	36	22
PB	10	16	14	10
NI	6	7	5	5
Y	25	99	63	29
Q	300.48	33.39	16.95	14.45
OR	7.22	27.61	30.34	15.10
AB	47.49	27.91	42.86	48.37
AN	4.53	0.0	2.57	8.22
COR	1.65	0.0	0.0	2.16
DIO	0.0	0.0	0.0	0.0
HY	2.94	0.17	0.50	2.27
OL	0.0	0.0	0.0	0.0
MAG	0.0	0.0	0.0	0.0
ILM	0.97	0.70	1.05	1.39
HM	3.24	8.88	5.16	6.79
AP	0.0	0.0	0.0	0.0

CONNECTING POINT GROUP VOLCANICS

SAMPLE	DB 385	DB 357	DB 1000
SIO2	53.10	48.90	72.50
TIO2	0.72	1.88	0.22
AL2O3	18.60	14.70	14.70
FE2O3	1.94	1.17	0.46
FEO	6.52	11.80	1.00
MNO	0.14	0.24	0.05
MGO	5.18	5.92	0.79
CAO	3.76	8.42	0.58
NA2O	4.97	3.23	6.66
K2O	0.38	0.24	0.63
P2O5	0.0	0.09	0.0
LOI	4.07	2.12	1.33
TOTAL	99.38	98.71	98.92
ZR	100	129	98
SR	367	119	132
RB	10	6	19
ZN	101	106	48
CU	80	27	6
GA	19	21	13
PB	8	6	12
NI	33	22	8
Y	14	26	12
Q	2.79	0.0	29.09
OR	2.36	1.47	3.82
AB	44.12	28.30	57.75
AN	19.57	25.78	2.95
COR	3.33	0.0	2.06
DIO	0.0	14.05	0.0
HY	23.44	18.48	3.23
OL	0.0	6.26	0.0
MAG	2.95	1.76	0.68
ILM	1.43	3.70	0.43
HM	0.0	0.0	0.0
AP	0.0	0.22	0.0

SCHISTOSE VOLCANIC PEBBLE,

CANNING'S COVE FM, BREAD C

	GABBRO			TRAYTOWN GRANITE	
SAMPLE	DB 176	DB 702	DB 100	DB 87	DB 178
SIO2	46.20	44.80	44.40	78.70	77.10
TIO2	0.32	0.50	1.36	0.08	0.02
AL2O3	18.60	25.90	18.20	11.60	12.20
FE2O3	1.40	0.47	3.03	0.62	0.72
FEO	5.37	5.25	7.62	0.93	0.87
MNO	0.12	0.05	0.20	0.02	0.01
MGO	11.40	3.52	8.18	0.0	0.0
CAO	10.66	12.86	5.98	0.0	0.0
NA2O	1.80	2.52	3.10	4.01	4.22
K2O	1.20	0.12	2.40	4.51	4.69
P2O5	0.0	0.0	0.30	0.0	0.0
LOI	3.60	1.93	5.12	0.50	0.54
TOTAL	100.67	97.92	99.89	100.97	100.37
ZR	39	88	123	208	222
SR	298	878	290	5	4
RB	33	3	16	212	212
ZN	53	55	132	127	146
CU	63	83	70	4	3
GA	16	22	17	33	33
PB	7	7	7	20	13
NI	78	34	57	5	5
Y	12	8	20	53	45
Q	0.0	0.0	0.0	37.44	34.21
OR	7.31	0.74	14.96	26.53	27.76
AB	14.26	17.84	20.59	33.77	35.77
AN	40.31	61.47	29.25	0.0	0.0
COR	0.0	0.0	0.36	0.12	0.18
DIO	11.33	4.13	0.0	0.0	0.0
HY	0.0	0.0	0.0	1.10	0.99
OL	23.30	11.75	22.90	0.0	0.0
MAG	2.09	0.71	4.64	0.84	1.05
ILM	0.63	0.99	2.73	0.15	0.04
HM	0.0	0.0	0.0	0.0	0.0
AP	0.0	0.0	0.74	0.0	0.0
Neph	0.77	2.37	3.84		

DYKES

SAMPLE	DB 64	DB 197	DB 112	DB 6	DB 501
SIO2	82.30	74.10	62.70	52.80	49.10
TIO2	0.12	0.16	0.70	2.08	1.66
AL2O3	8.60	12.80	13.20	12.70	16.00
FE2O3	0.45	1.27	1.67	8.05	2.76
FEO	1.46	0.86	5.80	5.94	7.03
MNO	0.03	0.07	0.32	0.49	0.19
MGO	0.32	0.16	1.44	2.38	5.98
CAO	0.78	0.74	2.76	5.90	9.00
NA2O	4.10	3.25	4.85	1.95	2.89
K2O	0.44	5.56	1.94	2.23	0.92
P2O5	0.0	0.0	0.22	1.06	0.16
LOI	1.02	0.31	3.25	2.97	2.47
TOTAL	99.62	99.30	98.85	98.55	98.16
ZR	255	286	755	263	192
SR	49	59	85	259	393
RB	5	100	46	32	36
ZN	61	34	161	171	88
CU	4	6	4	4	56
GA	14	24	25	24	2
PB	13	13	8	9	8
NI	5	4	4	0	55
Y	26	49	53	35	23
Q	54.42	32.16	17.22	20.47	0.67
OR	2.64	33.31	11.99	13.78	5.68
AB	35.19	27.78	42.92	17.26	25.55
AN	3.82	3.71	8.91	20.20	29.23
COR	0.0	0.07	0.0	0.0	0.0
DIO	0.09	0.0	3.34	2.59	13.28
HY	2.96	0.80	11.16	6.78	17.72
OL	0.0	0.0	0.0	0.0	0.0
MAG	0.66	1.86	2.53	12.21	4.18
ILM	0.23	0.31	1.39	4.13	3.29
HM	0.0	0.0	0.0	0.0	0.0
AP	0.0	0.0	0.53	2.58	0.39

		DYKES			
DB 27	DB 255	DB 500	P 60	DB 103	DB 97
48.80	46.60	43.90	40.80	0.0	0.0
2.48	2.00	2.24	2.43	0.0	0.0
13.60	15.30	16.00	17.60	0.0	0.0
5.36	3.54	2.02	3.75	0.0	0.0
5.68	9.91	9.76	10.44	0.0	0.0
0.23	0.24	0.21	0.33	0.0	0.0
4.00	7.24	7.56	7.39	0.0	0.0
6.08	10.02	10.30	6.16	0.0	0.0
1.71	2.48	1.91	3.00	0.0	0.0
4.64	1.02	1.49	0.71	0.0	0.0
1.46	0.42	0.24	0.36	0.0	0.0
5.85	1.80	2.33	6.16	0.0	0.0
99.89	100.57	97.96	99.13	0.0	0.0
222	187	180	218	162	153
105	407	328	561	101	197
82	16	84	19	3	50
180	118	98	150	143	95
5	75	60	77	117	42
21	19	20	25	18	21
9	8	6	8	3	10
1	76	68	75	128	46
41	24	28	24	21	22
6.59	0.0	0.0	0.0	0.0	0.0
29.15	6.10	9.21	4.51	0.0	0.0
15.38	21.24	14.94	27.30	0.0	0.0
16.72	27.95	32.09	30.36	0.0	0.0
0.0	0.0	0.0	1.67	0.0	0.0
4.22	16.04	1.06	0.0	0.0	0.0
11.07	6.90	0.0	0.18	0.0	0.0
0.0	11.73	18.49	0.0	0.0	0.0
8.26	5.20	3.06	5.85	0.0	0.0
5.01	3.85	4.45	4.96	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
3.61	0.99	0.58	0.0	0.0	0.0

ROCKY HARBOUR FORMATION

SAMPLE	DB 141	DB 46	DB 59	DB 20	DB 1
SIO2	74.90	74.60	62.90	61.60	61.30
TIO2	0.20	0.32	0.86	0.58	1.10
AL2O3	12.20	11.00	17.30	17.10	16.10
FE2O3	1.92	0.96	2.30	2.05	4.39
FEO	1.36	3.46	2.43	2.31	2.36
MNO	0.05	0.12	0.16	0.06	0.17
MGO	0.66	2.12	2.26	0.92	2.04
CAO	1.40	0.68	3.06	1.34	2.62
NA2O	4.81	2.42	4.70	1.17	4.36
K2O	1.66	1.66	1.83	9.94	2.43
P2O5	0.0	0.0	0.0	0.10	0.10
LOI	0.92	2.58	2.26	2.08	2.23
TOTAL	100.08	99.92	100.06	99.25	99.20
ZR	356	579	174	172	185
SR	150	50	377	55	252
RB	23	40	50	237	59
ZN	81	109	106	82	140
CU	6	8	8	10	11
GA	26	22	21	23	22
PB	13	8	11	12	10
NI	7	14	8	8	10
Y	39	48	22	42	24
Q	36.62	48.45	18.38	12.36	18.83
OR	9.89	10.08	11.06	60.45	14.81
AB	41.05	21.04	40.66	10.19	38.04
AN	6.85	3.47	15.52	6.18	12.74
COR	0.0	4.09	2.07	2.28	1.83
DIO	0.12	0.0	0.0	0.0	0.0
HY	2.28	10.82	7.23	4.11	5.24
OL	0.0	0.0	0.0	0.0	0.0
MAG	2.81	1.43	3.41	3.06	5.13
ILM	0.38	0.62	0.0	1.13	2.15
HM	0.0	0.0	0.0	0.0	0.99
AP	0.0	0.0	0.0	0.24	0.24

ROCKY HARBOUR FORMATION

SAMPLE	DB 114	DB 158	DB 647	DB 3	DB 58
SIO2	59.90	0.0	0.0	0.0	0.0
TIO2	0.70	0.0	0.0	0.0	0.0
AL2O3	18.30	0.0	0.0	0.0	0.0
FE2O3	2.51	0.0	0.0	0.0	0.0
FEO	3.51	0.0	0.0	0.0	0.0
MNO	0.12	0.0	0.0	0.0	0.0
MGO	1.96	0.0	0.0	0.0	0.0
CAO	1.68	0.0	0.0	0.0	0.0
NA2O	4.81	0.0	0.0	0.0	0.0
K2O	2.67	0.0	0.0	0.0	0.0
P2O5	0.16	0.0	0.0	0.0	0.0
LOI	2.55	0.0	0.0	0.0	0.0
TOTAL	98.87	0.0	0.0	0.0	0.0
ZR	175	99	188	239	242
SR	198	118	136	118	128
RB	78	81	86	108	104
ZN	108	99	131	239	89
CU	8	10	6	7	9
GA	23	22	19	20	24
PB	8	9	13	11	10
NI	10	13	5	5	9
Y	25	27	26	36	31
Q	14.60	0.0	0.0	0.0	0.0
OR	16.38	0.0	0.0	0.0	0.0
AB	42.25	0.0	0.0	0.0	0.0
AN	7.58	0.0	0.0	0.0	0.0
COR	5.01	0.0	0.0	0.0	0.0
DIO	0.0	0.0	0.0	0.0	0.0
HY	8.64	0.0	0.0	0.0	0.0
OL	0.0	0.0	0.0	0.0	0.0
MAG	3.78	0.0	0.0	0.0	0.0
ILM	1.38	0.0	0.0	0.0	0.0
HM	0.0	0.0	0.0	0.0	0.0
AP	0.39	0.0	0.0	0.0	0.0

ROCKY HARBOUR FORMATION

SAMPLE	DB 542	DB 489	DB 456	DB 25	DB 6A
SIO2	0.0	0.0	0.0	0.0	0.0
TIO2	0.0	0.0	0.0	0.0	0.0
AL2O3	0.0	0.0	0.0	0.0	0.0
FE2O3	0.0	0.0	0.0	0.0	0.0
FEO	0.0	0.0	0.0	0.0	0.0
MNO	0.0	0.0	0.0	0.0	0.0
MGO	0.0	0.0	0.0	0.0	0.0
CAO	0.0	0.0	0.0	0.0	0.0
NA2O	0.0	0.0	0.0	0.0	0.0
K2O	0.0	0.0	0.0	0.0	0.0
P2O5	0.0	0.0	0.0	0.0	0.0
LOI	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	0.0	0.0	0.0
ZR	164	222	255	207	137
SR	215	219	148	58	148
RB	68	93	75	151	100
ZN	94	82	80	85	92
CU	11	11	15	9	9
GA	21	21	17	18	17
PB	10	14	10	11	10
NI	8	8	9	7	0
Y	22	30	36	34	24
Q	0.0	0.0	0.0	0.0	0.0
OR	0.0	0.0	0.0	0.0	0.0
AB	0.0	0.0	0.0	0.0	0.0
AN	0.0	0.0	0.0	0.0	0.0
COR	0.0	0.0	0.0	0.0	0.0
DIO	0.0	0.0	0.0	0.0	0.0
HY	0.0	0.0	0.0	0.0	0.0
OL	0.0	0.0	0.0	0.0	0.0
MAG	0.0	0.0	0.0	0.0	0.0
ILM	0.0	0.0	0.0	0.0	0.0
HM	0.0	0.0	0.0	0.0	0.0
AP	0.0	0.0	0.0	0.0	0.0

APPENDIX III

Analytical Methods

TABLE A-III

PRECISION OF MAJOR ELEMENT ANALYSES (8 ANALYSES FOR EACH OXIDE, WT. %)

Oxide	Range	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.
S_iO_2	76.0 - 76.6	76.4	0.2976	62. 2 - 63. 1	62.7	0.2973	46.0 - 46.9	46.5	0.3024
T_iO_2	0.12 - 0.22	0.17	0.0366	0.20 - 0.40	0.31	0.0674	3.00 - 3.34	3.17	0.1136
Al_2O_3	11.8 - 11.9	11.9	0.0463	14.4 - 14.8	14.6	0.1458	13.1 - 13.4	13.20	0.1126
Fe_2O_3	1.06 - 1.13	1.08	0.0301	4.49 - 4.80	4.68	0.1178	16.60 - 16.56	16.30	0.1859
MnO	0.01 - 0.01	0.01	0.00	0.10 - 0.10	0.10	0.00	0.30 - 0.31	0.31	0.005
MgO	0.24 - 0.28	0.26	0.0167	2.32 - 2.40	2.37	0.0301	4.58 - 4.72	4.63	0.0466
CaO	0.40 - 0.50	0.45	0.0354	3.72 - 3.86	3.78	0.0483	8.66 - 8.74	8.72	0.0316
Na_2O	2.67 - 2.75	2.71	0.0324	2.15 - 2.19	2.18	0.0160	3.30 - 3.39	3.35	0.0338
K_2O	4.22 - 4.34	4.28	0.0351	4.10 - 4.28	4.15	0.0632	0.96 - 1.00	0.98	0.0128

APPENDIX III (CONTINUED)

PRECISION OF TRACE ELEMENT ANALYSES (12 ANALYSES FOR EACH ELEMENT, PPM)

DB-668			
Element	Range	Mean	S.D.
Pb	1	12.50	0.204
Rb	2	70.91	0.186
Sr	1	20.25	0.144
Y	1	58.16	0.117
Zr	14	463.25	1.227
Ga	3	29.50	0.527
Zn	9	121.83	0.807
Cu	1	3.50	0.204
N_i	2	5.66	0.235

APPENDIX III (CONTINUED)

PROCEDURE USED FOR PULVERIZING ROCK SAMPLES

1. Each sample was broken into small chips of suitable size for pulverizing ($\simeq$ 5 mm square).
2. The chips were cleaned so as to extract any foreign matter and placed in a tungsten-carbide bowl.
3. The bowl was then placed in a Seibtechnik swing mill, and the sample was pulverized.
4. The powder was then stored in 4 oz. glass jars.

PROCEDURE USED IN PLACING ROCK POWDER INTO SOLUTION FOR ATOMIC ABSORPTION ANALYSIS

1. 0.1000 g. of powder was weighed out and placed in a digestion flask (polycarbonate centrifuge bottle).
2. To the flask was added 5 ml. of concentrated hydroflouric acid, the flask was then capped and placed on a water bath for 30 minutes.
3. After the flask had cooled, 50 ml. of saturated boric acid solution was added, then 145 ml. of distilled water was placed in the flask to bring the total liquid volume to 200 ml. A portion of the solution was then stored in a 50 ml. polyethylene bottle.

   The samples were analysed on a Perkin Elmer 370 atomic absorption spectrophotometer. The precision of the instrument may be seen in Table A-III.

APPENDIX III (CONTINUED)

PROCEDURE USED IN PREPARING ROCK POWDER FOR X-RAY FLUORESCENCE ANALYSIS

1. 10 g. of rock powder was weighed out and placed in a glass jar along with 1 g. of binder.

2. The jar was then capped and placed in an oscillator for 10 minutes.

3. The powder plus binder was then placed in a Herzog compressor and underwent a pressure of 25 tons/ sq. inch for 60 seconds.

4. The resultant pellet was placed in an oven set at 200°C for 10 minutes.

5. The pellet was then allowed to cool, was labelled and stored.

The pellets were analyzed on a computerized x-ray fluorometer PW1450. The precision of the instrument may be seen in Table A-III.

PROCEDURE USED FOR THE DETERMINATION OF FeO AND Fe_2O_3

1. 0.2000 g. of sample were weighed out and placed in a 60 ml. plastic vial.

2. To the vial was added, firstly, 5 ml. of ammonium vanadate solution and, secondly, 10 ml. of concentrated hydrofluoric acid.

3. The vial was then covered and placed in an oscillating device overnight.

4. Next morning 10 ml. of sulfuric-phosphoric acid mixture was added.

5. The contents of the vial was then placed in a beaker and combined with 200 ml. of boric acid solution. Care was taken to ensure that all contents of the vial entered the beaker.

6. 10 ml. of ferrous ammonium sulfate solution was added along with 1 ml. of barium diphenylamine sulfonate indicator to the beaker.

7. Standard potassium dichromate solution was titrated into the beaker till the grey end point was reached.

8. The following formula was used to determine FeO wt. %.

   wt. % FeO = [(ml. of solution titrated for sample--ml. titrated for blank) x 7.185 N]/sample wt.(g.).

9. wt. % Fe_2O_3 = wt. % Total Fe - wt. % FeO.

10. If wt. % Fe_2O_3 plus wt. % FeO does not equal total Fe wt. %, then the difference is added to loss on ignition.

PROCEDURE USED IN MEASURING LOSS ON IGNITION

1. A dry crucible was weighed, the weight was recorded.

2. Approximately 0.5 g. of rock powder was weighed into the crucible, the total weight was recorded.

3. The crucible was then placed in an oven and left for two hours at a temperature of 1050°C.

4. The crucible and sample, upon being allowed to cool were reweighed and the weight was recorded.

5. Gloves must be worn for the above steps to prevent perspiration from coming into contact with the crucible.

6. The following formula was used to find the loss on ignition value for the individual sample.

   $b - a = c - a + x$

   a = wt. of crucible
   b = wt. of crucible and powder
   c = wt. of ignited crucible and powder
   x = L.O.I.