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THE VOLCANIC GEOLOGY OF THE  
MT KARIOI REGION

A thesis  
submitted in partial fulfilment  
of the requirements for the Degree  
of  
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by  
STEPHEN GRANT MATHESON

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## ABSTRACT

Mt Karioi is a 756 m high stratovolcano of Pliocene age (2.9 - 2.3 m.y. B.P.) situated south of Raglan, on the west coast of the North Island. Immediately surrounding Mt Karioi are a number of small low-lying volcanic centres of the Plio-Pleistocene Okete Volcanic Formation (3.79 - ~~2.08~~ 1.80 m.y. B.P.) which can be separated from the Karioi Volcanic Formation by their volcanic form, petrology and petrochemistry.

The Karioi Volcanic Formation consists of basalt, basaltic andesite and andesite lavas, volcanic breccias and tuffs produced by strombolian eruptions, and lahar deposits initiated by heavy rain on the upper slopes of the volcano. The Okete Volcanic Formation, comprising olivine basalt lava flows, scoria cones and ash, was produced by strombolian and phreatomagmatic activity. Karioi lavas are generally coarse-grained porphyritic rocks with large phenocrysts of plagioclase, clinopyroxene and olivine. The Okete lavas are dominated by olivine phenocrysts set in a fine-grained pilotaxitic groundmass.

Thirteen new analyses of lavas in the region are presented and discussed with ten previously published analyses. Chemically the Karioi lavas show a complete range from basanitoids to quartz tholeiites. The Okete lavas show less variation and are mainly basanitoids with minor alkali olivine basalts and olivine tholeiites. From the trace element data, strontium isotope information and restriction of ultramafic nodules to the Okete Volcanics, it is apparent that these two formations are not linked petrogenetically. The Karioi calc-alkaline rock series is largely the result of amphibole fractionation of a nepheline normative hydrous basaltic melt which produced a series of liquids which crossed the critical plane of undersaturation. The Okete Volcanics underwent little or no differentiation; each magma type is the result of varying degrees of partial melting of mantle at different depths which produced a variety of melts with a range in saturation.

The basalts of both volcanic formations are behind-arc basalts which show little pattern in relation to a subducting lithospheric slab and were probably derived from a source in the lower velocity zone of the upper mantle. The limited volumes of andesite having been derived by fractional crystallisation of a basalt cannot themselves be anyway related to the Benioff Zone.

A summary of the volcanic history of the Mt Karioi region is discussed and shown in a series of schematic diagrams.

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## CHAPTER I

### INTRODUCTION

#### 1.1 INTRODUCTION

Mt Karioi is an extinct basaltic volcano of Pliocene age, situated on the west coast of the North Island, immediately south of Raglan Harbour.

It is unusual in two main respects. Firstly, because of its young age and situation on the coast, cliffs ranging from 30 - 180m in height have exposed a continuous sequence of a variety of lavas, volcanic breccias, dykes, lahars, and epiclastic sediments. Secondly, and surprisingly in view of the excellent exposures, it has not been studied previously in detail except briefly by Henderson and Grange (1926) in the geology of the Huntly - Kawhia Subdivision.

These factors make it ideal for a study of the structure and petrology of a composite basaltic strato-volcano.

#### 1.2 AIMS AND SCOPE OF STUDY

The main objectives of this study are:-

- (i) to identify and describe the variety of rock types of Mt Karioi and neighbouring olivine basalt volcanics;
- (ii) to produce a geological map of the study area;
- (iii) to draw geological cross-sections of selected high cliff coastal exposures to elucidate the structure and volcanic history of the volcano; and

- (iv) to chemically analyse some selected rocks so that the petrochemistry and petrogenesis of the volcanic rocks can be described.

This study represents only a part of a much larger project on the nature and origin of the Alexandra Volcanics presently being conducted at the University of Waikato. Obviously a full petrological study of Mt Karioi volcano in relation to others in the area like Pirongia, and the volcanic rocks elsewhere in the North Island and its full significance to the whole Pliocene-Quaternary volcanism in New Zealand, is too large a scope within the realms of a MSc thesis.

It is hoped that the achievement of the objectives of this thesis will provide a reliable base of information for future work, and may make a small contribution to the understanding of island-arc volcanism in New Zealand.

### 1.3 LOCATION

The area of study (Figs 1.1 and 1.2) comprises approximately 100km<sup>2</sup> and is essentially that covered by the Karioi Volcanics, but immediately adjacent areas have also been included. The approximate boundaries of this study are the west coast, Raglan Harbour to the north, a line from Raglan township to Te Mata in the east, and Waimaori Road to the south.

### 1.4 PHYSIOGRAPHY

Mt Karioi dominates the topography of the area. Its rugged outline of steep razorback ridges near the summit and dissected plateaus of lava flows down the slopes have resulted in a typical radial drainage pattern. (Fig.1.2)

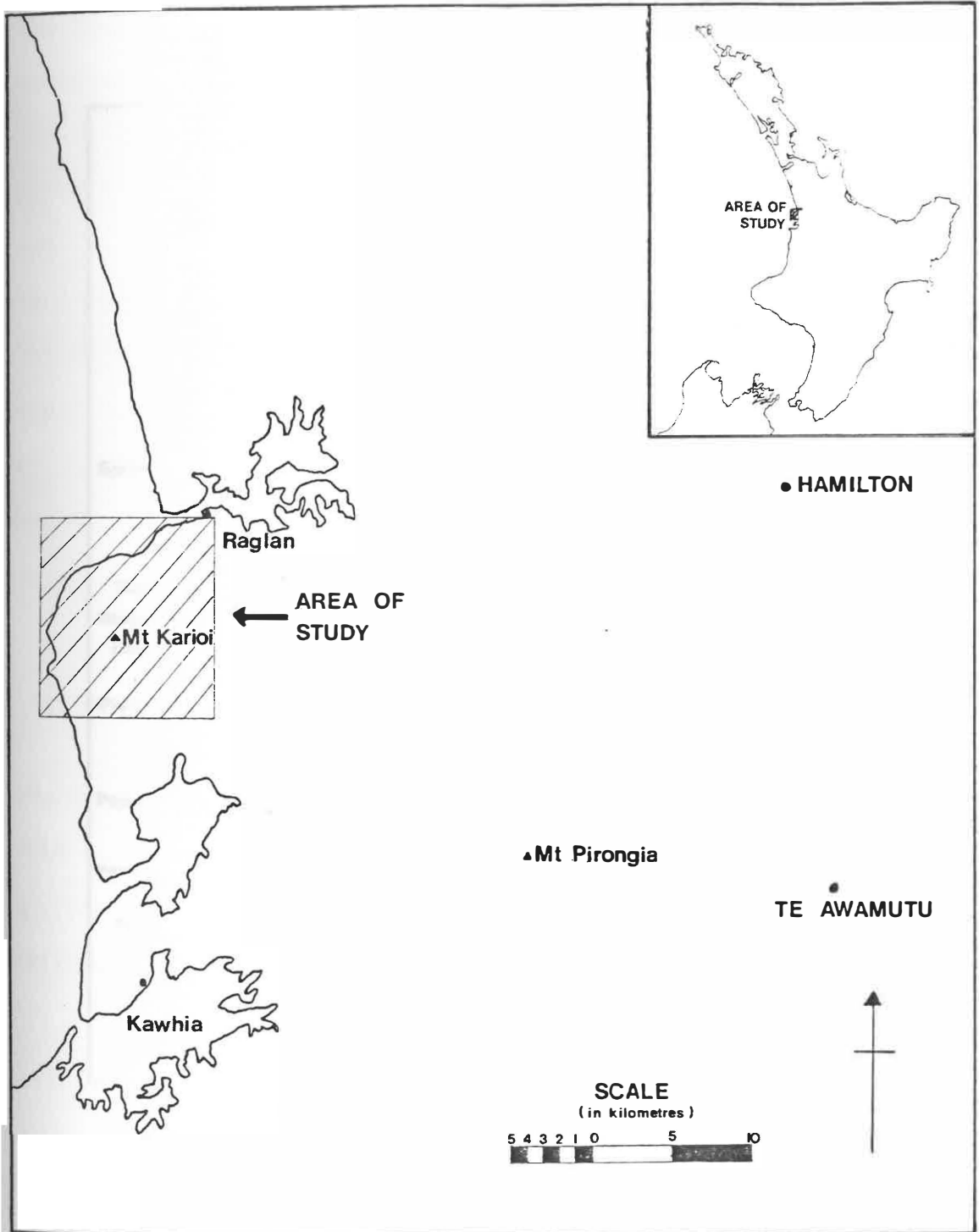


Fig. 1.1 - Location map of study area.

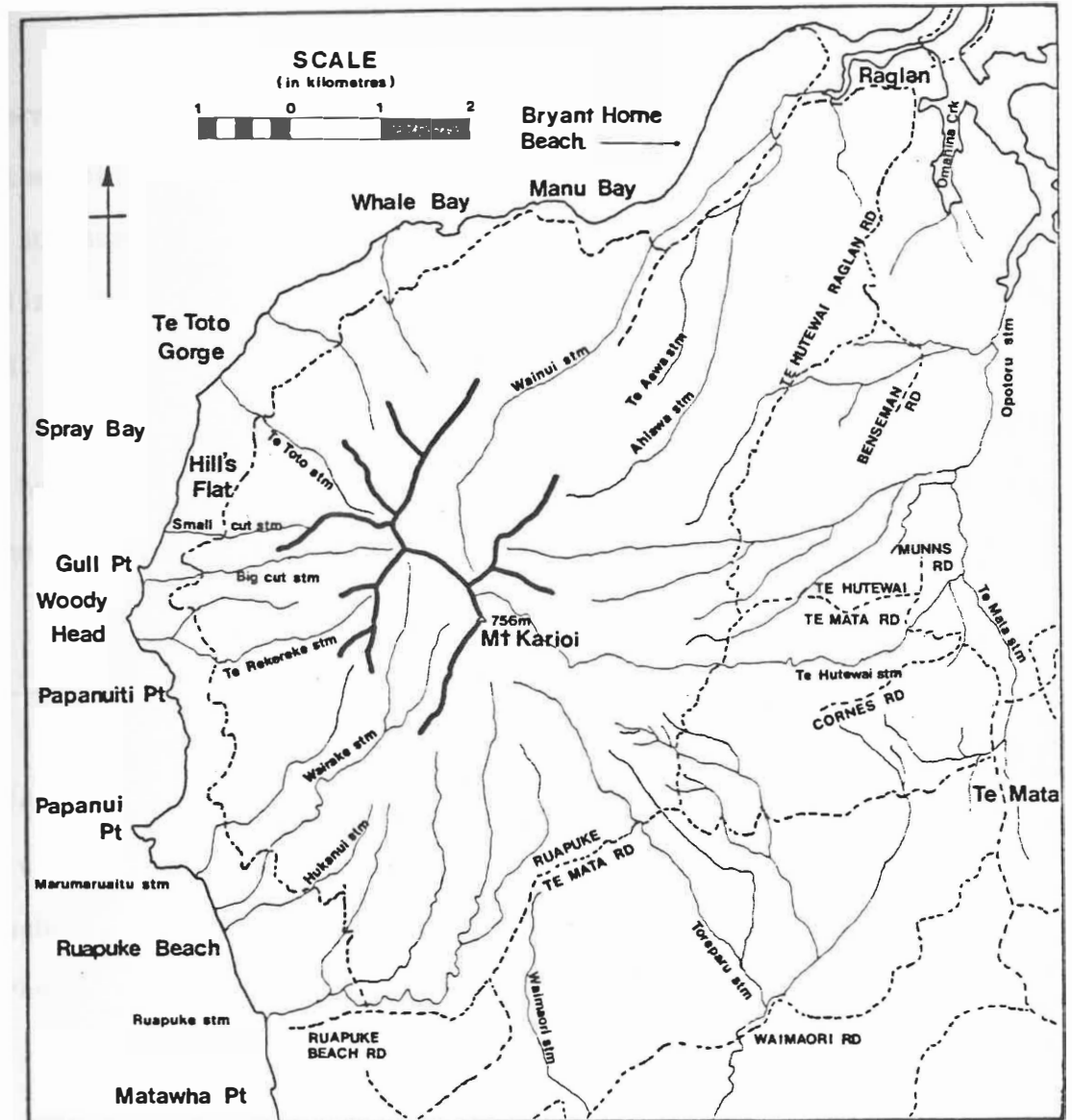


Fig. 1.2 - Physiographic features and major roads in the Mt Karioi district (ridges in bold lines and roads in dotted lines).

The mountain is considerably eroded and has no obvious crater or main vent. Kear (1957: 672, 680) states that the mountain has entered the residual mountain stage of erosion, and as such no longer exhibits any recognisable original cone surface. The highest point (756m) is at the southern end of the mountain although most of the main ridges are at least 600m in height.

To the east and south of Mt Karioi the topography and drainage pattern is more variable. Streams flow to the west toward Mt Karioi and the radial drainage pattern mentioned above no longer occurs. The land surface is hummocky and rolling, this being the result of smaller localised volcanic centres comprised of low scoria cones and small lava flows.

To the south-west of Papanui Point large stable sand dunes have been built up from the coast (to 120m) and have gradually migrated inland overlapping on to the flanks of the volcano.

### 1.5 LAND TENURE

The bulk of the upper mountain is covered in bush and makes up the Te Hutewai State Forest. Pasture occurs approximately below the 300m contour level and hence a knowledge of land tenure was important throughout the field work and is shown in Fig.1.3 for location and reference in the text.

### 1.6 FIELD WORK

Field work was carried out over about 12 weeks, mainly during the 1979-80 summer, although further work continued throughout 1980. Access to all areas of Mt Karioi and the surrounding districts was facilitated by a metal road that passes right around the mountain.

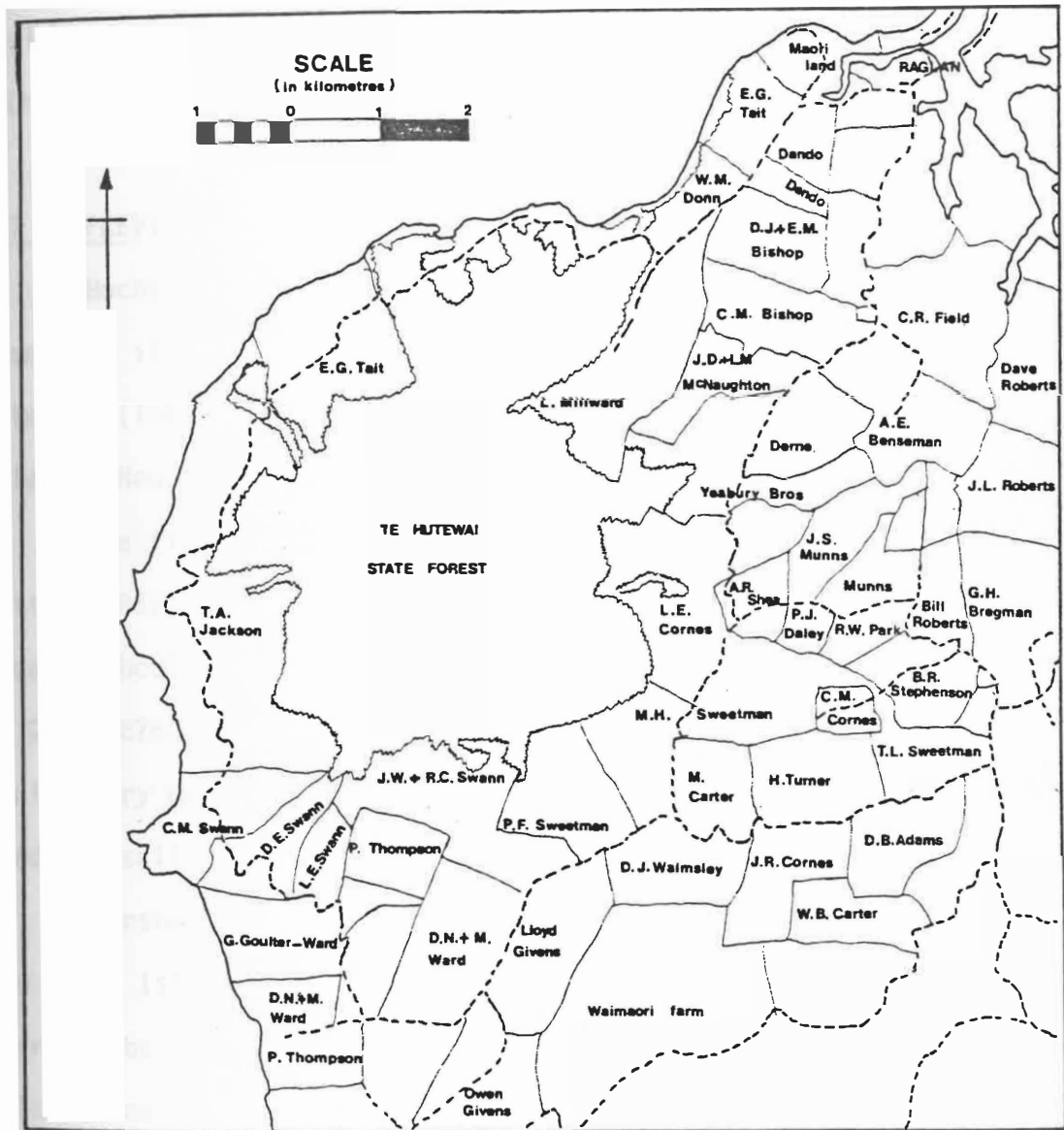


Fig. 1.3 - Land tenure of important properties in the mapping area.

There is only one marked track on the mountain itself, beginning from Mr L. Millward's farm in the north, traversing the mountain and passing by the trig before dropping down to Mr J.W. Swann's farm in the south. Access is possible, however, along the other main ridges where goat tracks have made relatively easy routes. Access to coastal sections was more difficult but all areas of the coastline from Raglan to Matawha Point were examined except for a small inaccessible 100m section near Gull Point.

### 1.7 PREVIOUS WORK

Hochstetter (1864) was the first to mention Mt Karioi. He described it as an old basalt volcano, although Hochstetter and Peterman (1864) described it in their geological and topographical Atlas of New Zealand as a trachydolerite volcano.

The first detailed geological study of the Waikato area was by Hutton (1867) who mapped Karioi as an extinct volcano surrounded by basaltic boulders and Whaingoroa Clay to the north. Further studies by Cox (1876, 1877) and Park (1885) were also mainly concerned with sedimentary deposits and merely mapped enormous areas of lavas, black-sands, basaltic boulders and tuffs as "boulder formation".

Marshall (1907: 96), looking at the geology of the whole of the North Island, described the rocks of Karioi as generally basaltic, "perhaps best called a dolerite" which "differs markedly from all other volcanic material of the North Island".

The first study of any real significance, and in fact the best description of the geology of the area to date, is that of Henderson and Grange (1926) in their geology of the Huntly - Kawhia subdivision. They mapped the area on a 1:63,360 scale, describing the petrography of some of the rocks and presented seven chemical analyses of selected rocks.

More recent studies have tended to be of a more general geological nature, mentioning only briefly some aspects of the Karioi volcanics. Player (1958) was concerned with the geology of north Kawhia and described some of the rocks in the south of the mapping area.

Kear (1957, 1959, 1964) looked at the erosional stages, stratigraphy and volcanic alignments of North Island volcanoes, while Kear (1960) mapped the whole Waikato region on a scale of 1:250,000, largely following the work of Henderson and Grange (1926).

Further studies concerning Mt Karioi volcanics were done in Quaternary geology and the dating of the Plio-Pleistocene boundary (Chappell 1964, 1970; and Stipp *et al.*, 1967); in the significance of calc-alkaline andesites in New Zealand (Hatherton 1968, 1969; and Hatherton and Dickinson, 1968) who used Mt Karioi lavas as examples of High-K behind-arc volcanoes.

Stipp (1968) and Robertson (1976) were concerned with geochronology and paleo-magnetism of the North Island Cenozoic volcanics, and presented some K-Ar dates for Mt Karioi and other Alexandra Group volcanics.

Recent studies have also considered Mt Karioi as a behind-arc volcano and used petrochemical data of Henderson and Grange (1926) - for example, Sameshima (1975) determined silica indices and Ballance (1976) deduced Magmatic arc movements in New Zealand during the Upper Cenozoic.

## CHAPTER 2

### GEOLOGICAL SETTING

#### 2.1 REGIONAL GEOLOGY

The regional geology of the Raglan-Kawhia area is summarised in Fig 2.1. The rocks are classified broadly into four groups on the basis of lithology and age: the Quaternary sediments, the Plio-Pleistocene volcanics, the Oligocene limestones and sandstones, and the Triassic-Jurassic siltstones, sandstones and conglomerates. The Triassic-Jurassic rocks have been subdivided in Fig.2.1 into the Puaruan or uppermost Jurassic, and the rest of the Jurassic and Triassic strata. This enables the relationship between age and topography to be distinguished, with the rocks becoming progressively older from the west coast to the top of the Hakarimata Ranges in the west.

It is convenient to describe the regional geology in terms of the rocks associated with the above four periods.

#### TRIASSIC - JURASSIC

The Triassic and Jurassic rocks which form the basement rocks of the Raglan and Kawhia areas, are relatively hard bluish-grey argillites, mudstones, sandstones, greywackes, and conglomerates. They are very thick, probably exceeding 7.5km (Suggate et al., 1978), and accumulated as shelf deposits on the upper margins of a geosyncline (Schofield, 1967).

These geosynclinal rocks have been variously called Shelf, Western or Facies, but following the proposal of Kear (1971) the term Oparau Facies is used here to describe those Triassic-Jurassic west of the Waipa fault. They are abundantly fossiliferous, including species of Halobia, Mantacula, Otapira, Inoceramas and Buchia as well as common belemnites and ammonites (Kear, 1960).

After deposition, extensive faulting, folding and erosion occurred. The bulk of the movement probably took place in the uppermost Jurassic and resulted eventually in the non-marine sequence of the Huruwai Formation (Purser, 1961) to the north.

However, some orogenic activity certainly took place in mid-Jurassic times as well (Kear and Schofield, 1978). The total period of orogenic activity in the Jurassic was named the Post-Hokonui Orogeny by Schofield (1967) and the term Rangitata Orogeny is now widely used for this period of movement which probably continued in the late Cretaceous (Suggate, et al., 1978).

The Mesozoic rocks are typically folded along the north-south trending axes (see Fig.2.2 for regional structure). The two major features are the Kawhia Syncline and the Hakarimata Anticline. The Kawhia Syncline actually consists of two major synclines, an anticline and several minor folds (Kear, 1960). The Hakarimata Anticline is a major fold with minor folds superimposed on its western flank.

These folds are clearly seen to the north, in the Te Akau and Port Waikato areas (Kear 1960), and to the southeast, but in the Raglan area they are obscured by Tertiary sediments and Plio-Pleistocene volcanics (Suggate, et al., 1978).

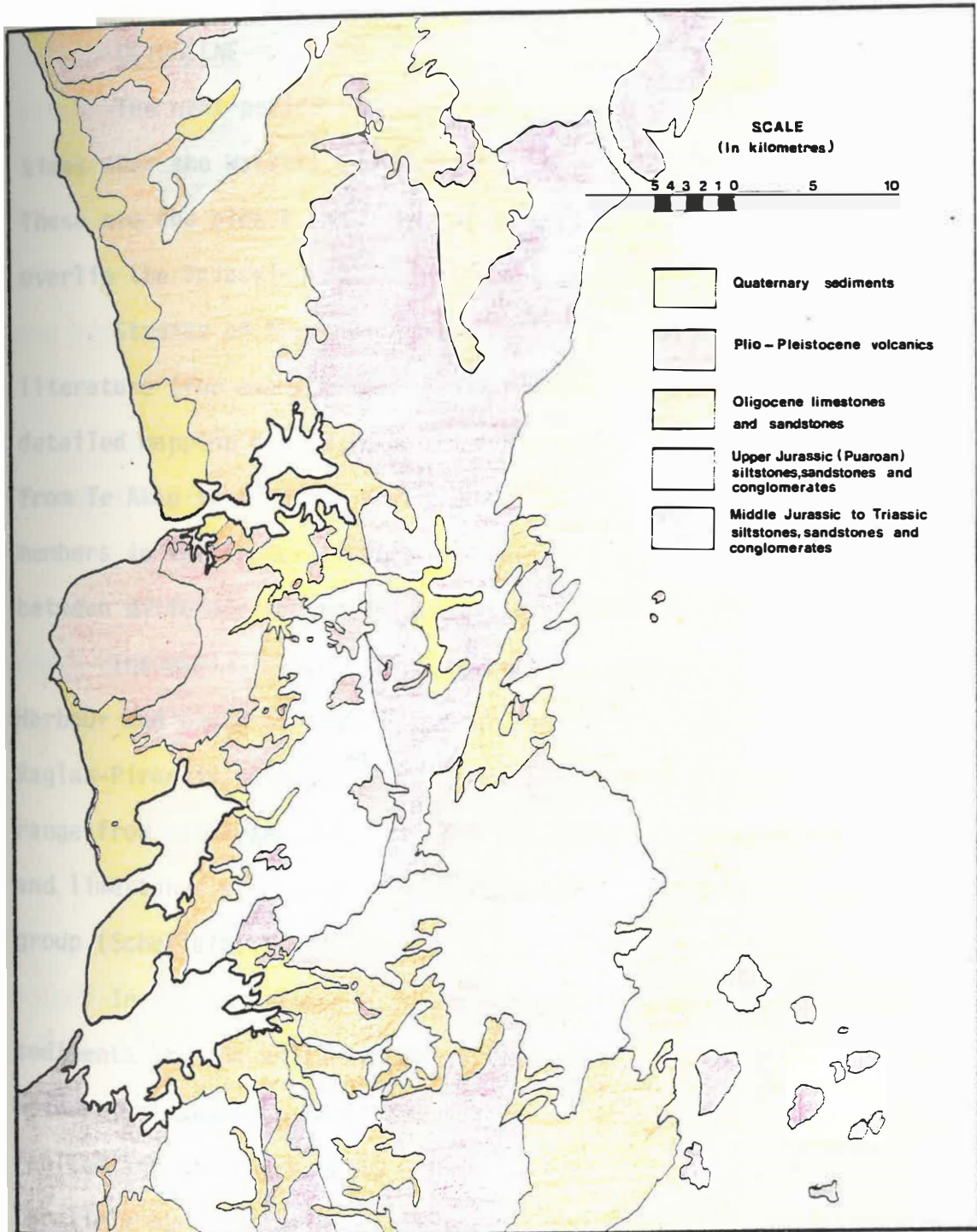


Fig. 2.1 - Regional geology of the Raglan-Kawhia area (after Kear, 1960).

Faulting during the Rangitata Orogeny is not common and because of the general lack of reliable marker beds, is difficult to interpret (Kear and Schofield, 1978). It is known that most major faults, for example the Waipa Fault, parallel Rangitata structural trends and strike roughly north-south.

#### OLIGOCENE

The next period of recorded sedimentation was in Upper Eocene times when the Waikato Coal Measures were deposited (Schofield, 1967). These are the oldest rocks in the Te Kuiti Group and unconformably overlie the Triassic and Jurassic basement rocks.

Studies of these Oligocene rocks are well documented in the literature (for example Kear and Schofield, 1978; Nelson, 1978) but detailed mapping of the formations has not yet been done in the area from Te Akau to Kawhia. Nomenclature of the various formations and members in the Te Kuiti Group has varied greatly from area to area and between different authors (summarised by Nelson, 1978).

The marine Oligocene rocks crop out widely north of Raglan Harbour and south of Kawhia Harbour, but in the intervening region of Raglan-Pirongia outcrops are thinner and more localised. The deposits range from estuarine mudstones and sandstones to open marine sandstones and limestones which become more calcareous towards the top of the group (Schofield, 1967).

In the late Miocene, subsequent to the deposition of the Oligocene sediments and the Waitemata Group sediments, major Kaikoura Orogenic movements took place (Kear and Schofield, 1978). Large areas were block faulted and these generally dip to the north-west. This faulting parallels much of the Rangitata structural trends in the Triassic-Jurassic rocks and may in part record rejuvenation along the older fault planes. Minor faults occur in a north-easterly direction suggesting a change in stress direction since the Rangitata Orogeny (Kear, 1964).

The harbours of Raglan, Aotea, and Kawhia occur in depressions formed by north-east trending faults and associated downwards block faulting during this late Miocene period (Chappell, 1970).

#### LATE PLIOCENE TO PLEISTOCENE

The most important period as regards this thesis is the onset of volcanism in the area. The geology of the Alexandra Volcanics will be discussed in the next section (Chapter 2.2), but volcanism also occurred in surrounding areas at similar times.

To the north, the South Auckland (Bombay and Franklin) field of alkaline olivine basalt centres of 1.6 to 0.51 m.y. B.P. produced lava and extensive scoria over an area of 190 square kilometres (Rafferty, 1977; Rafferty and Heming, 1979).

The Ngatutura Volcanics are further south of the Franklin and Bombay fields, at Kaawa (Henderson and Grange, 1926; Kear, 1957; Rodgers et al., 1973; Spratt and Rodgers, 1975). They produced alkaline olivine basalt lava and breccias that were erupted close to the west coast during the period 1.8 - 1.4 m.y. B.P. (Stipp, 1968).

South of the mapping area at Albatross Point are the Orangiwhao Volcanics of Upper Miocene to Pliocene age, comprising andesites and dacites (Henderson and Grange, 1926; Kear, 1959).

The Miocene Kiwitahi Volcanics occur to the east of the Hamilton Basin and have been described by Henderson and Grange (1926), Kear and Schofield (1964, 1978) and Cole (1978). They consist of andesite cones and dykes, and occur in a number of volcanic centres extending from Miranda in the north to Maungatautari in the south.

#### QUATERNARY

After the period of volcanism had subsided the landscape was subjected to many climatic changes, resulting in fluctuating sea levels. This produced the overlying sediments of the Kaihu Group and the high level terraces seen on the west coast of the region.

More recent deposits of sand have been blown on to the coast, and alluvial gravels, sands, muds and swamp deposits occur in modern river terraces and about the harbours' margins.

Over the last 750,000 yr. volcanic eruptions in the central North Island and Taranaki areas have produced numerous tephra deposits, some of which reached the Raglan area. Although they are largely weathered, and in some cases totally eroded off the steeper slopes, they are remarkably well preserved as compacted ash deposits in the low-lying areas near Te Uku (Salter, 1979). These have been mapped to the east by Pullar (1967) and Ward (1967), and more recent work by Pain (1975, 1976) has shown that some tephras extend out to the west coast and may be correlated with the coastal formations.

## 2.2 VOLCANIC GEOLOGY

### 2.2.1 Separation of the Okete Volcanics

The term Alexandra Volcanics was first proposed by Kear (1960) to designate a group of basic volcanic cones that are mainly aligned in a north-westerly direction and which include Karioi, Pirongia, Kakepuku, Te Kawa and Tokanui (Kear and Schofield, 1978). These have been previously described by Henderson and Grange (1926: 67-68) as "Olivine andesites and basalts of Karioi, Pirongia and related volcanic masses".

However, within this group, two types of volcanics can be separated on geomorphological, petrographical and chemical grounds. These two different volcanic groups have been previously noticed by Henderson and Grange (1926: 29) who stated "there is a second group of basic lava flows and scoria in the Karioi Survey District and small patches of similar material occur in the adjoining survey districts". Henderson and Grange also noted that "because they are coalescent, they are not as conspicuous as the Ngatutura or similar volcanics". However, little has been done to distinguish or map the separate volcanic groups, and Henderson and Grange (1926) and Kear (1960) included all these volcanics

within the one formation.

It is proposed to call the smaller centres of scoria and lava that outcrop around and among the larger masses of Karioi, Pirongia, Kakapuku, Te Kawa and Tokanui, the Okete Volcanic Formation (R.M. Briggs, in prep).

The products of each of these other main centres (for example, Karioi) shall be considered as one formation (Kear and Schofield, 1978) and all these volcanic formations (for example, Pirongia Volcanic Formation etc) together constitute the Alexandra Volcanic Group (see Table 2.1 and Fig.2.2).

TABLE 2.1 - Formations of the Alexandra Volcanics Group

GROUP	FORMATION	MAIN LITHOLOGIES PRESENT
ALEXANDRA VOLCANIC GROUP	OKETE	Olivine basalt lava, scoria and tuff
	KARIOI	Basalt, basaltic andesite and andesite lavas and tuffs; andesite dykes; and volcanic breccias
	PIRONGIA	Basalt and basaltic andesite lavas, and volcanic breccias
	KAKAPUKU	Basalt lava
	TE KAWA	Basalt lava and scoria
	TOKANUI	Basalt lava

The Okete Volcanics are distinctive because of their low-lying morphology, fine grained petrographic nature and chemical characteristics (particularly weight %  $TiO_2$ ) as discussed in later sections. The type site is at Okete Quarry (N64 438439) and the distribution of these volcanics as shown on Fig.2.2. Possible sites of eruption are also shown in Fig.2.2, but as the material ejected by these centres has "for the most part concealed the fractures or other vents by which the lava and stream reached the surface" (Henderson and Grange, 1926: 69), these

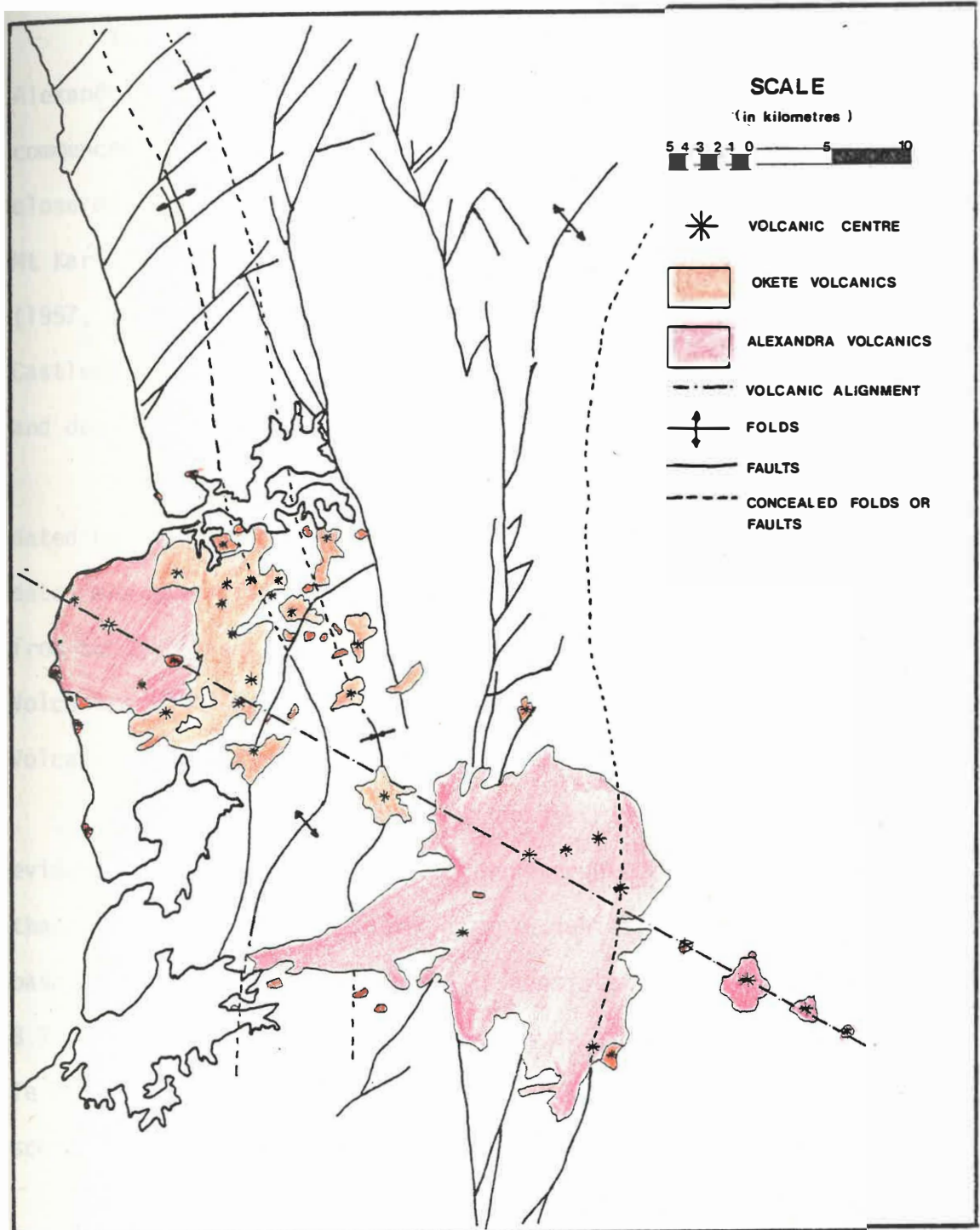


Fig. 2.2 - Volcanic geology and regional structure (after Kear, 1964 and R.M. Briggs, in prep.).

remain speculative.

Further detailed studies of these volcanics (Briggs, in prep) should distinguish the distribution of the numerous centres involved, possibly as many as forty.

### 2.2.2 Age

There has been considerable speculation on the age of the Alexandra Volcanics. Henderson and Grange (1926) thought that volcanism commenced with the eruption of the Pirongia group of volcanics at the close of the Pliocene. Player (1958) suggested that the main cone of Mt Karioi was built in the Upper Nukumaruan (late Pleistocene), and Kear (1957, 1959) considered Karioi and Pirongia to be of Waititaran - Castlecliffian (middle Pleistocene) age on the basis of paleobotany and degree of erosion.

Several samples of Alexandra Volcanics have subsequently been dated by the K-Ar method by Stipp (1968) and Robertson (1976). Their dates are summarised in Fig.2.3. Robertson gives two dates derived from two different grain sizes of the ground samples. The Karioi Volcanics yield an age range of 2.92 - 2.16 m.y. B.P. and the Okete Volcanics a range of 3.79 - ~~2.08~~<sup>1.80</sup> m.y. B.P.

It is likely, however, from both stratigraphic and erosional evidence that the Okete Volcanics were erupted over a longer period than these dates suggest. For example, while the Wharaurua Plateau basalt is very deeply eroded and is consistent with its date of 3.79 m.y. B.P. (Briggs, pers. comm.) some of the scoria cones in the Te Mata area appear much younger, since well bedded, weakly weathered scoria still remains, and may be as young as 0.5 m.y. B.P.

Although the oldest date recorded for Mt Karioi is 2.92 m.y. B.P., volcanism may have commenced earlier than this, as the lavas dated at Jacksons Cut (2.92 m.y. B.P.) are not the oldest on the volcano. The date of 2.31 m.y. B.P. from the andesite dyke at the summit, probably marks the culmination of volcanic activity as the dyke appears to have

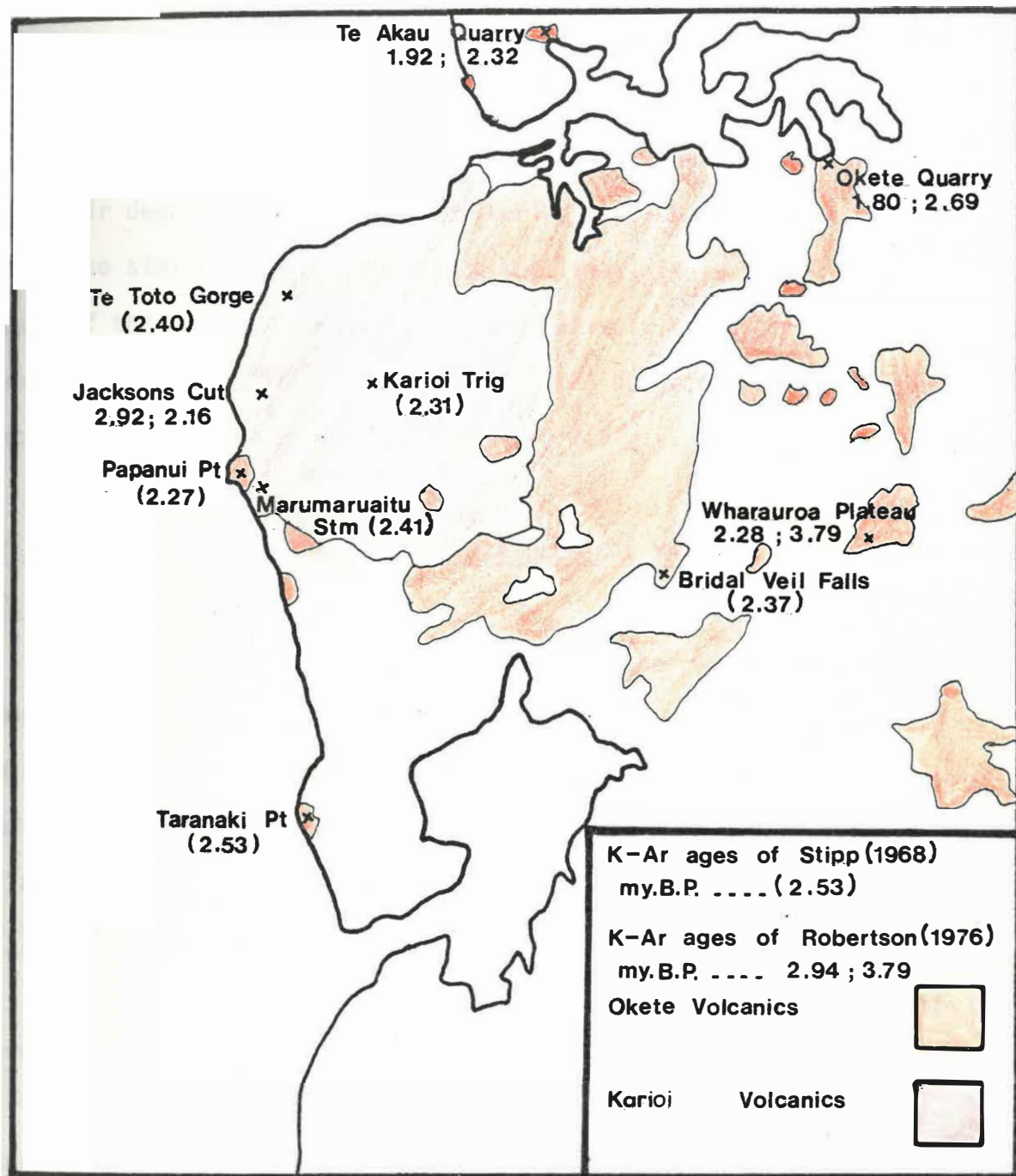


Fig. 2.3 - Ages of the Karioi and Okete Volcanics in the mapping area (Stipp, 1968 data in brackets, and Robertson, 1976 without brackets. Ages in millions of years before present.).

cut all previous lava flows and was a late differentiate phase of eruption.

It is likely than, that activity on Mt Karioi occurred over a somewhat shorter period than that for the Okete Volcanics, but it is still likely that volcanic activity lasted about one million years. However, considering that the lavas throughout the volcano are similar in their degree of erosion and weathering, and the lahars on the surface are also similar in this respect to the lavas, it is likely that the bulk of the activity occurred over a relatively short period, perhaps about 2.4 m.y. ago. Stipp (1968: 202) suggested that eruptions occurred over 0.3 m.y., from 2.6 m.y. to 2.3 m.y. ago.

## 2.3 STRATIGRAPHIC SUMMARY OF THE GEOLOGICAL MAP

### 2.3.1 Introduction

The base map used for construction of the geological map (see map pocket) of the study area was produced from enlargements taken from N.Z.M.S. 1 topographical map (N64, 1971) and drawn initially on a scale of 1:12,650. This was subsequently reduced to 1:20,000 after the final draft had been prepared.

### 2.3.2 Stratigraphic Summary

A stratigraphic summary of the geological units mapped in the area is presented in Table 2.2.

The oldest rocks outcropping in the immediate vicinity of Mt Karioi (and the presumed basement beneath Mt Karioi) are Te Kuiti Group limestones and sandstones. They crop out at 15 - 30m above sea-level in topographical lows along streams or in estuaries. Immediately south of the area at Taranaki Point they occur (probably Waitatuna Limestone) extensively along the coast over a distance of 2.5 km and up to 60 m a.s.l. While the Te Kuiti Group rock types present, such as limestones, sandstones, or mudstones, are mapped as one unit because of their limited extent in the area, possible formations present are

TABLE 2.2 - Stratigraphic Summary of Mapping Units

GROUP	FORMATION	LITHOLOGY	AGE
Undifferentiated		Recent alluvial gravels, sands, muds and swamp deposits	Recent
Kaihu Group	Undifferentiated	Fixed sand dunes	Pleistocene
UNCONFORMITY			
Alexandra Volcanic Group	Okete Volcanics Formation (n. fm.)	Olivine basalt lava, tuff and scoria	Plio-Pleistocene
	Karioi Volcanics Formation	Lahars	Pliocene
		Andesite dykes	
		Andesite lavas	
		Volcanic breccia	
Basalt lava			
Undifferentiated		Epiclastic siltstones, sandstones and conglomerates	Pliocene
MAJOR UNCONFORMITY			
Te Kuiti Group	Various Formations (see Chapter 3.10.2)	Glauconitic and calcareous sandstones, siltstones and limestones	Oligocene

postulated in Chapter Three (see Table 3.2).

Eipclastic sediments occur at numerous places in the coastal sections and are of varying thickness and extent in the mapping area. These are sufficiently widespread to be mapped as a separate unit.

The Karioi Volcanic Formation is subdivided into several members: basalt lavas, andesite lavas, andesite dykes, volcanic breccias and lahars. The lahars, which only occur on the surfaces of the lower flanks of Mt Karioi, are represented as an overshadowed area on the map above the basalt lavas, which are volumetrically the major component.

It has not been the intention of this thesis to study the Kaihu Group which have been described in neighbouring areas by Chappell (1964, 1970) and Pain (1976). Any sand deposits of significant size (mostly Kaihu Group) have been mapped as fixed sand dunes of undifferentiated formations.

Recent stream deposits of gravels, sands, muds and swamp deposits are shown as one combined unit. In many places, particularly in the east, the area is covered thinly by tephra deposits derived from the Central North Island and Taranaki areas, but no attempt has been made to map or distinguish them.

## CHAPTER THREE

### DISTRIBUTION AND STRATIGRAPHY

#### 3.1 INTRODUCTION

An understanding of the distribution of the geological deposits of an area and their relationship to one another, is fundamental to all geological studies and especially so in the study of the history of volcanic deposits.

This chapter incorporates most of the detailed field work completed in the course of this thesis, in particular the work done on the coastal sections, and discusses the main rock types, their size, distribution and field relations. A reference list of all the samples referred to in the text is displayed in Appendix IV, showing field number, location and rock type.

#### 3.2 CROSS SECTIONS

##### 3.2.1 Introduction

Eleven cross-sections have been drawn to give a visual insight into the stratigraphy of these deposits, and are included in the back map pocket. Their field location is shown in Fig. 3.1.

The following section describes the location and stratigraphy of each cross-section and the relationship of its geology to the surrounding area. The geological units themselves are discussed in later parts of this chapter.

##### 3.2.2 Section A - Tauranga Trig

This section occurs on the southern end of the headland which is located south of Whale Bay. Henderson and Grange (1926) referred to a

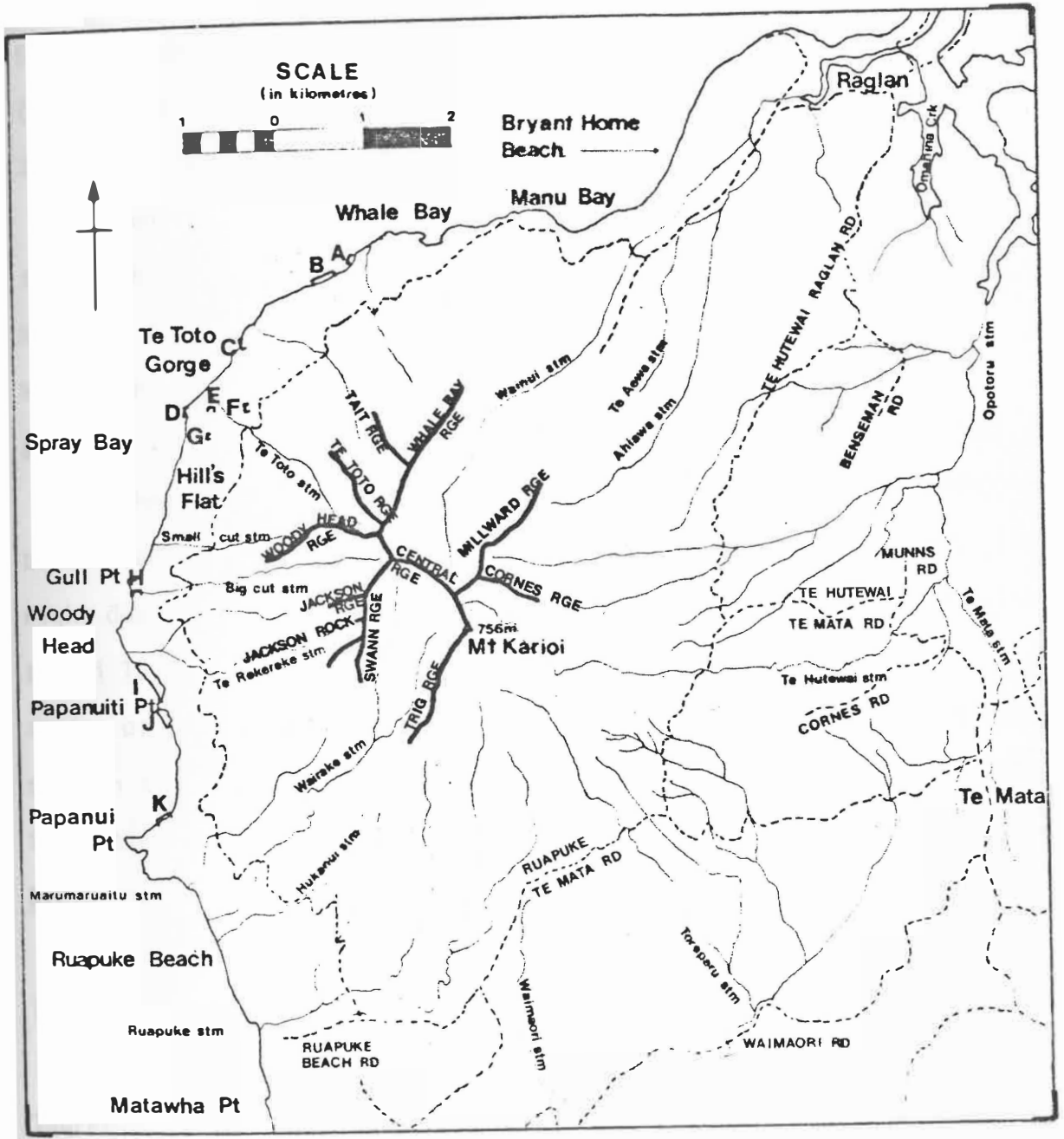


Fig. 3.1 - Physiography of Mt Karioi region showing main ridges and section locations.

Tauranga Trig on the highest point of this headland, but this is not shown on modern maps.

Thin olivine basalt lava flows crop out from Bryant Home Point to Manu Bay. From Manu Bay to Whale Bay, Karioi flows with typically large clinopyroxene phenocrysts occur. These lavas are thin and generally scoriaceous and appear to be the distal margins of flows. South of Whale Bay the flows are overlain by a thin coarse grained Karioi basalt flow (W17017) and a 12 metre thick Karioi porphyritic basalt lava flow (Fig. 3.2) which makes up the bulk of the Tauranga Trig headland.

Henderson and Grange (1926) described three rocks in this area for which they had chemical analyses. It would appear that analysis No. 9 is the thick Karioi porphyritic basalt flow (W17018), analysis No. 10 the underlying thin coarse grained Karioi basalt (W17017) and analysis No. 13 the underlying Okete olivine basalt lava flow (W17020).

The section itself shows the underlying Okete lava flows with brecciated and scoriaceous margins, which continue throughout the section right down the coast past the Tait section and are overlain by the thick Karioi lava flow of the headland. The coastal cliffs are made up of a series of thin Karioi flows which overlie the Okete lavas. In this section a series of tuffs and tuff breccias overlie the Okete lavas and intercalate with the lower Karioi flows.

### 3.2.3 Section B - Tait

Tait section lies on a fairly inaccessible piece of coastline 150 m south of Tauranga Trig section.

The section is typical of the two kilometre part of coastline from Tauranga Trig to the northern tip of Te Toto Gorge. Okete olivine basalt lava flows occur at the bottom of the section and are overlain by Karioi breccias, lapilli tuffs and tuffs. Karioi lavas, on average 5 m thick, overlie and intercalate with the pyroclastics and continue to the top of the cliffs.

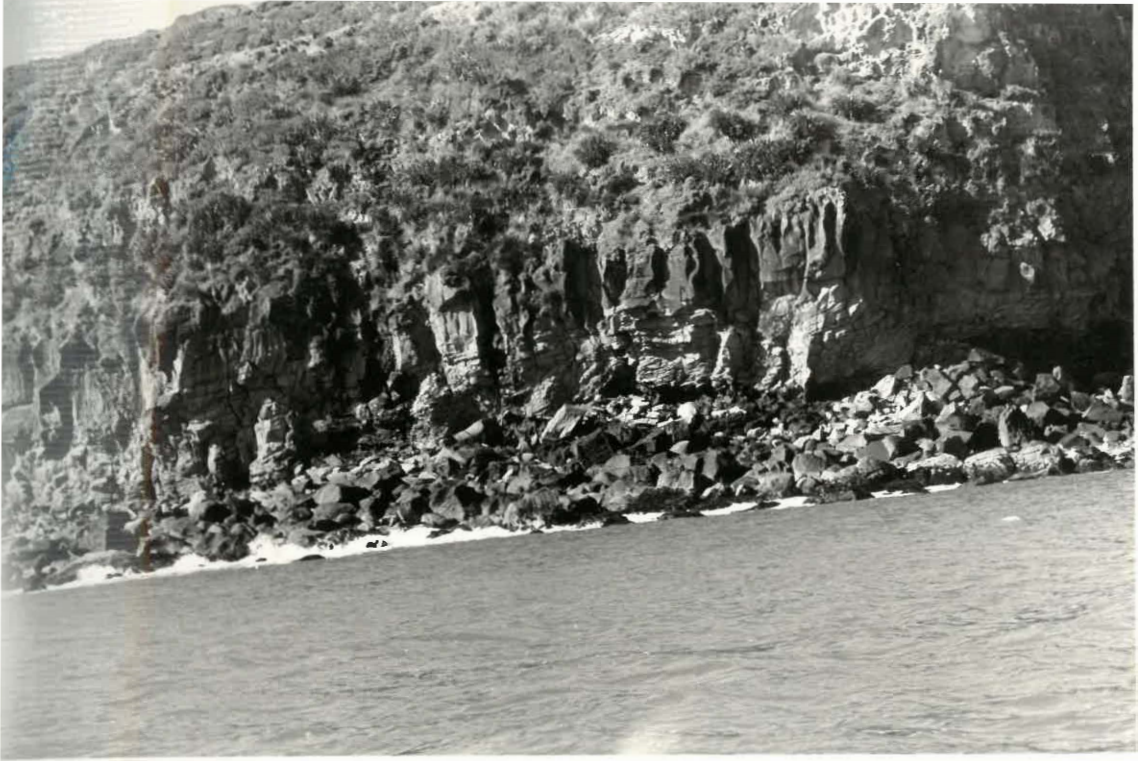


Fig. 3.2 - 10 m thick Karioi basaltic lava flow south of Whale Bay. The lava flow shows platy jointing at the base grading into blocky and finally columnar jointing at the top.

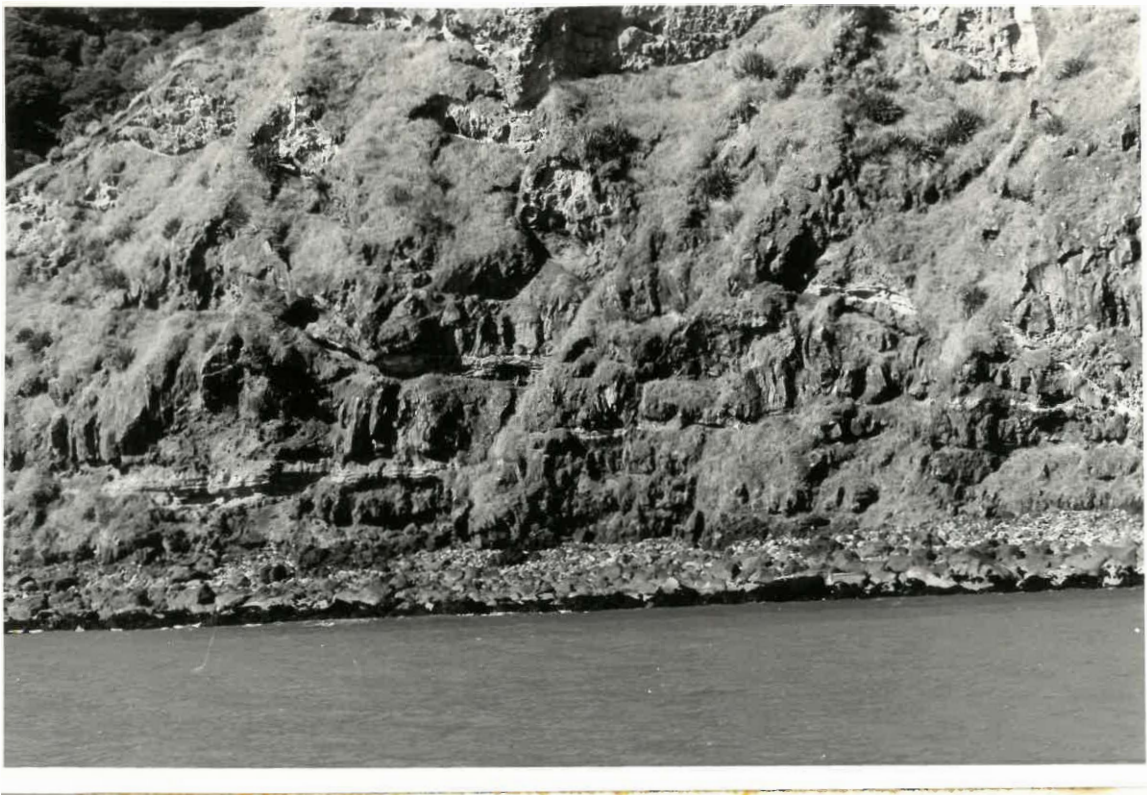


Fig. 3.3 - Typically small fault with 2 m displacement in Karioi basaltic lavas and tuffs at Tait Section (see Section B).

Small faults, striking both north-east and south-east with only centimetre to several metre displacements are typical of this area and occur frequently throughout the section (Fig. 3.3). One fault at the southern end of the section has downthrown the lavas so the Karioi lavas outcrop at the bottom of the section, instead of the stratigraphically lower Okete lavas.

Okete lavas are exposed in the bottom part of the section to the south and continue to the northern tip of Te Toto Gorge.

#### 3.2.4 Section C and D - Te Toto Northern Cliffs and Te Toto Southern Point

These two sections, one kilometre apart on opposite sides of the Gorge are stratigraphically similar but have some interesting differences.

Section C exposes epiclastic siltstones and sedimentary conglomerates at the coast level. These are overlain by an Okete olivine basalt lava flow which is seen at various points westward and inland on the grassed slopes of the Gorge (for example at W17135). The section is dominated by a series of thin flows with the typical brecciated upper surfaces. Thin (one metre) layers of lapilli tuff may occur (W17010) underlying some of the lava flows, and indicate that ash eruption often preceded the outpouring of lava.

Section D is stratigraphically similar to Section C, as columnar jointed Okete lava crops out within the cliff section (W17043), and as a prominent point on the beach (W17042), beside and below the epiclastic sediments. The epiclastic sediments range from well sorted siltstones and sandstones to chaotic conglomerates. The feature of the section is an Okete olivine basalt dyke which intrudes the sediments (see Chapter 3.5.2). Karioi lapilli tuff and a thin Karioi lava flow overlie the epiclastic sediments and are in turn overlain by a much thicker (10 m) Karioi coarse grained basalt flow with a well developed coarse columnar jointing, and a series of thin Karioi lavas with brecciated upper surfaces.

### 3.2.5 Section E - Te Toto Remnant

This outstanding structure of well-bedded and well-sorted epiclastic sediments capped by a Karioi tuff and basaltic lava flow lies on the middle of the sloping plain of the Te Toto Gorge, 400 m from the southern point. It is stratigraphically similar to Section D and probably represents an erosional remnant. This would imply that the cliffs of the gorge did at one time extend down to the coastline.

### 3.2.6 Section F - Te Toto Vent

This section shows a volcanic vent that is presumed to be the site of a former flank eruption of Mt Karioi.

The Te Toto vent site is situated right beside Te Toto stream just as it opens out from the Gorge into the semi-circular bay which slopes down to the beach (Fig. 3.4). Evidence for a vent here is seen by the steeply dipping lavas (W17041, W17044), volcanic breccias and pyroclastic deposits (Fig. 3.5, 3.6). The lavas dip  $50^{\circ}$  southeast and have thick brecciated, scoriaceous surfaces. The rock is a coarse grained Karioi basalt lava which is petrographically distinct from the lavas in the Te Toto Northern and Southern sections.

Airfall tuffs underlie the dipping lavas and are also found underlying a massive breccia to the south. They are crystal-rich lapilli tuffs which contain small angular rock fragments (generally less than 1.5 cm). The tuffs vary from ash to lapilli size and may contain occasional blocks which are more common near the wavy, upper contact with the overlying lavas and breccias. The airfall tuffs dip at low angles of  $20^{\circ}$  or less, generally to the east, in contrast to the epiclastic sediments which dip off the mountain to the west (compatible with a fluvial or marine origin).

The airfall tuffs are overlain at the southern end of the section by a massive chaotic volcanic breccia, which is also exposed in the low lying basin-like area to the west (Fig. 3.4). The breccia is massive, clast rich and contains angular blocks of lava and scoriaceous material.

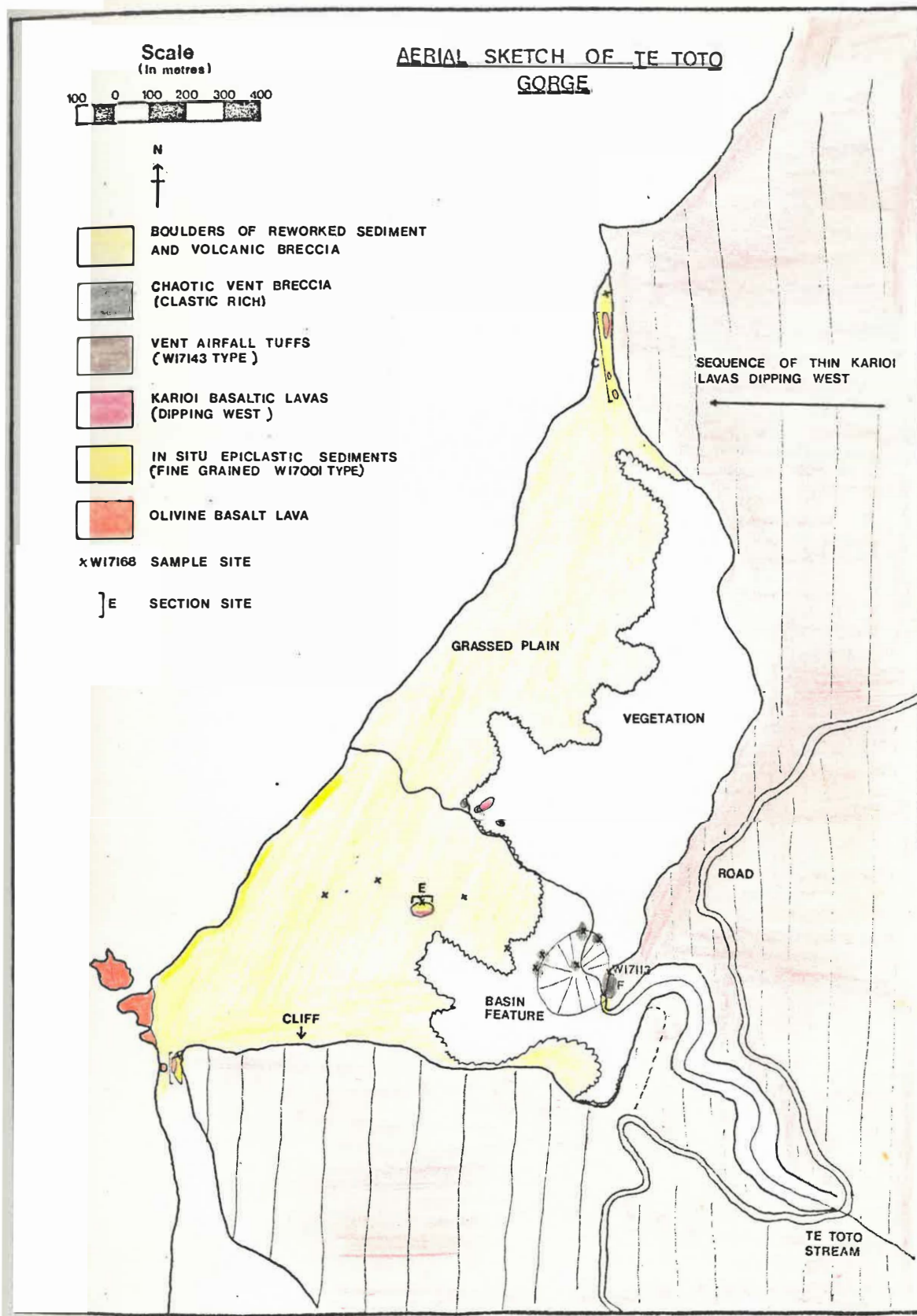


Fig. 3.4 - Aerial sketch of Te Toto Gorge showing main physiographic and geology features relevant to Te Toto vent site.



Fig. 3.5 - Steeply dipping lavas, brecciated lavas and volcanic breccias of the Te Toto Vent site (geological hammer, bottom left for scale).



Fig. 3.6 - Airfall tuffs from Te Toto Vent site overlain by volcanic breccia and brecciated lava (geological hammer for scale).

These deposits are interpreted as being vent breccia material derived from explosive phreatomagmatic eruption. A further deposit of this volcanic breccia is also found 600 m northwest of the Te Toto Vent site which indicates volcanic material was ejected for considerable distances.

A second type of volcanic breccia is also seen in the gorge area as large boulders west of the basin towards the beach. This breccia is crystal-rich, reddish-orange, and contains small clasts of both Karioi and Okete Volcanics. The origin of this deposit is unknown, although the presence of olivine basalt clasts and finer ash material suggests that it may be a volcanic breccia erupted from Te Toto Vent that has been reworked and deposited by fluvial or marine processes.

There is little evidence to suggest that the vent deposits were intruded or erupted through pre-existing lavas since there is no shattering or baking of the lavas, or any dykes exposed. It would seem likely then that these cliffs were eroded back to much the same position as they are at present, before the Te Toto flank eruption occurred.

Thus the volcanic products of this site (Section F) most likely represent a section through a volcanic vent. The vent itself probably lay to the southwest of these deposits at Section F and perhaps is marked by the basin-like feature at Te Toto (Fig. 3.4).

It would appear that if any deposits were erupted from this vent to the west, south or north of Section F, that they have been subsequently eroded, probably by fluvial and marine action.

### 3.2.7 Section G - Spray Bay

Immediately south of Te Toto Gorge is a small bay with similar topographical and geomorphological features to the Gorge itself. The cliffs are not right on the coastline but are set back inland in a semi-circular fashion with a grassed slope rising up to them from the shore.

The section is drawn in the middle of the Bay 500 m from the coast and 150 m a.s.l. The cliffs here are only 10 m high and expose an unusual sequence of sedimentary deposits. At the bottom, a conglomerate

of fine grained massive ash-sized material with clasts (5 cm) of limestone, chert, olivine basalt and siltstone, is overlain by a massive brown compacted siltstone with a blocky outward appearance. The siltstone is in turn overlain by a reverse bedded conglomerate which contains well bedded sands at the base and grades upward into a poorly bedded conglomerate with clasts up to 50 cm in diameter. A reddened lapilli tuff and a sequence of Karioi lava flows with brecciated upper surfaces are then exposed to the top of the section.

Epiclastic sandstones are exposed on the gentler grassy slopes of the Bay. Below the section and on the southern cliffs of the bay a 20 m thick sequence of conglomerate stratigraphically underlies Karioi lavas. It appears then that Section F, in the middle of the Bay represents the upper contact of this conglomerate with the Karioi lavas.

The Karioi lavas have numerous interbedded tuff deposits which are particularly prominent on the northern cliffs, reaching 4 m in thickness. The thick Karioi lava flow seen on the lower part of Section D is also exposed on these cliffs.

The thick sedimentary conglomerate can be traced south of Spray Bay from Hills Flat to Gull Point, and dips (approximately  $25^{\circ}$ ) to the west. Thick olivine basalt lavas crop out on numerous rocky points from Spray Bay to Gull Point for example W17047.

### 3.2.8 Section H - Big Cut Stream

Immediately south of Gull Point, Big Cut Stream which has cut an impressive gorge through the lavas, reaches the coast and falls to the beach over a 20m high waterfall.

This section shows a sequence of lavas exposed by the stream above the waterfall. In particular there are some platy jointed lavas which are rarely seen in the Karioi Volcanics. A sedimentary conglomerate occurs at stream level dipping gently to the west. Higher up in the valley, the road cutting exposes more lava and extensive lahar deposits.

### 3.2.9 Section I - Woody Head to Papanui Point

This long section of 350 m shows a great variety of deposits. The beginning of the section at the southern end of Woody Head exposes the thick flows typical of the cliffs around the whole of Woody Head.

As the coastline turns more north-south epiclastic sediments are exposed underlying the Karioi lava and vary from well-bedded sandstones to chaotic conglomerates. These epiclastic sediments contain abundant Karioi volcanic detritus and augite crystals, and dip at a variety of angles which suggests a changing depositional environment. To the south these sediments are gradually overlain by a sequence of thin Karioi lavas which extend almost right throughout the cliff section.

Immediately underlying the Karioi lavas is a well-bedded, thin white siltstone (W17142 - see chapter 3.9.5) that dips to the north, and is underlain by a sedimentary conglomerate composed of numerous angular large boulders of volcanic breccia, lava and tuff. Further south a Tertiary mudstone is exposed for 90 - 100 m along the beach and is subsequently overlain by a massive Okete volcanic breccia containing clasts of basalt and limestone set in a fine matrix. Both the breccia and mudstone show small-scale faulting.

### 3.2.10 Section J - Papanuiti Bay

This section occurs on the southern side of Papanuiti Point immediately south of Section I. The main feature is the extensive outcrop of Okete volcanic breccia seen in the previous section. The breccia occurs at beach level at the northern and southern ends of Papanuiti Bay. Epiclastic sediments are exposed in the middle of the Bay and are both underlain, and overlain by the breccia, and in the lower sediments (W17126) the breccia actually intrudes from within the bedded deposits. The volcanic breccia is very hard and compacted and shows both a crude columnar jointing and some bedding in places. The geology of this deposit is discussed in Chapter 3.7.2.

Slumped epiclastic sediment and lava overlie the breccia and these have moved from higher up the cliff where Karioi lava and finally lahar deposits occur. On the southern extremity of the section Tertiary siltstone and sandstone crop out at beach level.

A small stream south of this section follows the Homestead Fault (see Chapter 9), where a thick sedimentary sequence forms 100 m high cliffs to the south of the stream. The epiclastic sediments continue southwards for 800 m but are unconformably overlain by Karioi lavas and at Papanui Point the lavas continue from the beach right up the cliff.

### 3.2.11 Section K - Papanuiti Point

This section is on the northern facing cliffs of Papanui Point which is the site of a large Okete volcanic olivine basalt centre.

The section shows thick Karioi lavas (W17137) at beach level in contrast to the thinner flows on the beach north of Papanui Point. The Karioi lavas are overlain by two thick Okete olivine basalt lavas which show well developed columnar jointing. The contact between the Okete and Karioi lavas is very straight and initially appears faulted but olivine basalt lapilli tuff occurs on the contact below the Okete lava and this would have been disrupted if faulting had occurred.

Karioi basalt lava flows overlie the Okete olivine basalt lavas at the top of the cliff section on the grassy upper slopes of the Point and these are covered by a mantle of Pleistocene sands (Kaihu Group).

## 3.3 BASALTIC LAVAS OF MT KARIOI

The bulk of the volcanic deposits of Mt Karioi are porphyritic basaltic lavas. They are exposed on the coast from as far north as Bryant Home Beach to Marumaruitu Stream in the south and over most areas of the mountain itself, inland to Te Mata and Waimaori Road.

Typically these lavas are thin (1.0 - 2.5 m) and contain a highly brecciated scoriaceous upper margin, probably caused by the autobrecciation of the lava flows, and is typical of moving basaltic lavas which cool as they pass down the slopes of a volcano (Parsons, 1968).

Up to 20 such thin flows can be seen at Te Toto Gorge (see section C and D), with occasional interlayered tuff deposits (Fig. 3.7). These flows generally show a blocky jointing with a very poor development of columnar jointing. Several slightly thicker lava flows (3 - 4 m) at Big Cut Stream show a well developed horizontal platyjointing at the base which grades up into a zone of blocky jointing and finally into a brecciated upper surface.

However, in some places on the coast, for example Spray Bay, Woody Head, and Tauranga Trig, the flows may be up to 12 m thick and thus fewer individual flows are exposed together. These flows tend to show good platy jointing at the base, developing into a blocky jointing in the middle section with columnar jointing at the top (Fig. 3.8).

Generally Karioi flows tend to thicken toward the summit of Mt Karioi, seen for example, in several streams such as Te Toto or Hukanui streams where small gorges have exposed 6 - 8 m thick flows. Flows on the upper ridges are also well exposed and are of similar thickness.

At the base of some coastal sections the Karioi basalt flows are seen to stratigraphically immediately overlie either volcanoclastic sediments or olivine basalt lavas. As Karioi basalt flows are also seen on the surfaces of the upper flanks of the volcano they would seem to make up the bulk of Mt Karioi.

None of the lavas found on the coast show any pillow structure or glassy selvages, which led Stipp (1968) and Chappell (1970) to suggest that the lavas at Papanui Point flowed over a dry surface and did not come into contact with the sea. This may not be the case however, certainly for the Karioi aa lavas which would have travelled



Fig. 3.7 - Te Toto Gorge Northern Cliffs with Karioi basaltic lavas and occasional interbedded tuff (reddy-brown) with underlying Okete olivine basalt lava and epiclastic sediments (in grass). Cliffs are approximately 75 m high.



Fig. 3.8 - Close up of Karioi basaltic lava flow south of Whale Bay (Fig. 3.2). Platy jointing at bottom of flow grades into blocky and coarse columnar jointing at top.

over three kilometres from a summit vent and could have cooled considerably, and may not have formed pillow lavas even if they reached the sea.

While it seems likely that most of the flows were terrestrial, the evidence for either situation is not clear, and to use the criterion of absence of pillow lavas to indicate that sea level changes occurred between flows at Papanui Point (Stipp, 1968; and Chappell, 1970) and to base a Plio-Pleistocene boundary on this information (Stipp *et al.*, 1967) may be unfounded.

From projection of present landforms it is likely (see Chapter 3.11) that lava flows originally continued a further 300 m west of the present coastline.

### 3.4 BASALTIC ANDESITE AND ANDESITE LAVAS OF MT KARIOI

Petrographically these two groups can be distinguished on chemical and textural grounds (see Chapter 4.4). However, this distinction is not always possible in hand specimen in the field, and the basaltic andesites are gradational with both the basalts and the andesites. On the geological map (see back pocket) these have not been distinguished and only basalts and andesites are shown. However, the distinction between basalts and basaltic andesites can be made on the upper ridges of Mt Karioi where there are clearer exposures, and this is shown in Fig. 3.9.

#### 3.4.1 Andesite Lavas

Andesite lavas occur exclusively on the upper ridges of the mountain (above 600 m) and appear to be a late phase of eruption.

The andesites are exposed at the Trig (W17070, W17071) as a dyke (Chapter 3.5) but everywhere else occur as lava flows. On Millward Ridge a hypersthene andesite (W17016) is exposed as a platy jointed lava flow intercalated between breccias. Hypersthene andesite also occurs on the Woody Head Ridge (W17082) as an 8 m thick outcrop of whiteish lava.

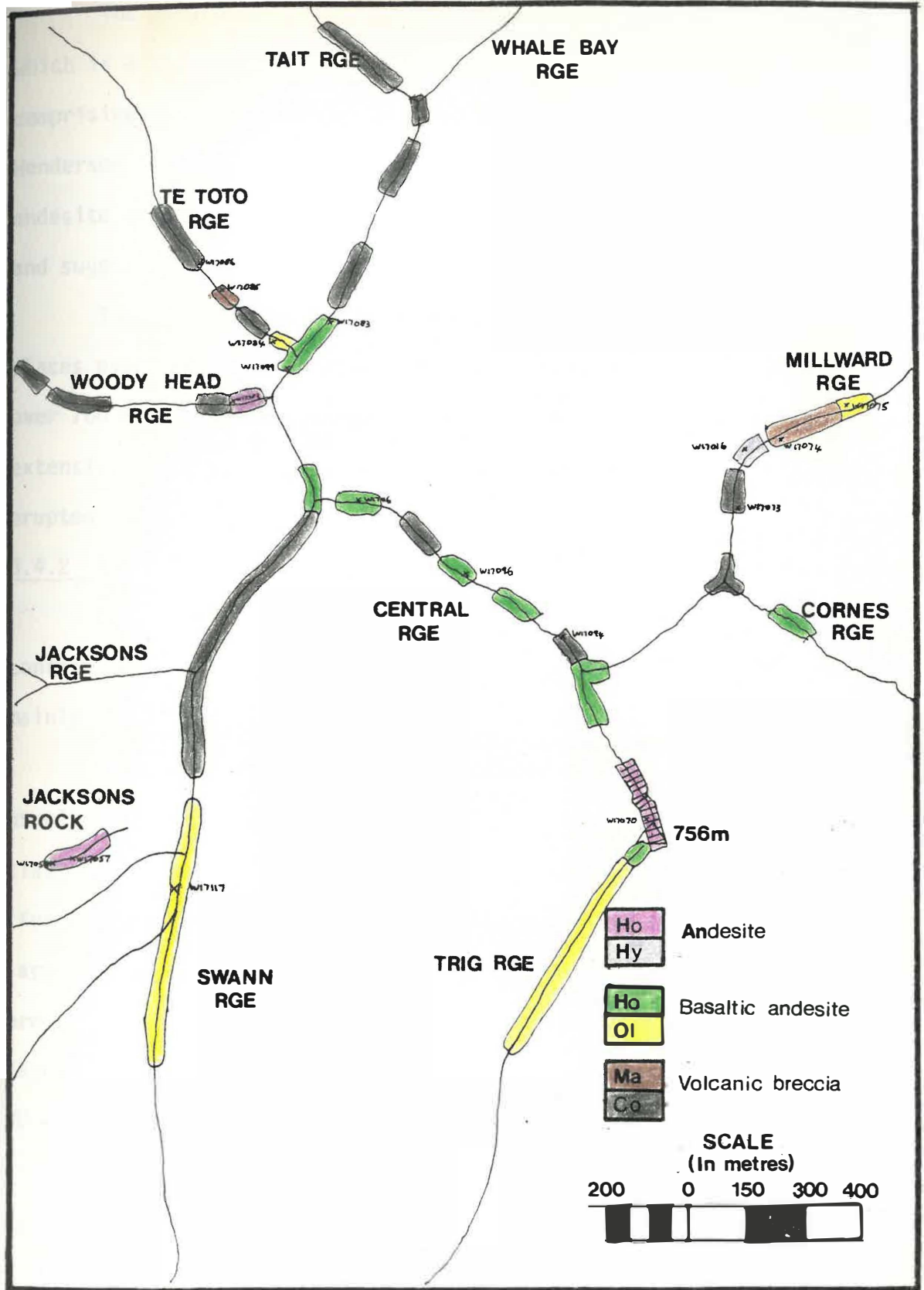


Fig. 3.9 - Geology of the upper ridges of Mt Karioi, with important sample sites (Karioi basalt is any blank area, Ho = Hornblende, Hy = Hypersthene, Ol = Olivine, Ma = Matrix rich, Co = Compact). See Chapters 3 and 4 for full explanation.

The only other andesite lava is at Jacksons Rock (W17057, W17059) which is a prominent outcrop, with 30 m high walls at its western end, comprising hornblende andesite which contains numerous cognate xenoliths. Henderson and Grange (1926) describe an olivine hornblende basaltic andesite at Jacksons Rock which may occur at the bottom of the outcrop and suggests that the rock is composed of several lava flows.

The distribution of these andesite outcrops at four different places over the mountain approximately 1 kilometre apart, 3 of which are over 700 m in altitude, tends to suggest that the andesites were more extensive than presently exposed. This is quite likely as they were erupted last, and therefore the first to erode.

#### 3.4.2 Basaltic Andesite Lavas

These rocks are similar in colour to the andesites but usually contain olivine phenocrysts and have a coarse groundmass. They are mainly confined to the upper ridges of the mountain.

On Central Ridge hornblende basaltic andesite predominates and usually overlies basaltic lavas, or may be intercalated with indurated clast-rich breccias. Flow banding is evident in some hand-specimens (for example W17116) and hornblende megacrysts are often exceptionally large (up to 5 cm). Cognate xenoliths are also common. The lavas and breccias along this ridge have been eroded and exposed in an unusual fashion with a series of four large remnant outcrops standing up to 20 m high above the main line of the ridge.

Hornblende and hypersthene basaltic andesites occur in lava flows up to 6 m thick on Whale Bay Ridge, particularly near Woody Head and Te Toto Ridges (for example W17083, W17084, W17099).

Olivine basaltic andesites with accessory hornblende and hypersthene occur predominantly on Trig Ridge (for example W17069, W17068, W17072) north and south of the andesite dykes, but are also present on all the other main ridges (for example W17117, W17075).

Olivine hornblende basaltic andesites are also found overlying the Okete olivine basalt lavas at Papanui Pt. Hornblende hypersthene basaltic andesites above the main headwater branch of the Oporuru Stream, and olivine hypersthene basaltic andesite on Mr M. Sweetman's property, occur on the eastern side of the mountain as lavas, boulders and lahars (for example W17078, W17087, W17102).

### 3.5 DYKES

#### 3.5.1 Andesite Dyke

A hornblende andesite dyke is exposed at the Trig at the summit of Mt Karioi. The dyke outcrops 10 m south of the Trig and continues north for approximately 150 m striking in a north-west direction (average  $148^{\circ}$ )

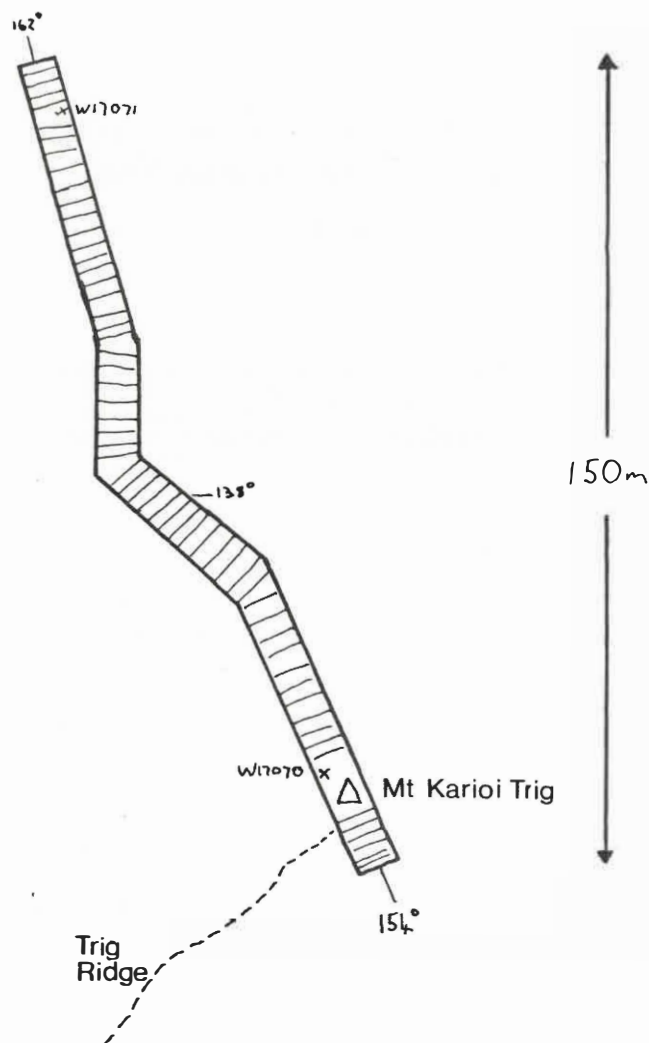


Fig. 3.10 - Andesite dyke at Mt Karioi Trig showing varying directions of strike.

The dyke varies in strike from  $135^{\circ}$  to  $155^{\circ}$  NW (Fig. 3.10) and crops out almost continually along the 150 m but is best exposed at the northern end. (Fig. 3.11). Jointing is mainly across the dyke, but varies from  $081 / 87^{\circ}$  N and  $087 / 75^{\circ}$  N to  $048 / 85^{\circ}$  N. The dyke is only 1 - 2 m wide but at the Trig may be 3 m wide. To the east a vertical drop of 30 m occurs.

Henderson and Grange (1926) stated that the highest point of the mountain consists of a system of radiating dykes but only this outcrop at the Trig has positively been identified as a dyke.

### 3.5.2 Basalt Dykes

Basaltic dykes have been found at two localities on Mt Karioi. Firstly, at the Homestead Fault area south of Papanuiti Pt, a 1 m thick Karioi basalt dyke (W17036) intrudes along a fault plane (Fig. 3.12). The country rock adjacent to the fault shows considerable comminution and slickensiding.

Secondly, at Te Toto Southern Cliffs a basalt dyke (see section D) introduces through an olivine basalt lava flow and continues through sedimentary conglomerate stopping below a series of Karioi lavas. The boundary between the dyke and conglomerate is sharp and near this contact the conglomerate is brecciated, chaotic and appears baked. The olivine basalt dyke (W17045, W17114) is petrographically distinct from the underlying olivine basalt lava flow (W17043) but is similar to the Tait Section Okete olivine basalt lavas (for example W17133). The dyke then must have been intruded after the deposition of the underlying Okete olivine basalt lava flow (W17043).

## 3.6 PYROCLASTIC DEPOSITS OF MT KARIOI

### 3.6.1 Introduction

The pyroclastic deposits will be classified here according to the nomenclature of Schmid (1979), which essentially follows Fisher (1961, 1966) (Table 3.1).



Fig. 3.11 -  
Andesite dyke on Trig  
Ridge, 150 m from the  
summit of Mt Karioi.  
Horizontal jointing is  
prominent below geological  
hammer.



Fig. 3.12 -  
Karioi basaltic lava  
(W17036) extrudes at  
Homestead fault along a  
small stream south of  
Papanuiti Bay.  
Geological hammer lies  
on a dyke and the  
country rock (Karioi  
lavas) to the left shows  
slickensiding and  
shearing effects.

TABLE 3.1 - Classification of pyroclastic rocks (after Schmid, 1979).

Clast Size (average)	Pyroclastic Fragments		Pyroclastic Deposit
64 mm	Bombs Blocks		Pyroclastic Breccia
	Lapilli		Lapilli Tuff
2 mm	Coarse Fine	Ash	(ash) Tuff
1/16 mm			

Pyroclastic deposits of mixed sizes are also classified according to Schmid (1979) for example lapilli-tuff breccia. The airfall deposits of this type as well as conventional tuffs and tuff breccias will be described first. The rest of the coarser deposits of volcanic origin will be considered as volcanic breccias (as classified by Wright and Bowes, 1963 and updated by Parsons, 1968) and subdivided according to their genesis.

Epiclastic rocks are discussed in Section 3.9.3. Parsons (1968: 266) considered that "interfingering of, and gradation between cone facies and epiclastic facies rocks is common and dissection of these facies is often a major problem in studying and mapping volcanic rocks", and while this is true with the Mt Karioi rocks, the epiclastic facies were not formed by volcanic processes and as such cannot be considered as 'volcanic' breccias but rather as true sedimentary rocks (cf Fisher, 1963).

### 3.6.2 Airfall Tuffs and Tuff Breccias

Airfall deposits from Mt Karioi are limited in their thickness and distribution and are only seen in high cliff sections or some road cuttings. Typically, only 3 to 4 thin (50 cm) deposits are seen within a series of up to 20 lava flows (30 - 40 m in height).

In some cases, airfall deposits are well sorted and may be mainly of one size range. For instance W17011 at Te Toto Northern Cliffs is a 40 cm thick tuff, composed of moderately sorted coarse ash sized material which contains mainly crystals, crystal fragments and ground up fragments. A similar tuff also occurs in Section D (probably the same as W17011 as it lies in a similar stratigraphic position).

However, airfall deposits are more commonly of mixed sizes, are poorly sorted, and can be described according to Schmid (1979) as ash-lapilli tuff, tuff breccia, or lapilli tuff breccias. Above Papanuiti Pt lying under the lowest Karioi lava is a thick 4 m deposit of tuff breccia, composed of mainly ash sized material but large clasts of up to 20 cm in diameter are set within the fine matrix. This grades into a well sorted tuff in the top 30 to 40 cm. Lapilli tuff breccias are the most common airfall deposit on Mt Karioi, frequently intercalated between lava flows. They are generally 3 - 4 m thick and contain large blocks and smaller lapilli sized rock fragments set in an ash matrix (Fig. 3.13).

Lapilli tuffs are also common and are very similar to the tuff breccias and lapilli tuff breccias, but vary in the size of the clasts present. Clasts in the lapilli tuff at Tait's Section are subangular, average 2 cm in thickness with the largest lapilli reaching 5 cm and are set in a coarse crystal rich ash matrix (Fig. 3.13).

Frequently, the pyroclastic airfall deposits grade one into the other and commonly form a sequence of units. The tuff breccia in Tait Section is one of these multiple event deposits. Fig. 3.14 shows that this deposit is composed of tuffs, lapilli tuff and tuff breccias.

These beds typically show inverse graded bedding within each unit.

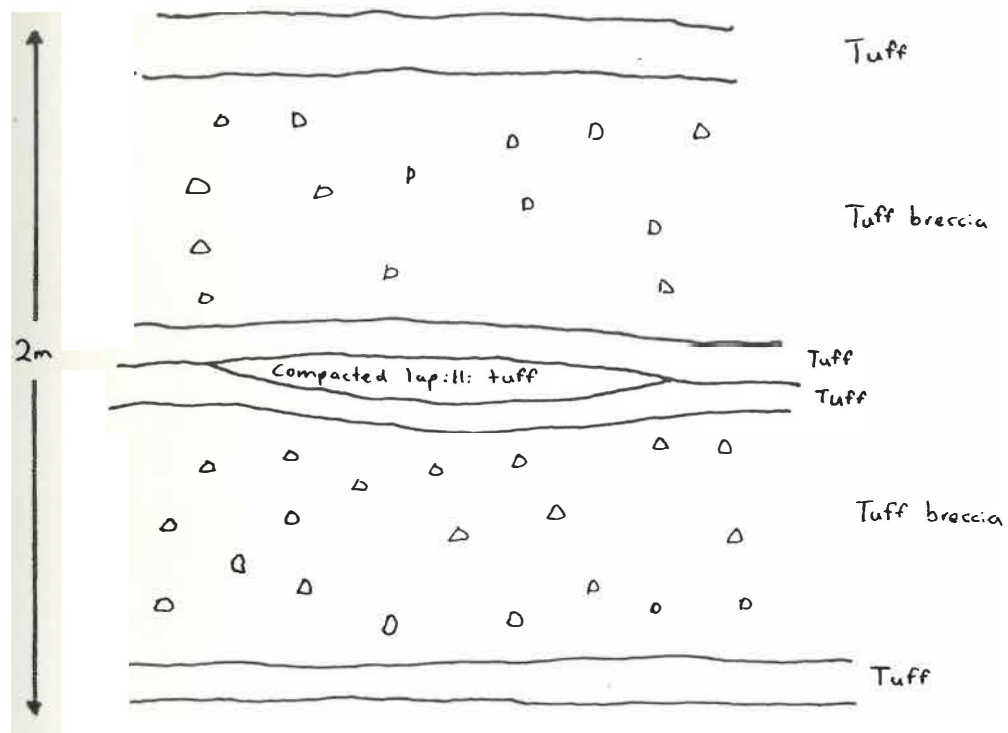


Fig. 3.14 - Tuffs and tuff breccias in a multiple event deposit, Tait Section.

Some tuffs and tuff breccias may reach 4 m in thickness although this is not frequent. Deposits of this size are generally tuff breccias or mixed deposits as above (Fig. 3.15).

The airfall deposits of Mt Karioi follow the general trend of basaltic volcanoes and strombolian eruptions (MacDonald, 1972) by forming an initial explosive component which precedes a lava flow. The airfall component is small in volume and may not occur with each outpouring of lava. The hot lava flow then overrides the airfall ash and lapilli, compacting, reddening and baking it to produce the characteristic sequences as shown in the coastal cliff sections and Fig. 3.4.

### 3.6.3 Pyroclastic Breccia - Matrix Rich

In two places on the mountain large deposits of massive matrix-supported breccia occur. The most conspicuous deposit is at Tamahine O Karewa Peak on Millward Ridge where the breccia is 25 m thick at the



Fig. 3.13 - Lapilli tuff at Tait Section with interbedded tuff layer (brown layer). Clasts are up to 5 cm across and crystal fragments common.



Fig. 3.15 - Karioi tuff between two Karioi basaltic lava flows. Tuff is approximately 4 m thick and reddened at the top by baking effects of the overlying lava flow.

south-eastern end, and 100 m thick on the western face. Lava and interbedded breccias occur at the northern end of the outcrop.

The breccia at the southern end is composed of two separate events. The bottom deposit is 3 m thick, massive, matrix-rich, fine grained and monolithological with clasts averaging 2 - 3 cm comprising vesicular basalt which contains large augite phenocrysts. The matrix is a crystal rich coarse ash, with large crystals of augite, and smaller crystals of olivine, plagioclase and hypersthene.

The overlying breccia is at least 15 m thick, massive and monolithological but contains larger (up to 7 cm) and more abundant clasts and rarer augite crystals.

The second outcrop of this deposit is on Te Toto Ridge (W17085) at a similar altitude where it occurs as a 15 m thick massive deposit. Clasts of Karioi basalt are up to 60 cm across and predominate at the base of the deposit.

The origin of these outcrops of volcanic breccia is unclear. Because of their height on the mountain and thus presumed closeness to source (Fig. 3.9) they may represent deposition from a central crater during the same event. The deposit has a basaltic nature and emplacement probably occurred by an explosive airfall eruption immediately before or during the period of the late phase of andesitic activity.

#### 3.6.4 Extensive Indurated Breccias

The breccias formed by the autobrecciation of Karioi lavas have been discussed in Chapter 3.3. These are very extensive and occur in all sections on the upper surfaces of the lava flows, and contain much scoriaceous and vesicular basaltic material.

However, on the main ridges (Fig. 3.9) a different hard, clast-rich (70 - 80%) matrix supported breccia occurs (Fig. 3.16) with clasts up to 30 cm in size. The matrix is crystal-rich coarse sized ash and the deposits may be multilithological with one dominant lava type or entirely monolithological. These breccias lie in all possible strati-



Fig. 3.16 - Volcanic breccia typical of the compact clast rich deposits found on the upper ridges of Mt Karioi.

graphic positions in relation to the lava flows. This is particularly apparent along Central Ridge (for example W17096) where basaltic lavas are found below the breccia and andesitic alongside it.

The breccias, being close to the top of the mountain, may be the result of an explosive airfall eruption, but they are quite different to the breccias discussed in 3.6.3. Autobrecciation of lavas is the most likely origin as the clasts are variable in size and have the outward appearance of a lava. The multilithological nature of some of the breccias could have been the result of the incorporation of previously consolidated country lava from the walls of the vent and crater, during the eruption.

### 3.7 OKETE VOLCANICS

#### 3.7.1 Introduction

The Okete Volcanics occur as small cones and centres on all sides of Mt Karioi within the mapping area (see Fig. 3.17).

Some of these, such as at Papanui Pt, are distinctive and can be mapped as individual centres. Other Okete Volcanic deposits, particularly in the east, overlap with Karioi Volcanics and the distinction of separate centres is more difficult.

The olivine basalt deposits are best described separately, showing the type and nature of each deposit, the geomorphology and stratigraphic relations in each case.

#### 3.7.2 Coastal Outcrops

Olivine basalt lavas crop out at numerous points right along the coast from Bryant Home Pt to Gull Pt (Fig. 3.17).

Vent breccias may also occur and these will be discussed separately.

#### Lavas

These can be subdivided into two types:

- a) medium grained olivine basalts which contain significant augite phenocrysts and occur as thin lavas with brecciated upper surfaces

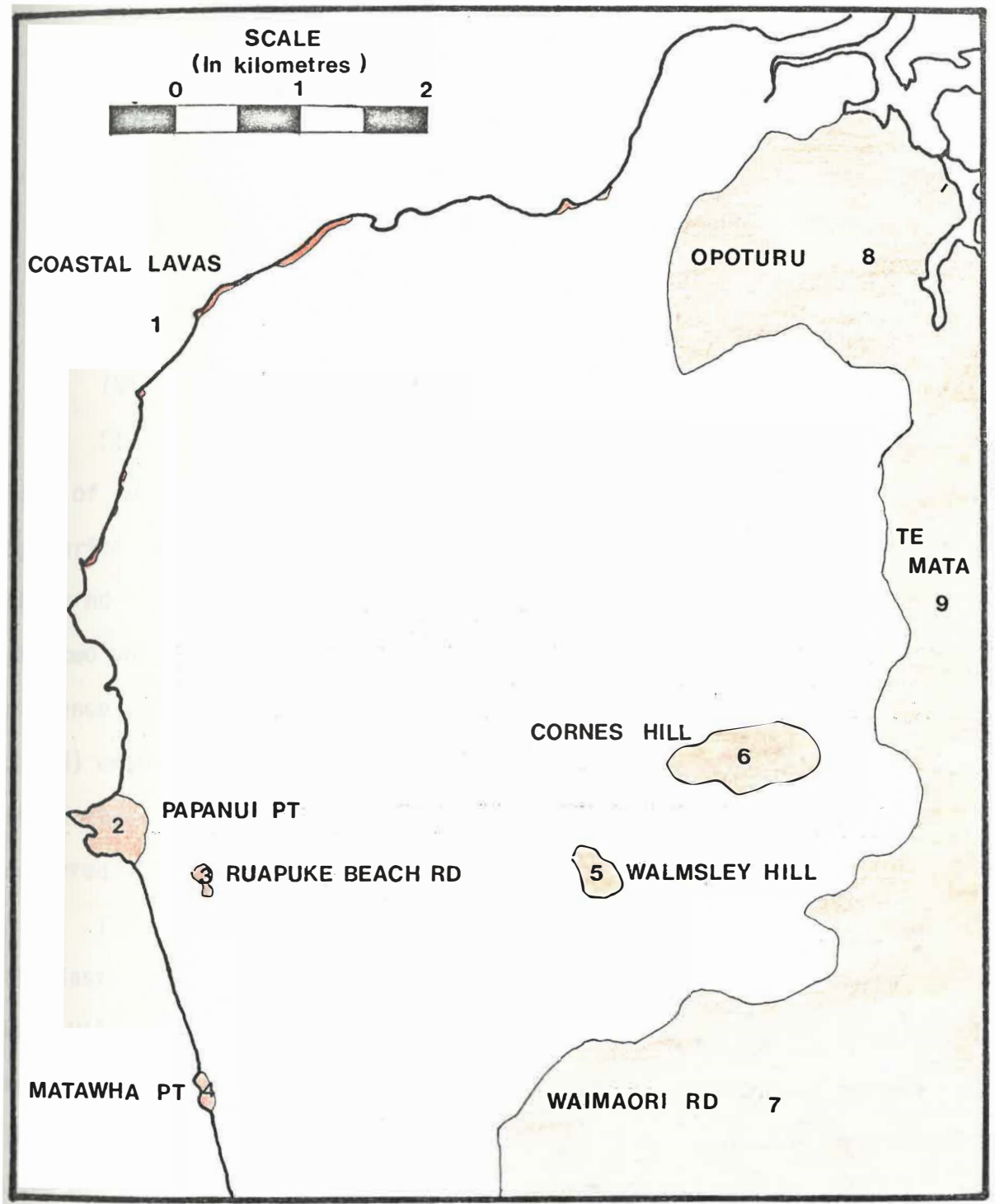


Fig. 3.17 Distribution of Okete olivine basalt centres in the mapping area.

similar to Karioi flows. These differ from the typical fine grained Okete type but contain quartz nodules and olivine megacrysts. They are exposed extensively south of Tauranga Trig section and also outcrop from Bryant Home to Manu Bay (W17003, W17022).

- b) Fine grained olivine basalts which generally form thicker flows, and only one or two flows may occur in an exposure. Typically they have a very fine grained groundmass with a pilotaxitic texture. They are predominantly exposed at Te Toto Gorge (W17012, W17042, W17045) but also occur to the south.

Stratigraphically the olivine basalts generally occur at the base of any one section right on the beach and are generally overlain by Karioi flows. The contact between these flows and the Karioi flows shows no erosional break (see Section A) suggesting that activity of the two volcanic types was almost contemporaneous and in fact stratigraphic evidence is found in a number of places, for example Papanui Pt (see 3.7.3) where Karioi flows both overlie and underlie Okete olivine basalts, which clearly proves that volcanic activity from the two formations occurred over a similar period.

The Okete Volcanic lavas may also be overlain or underlain by epiclastic sedimentary conglomerates (Fig. 3.18), for example Spray Bay, Hills Flat and Te Toto Southern Point. In this case the flows are usually of the second type - thicker flows without brecciated margins. Thick tuffs may also be present (Fig. 3.19). The epiclastic sediments vary widely in their grain size from siltstones, sandstones to conglomerates and may in some places both underlie and overlie olivine basalt lava (for example Te Toto Gorge).

In one section immediately south of Spray Bay (Fig. 3.20) three olivine basalt lavas with brecciated margins are overlain by the blocky margin of a thick W17018 type Karioi basalt flow which itself is overlain by a thick epiclastic conglomerate. The conglomerate also overlies other



Fig. 3.18 - West coast looking south below Hills Flat. Thick (25 m) sedimentary conglomerate with abundant Okete Volcanic clasts, overlies an Okete olivine basalt lava flow. Cliffs in the distance are made up of a series of Karioi basaltic lava flows.



Fig. 3.19 - Okete olivine basalt tuff with overlying lava flow, Te Toto Southern Point.

thin Okete flows that are exposed south of this outcrop up to Gull Pt, and is at least 20 m thick, containing predominantly olivine basalt volcanic detritus with lesser amounts of Karioi fragments.

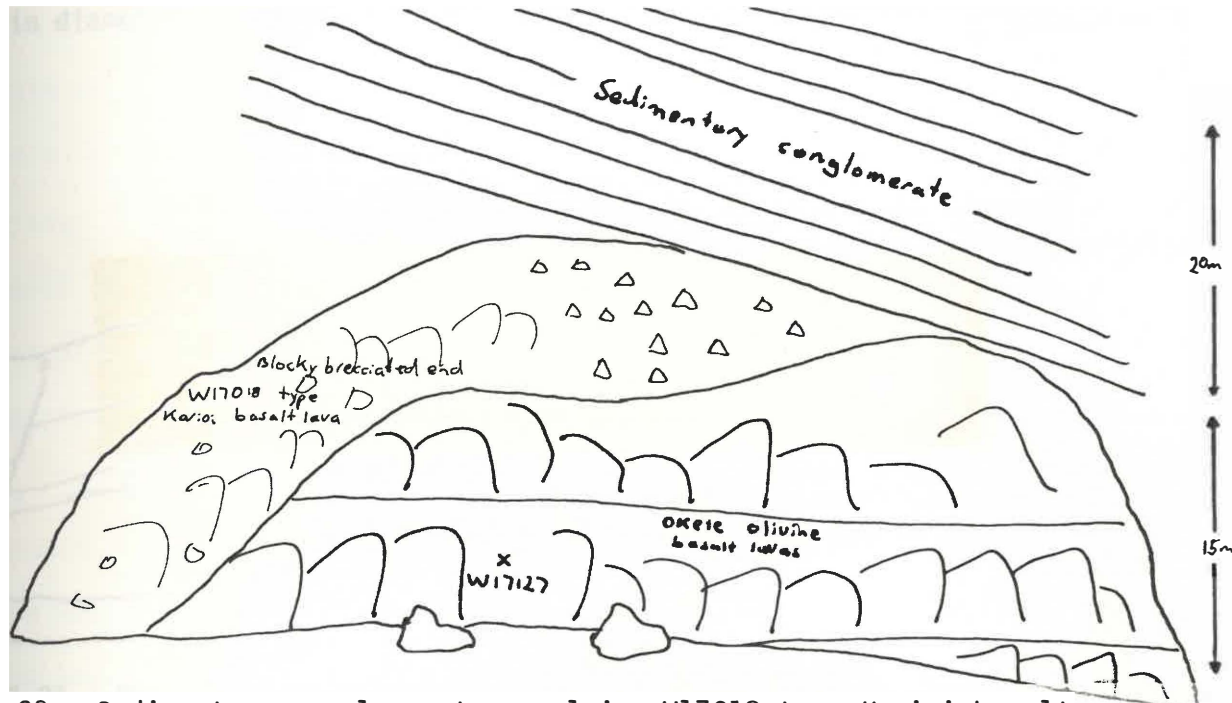


Fig. 3.20 - Sedimentary conglomerate overlying W17018 type Karioi basalt lava flow which is underlain by a series of Okete olivine basalt lavas.

Epiclastic well-bedded sandstones, siltstones and conglomerates are interbedded with thin Karioi lavas at Bryant Home Point (W17003, W17130 - 134). The conglomerate is composed of Karioi basalt lava types which implies that some Karioi lava had been deposited prior to the deposition of the sediments and overlying olivine basalt. The changing sediment size tends to suggest the depositional environment varied rapidly over a short space of time. The sediments have subsequently been faulted and brecciated and in some cases are very disrupted with beds dipping at a variety of angles. Penecontemporaneous deformation was also noted in one outcrop of sediments (W17029).

The volcanic vents from both groups of lavas have now been largely covered by Karioi Volcanics leaving little trace of their location.

#### Okete Pyroclastics

At several places on the coast large amounts of bedded tuff breccia containing olivine basalt fragments occur. It is likely that these outcrops represent volcanic breccia erupted from an olivine basalt

vent.

Firstly, at Bryant Home Beach a well-bedded deposit of fine ash sized material with vesicular clasts of angular olivine basalt (2 - 6 cm in diameter) overlies a poorly bedded breccia (Fig. 3.21)

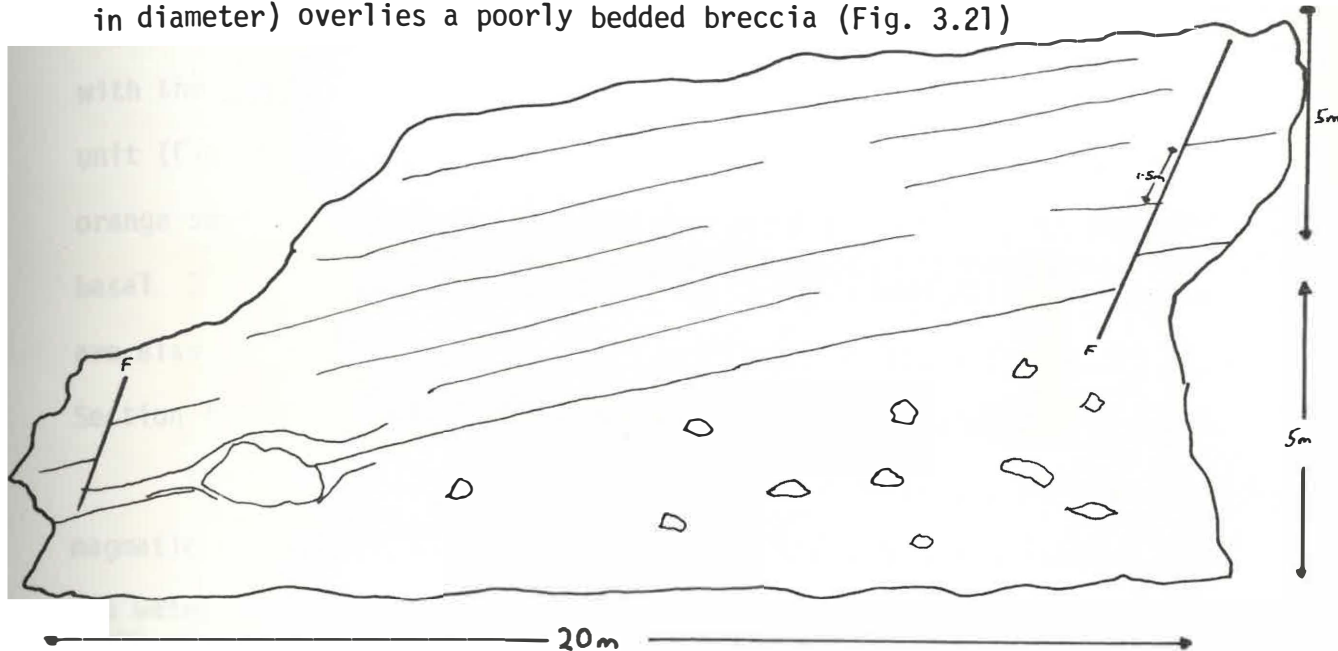


Fig. 3.21 - Okete Volcanics vent deposit, Bryant Home Beach. Bottom unit is from strombolian type eruption while upper unit shows cross-bedding and is of phreatomagmatic origin.

The breccia contains bombs of olivine basalt which in some cases have produced bomb sag features in the immediately underlying pyroclastic layers. The upper unit shows some cross bedding features which may represent the initial base surge phase of eruption from a nearby vent. Small faults also occur throughout the deposit. The monolithological nature, grain size characteristics and presence of fusiform bombs suggests the stratigraphically lower breccia is a strombolian deposit, but the much finer grained, well bedded nature of the overlying deposit appears to be phreato-magmatic deposit of tuff breccia where water has reacted with the magma.

The second deposit occurs at Papanuiti Pt (Section I and J). The point itself is made up of large amounts of angular and vesicular olivine basalt bomb fragments, set in a matrix of glassy ash sized material. The amount of matrix varies greatly throughout the outcrop. A crude bedding can be detected in some places and on the point itself, is strongly dipping to the west. The outcrop across the Bay (W17030;

Section J) shows only limited bedding in some places. Between this outcrop and Papanuiti Pt itself, the deposit appears to intrude through epiclastic sandstones and siltstones. Overall, the deposit is well compacted and has a coarse columnar jointing indicating rapid deposition, with the whole deposit of about 25 m thickness cooling as a simple cooling unit (Fig. 3.22). Xenoliths of Tertiary limestone, siltstone and an orange sandstone (Kaawa Sandstone?) are found particularly in the basal 3 - 4 m of the tuff breccia (Fig. 3.23). Some Karioi fragments are also seen in the exposure which overlies the Tertiary Mudstone in Section I.

This deposit may well be the result of a submarine phreato-magmatic eruption of olivine basalt magma, which came into contact with sea water, probably close to the shore. The xenoliths of limestone at the base of the outcrop may represent the initial blast of activity which cleared the vent of country rock, and the poorly bedded nature is typical of subaqueous deposition of a volcanic breccia (Parsons, pers. comm.). This type of eruption would also account for the nature of the outcrop in Section J where the erupted material may have passed through pre-existing epiclastic sediments (W17126).

A third outcrop of pyroclastic vent material is seen about 1.5 km north-east of Papanui Pt 300 m a.s.l. This outcrop is exposed on the side of a valley as a 20 m thick, hard compacted tuff deposit (W17062, W17134) showing a well defined micro-bedding but has a poorly bedded massive appearance on a macroscale. The deposit is highly deformed, faulted and brecciated. In thin-section phenocrysts of plagioclase, augite and olivine are present in a glassy groundmass (see Chapter 4.5). Calcite is abundant as a secondary cement and accounts for the hard nature of the tuff.

The tuff occurs then in a similar manner to the deposit at Papanuiti Bay, but the size of the material is much finer - only small ( 1.5 cm) rock fragments of olivine basalt, numerous phenocrysts and



Fig. 3.22 - Okete volcanic breccia at Papanuiti Point. The 12 m high outcrop shows limited columnar jointing and was the result of a phreatomagmatic eruption.



Fig. 3.23 - Close up of volcanic breccia in Fig. 3.22. This basal section of the breccia has abundant rounded boulders of limestone and sandstones which are country rock incorporated with the initial volcanic eruptive products.

fine ash material occur. The deposit appears to be of Okete Volcanics type and because of its stratigraphic position must have erupted up through the Karioi lavas from a vent possibly located along a north-easterly fault (see geological map, back pocket).

Another volcanic breccia occurs on the grassy slopes of Spray Bay. It is exposed on the sides and bed of the stream in the Bay and also on a 12 m high bank across the middle of the Bay. A similar breccia may also occur on the slopes of Te Toto Gorge. The volcanic breccia is a very red deposit, generally with few clasts and is mainly made up of compact vesicular, scoriaceous weathered rock and compact ash material.

The amount and size of the clasts varies from outcrop to outcrop, and the deposit has an overall massive appearance. The clasts are mainly Okete olivine basalt lavas but some Karioi Volcanic type are present.

It is likely then this breccia is also an Okete olivine basalt pyroclastic vent deposit derived in a similar manner to the strombolian deposits at Bryant Home Beach and the breccias above Jacksons Cut.

### 3.7.3 Papanui Pt

This is the best exposed olivine basalt centre in the Karioi area. Jutting out from the general northward trend of the coastline, 30 - 50 m vertical cliffs expose well developed columnar jointed olivine basalt flows (Fig. 3.25). Sediments of the Kaihu Formation (mainly sands) mantle the whole of the point (Chappell, 1970).

Flows on the northern side are thick and generally only two can be distinguished along the cliff section. Contacts between flows generally show no scoria or ash and presumably were erupted within a short space of time.

One section on the Northern side (Section K) shows a 1 m thick tuff deposit comprised of scoriaceous lapilli and ash lying on a sharply dipping contact of Karioi lavas. The contact is very straight and sharp (005/25W) and appears to be an unusual erosional surface rather than a fault which would have disrupted any pre-existing ash deposit.

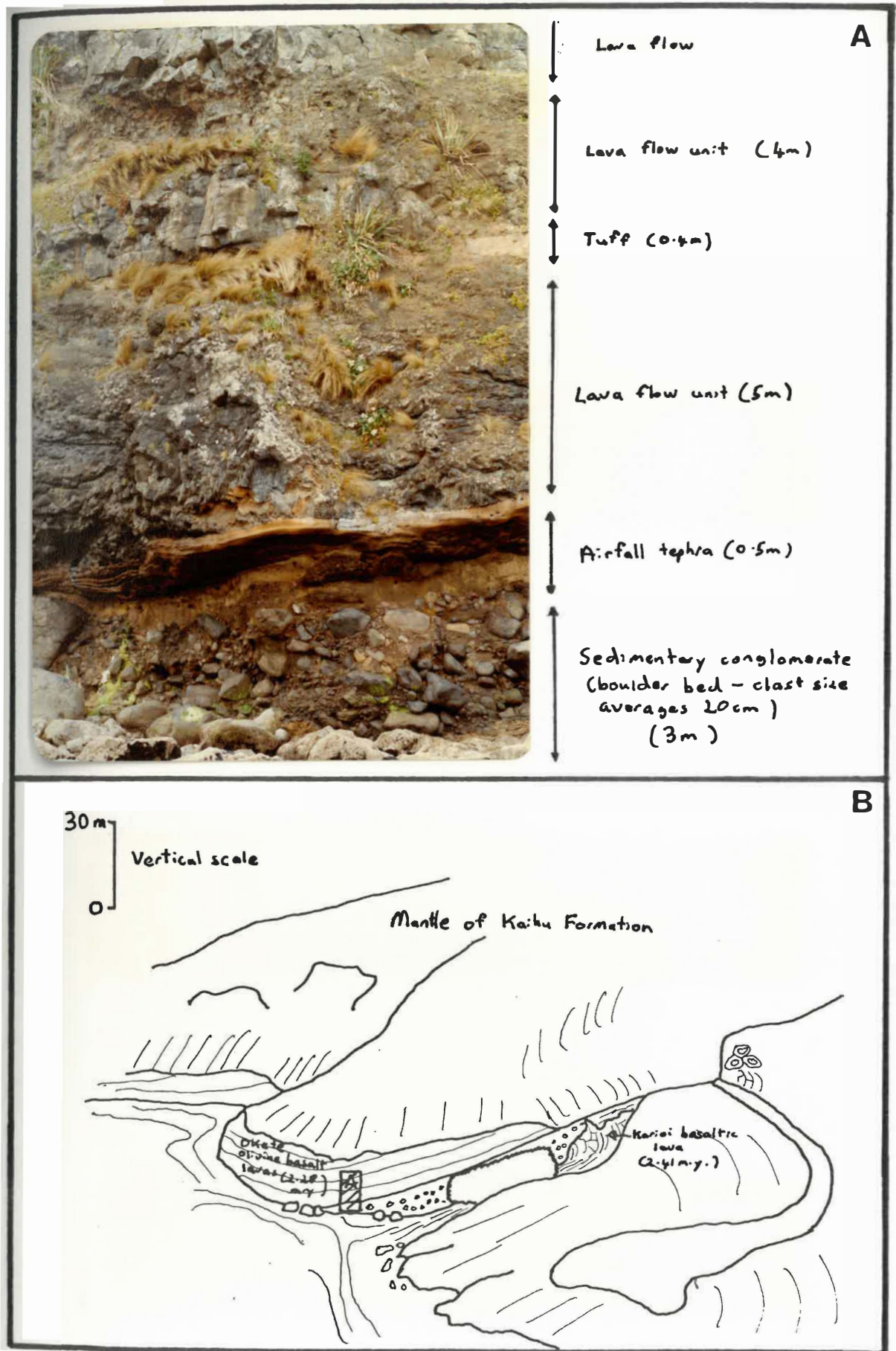


Fig. 3.24 - A. Stratigraphic column at Marumaruitu strm, southern end of Papanui Pt.

B. General view of Marumaruitu section showing underlying Karioi lavas (after Stipp, 1968; Chappell, 1970).



Fig. 3.25 - Northern cliffs of Papanui Point exposing Okete olivine basalt lava flows which show moderately developed columnar jointing.



Fig. 3.26 - Well bedded scoria and deep red regolith from an Okete olivine basalt centre on Waimaori Road.

Flows to the south near Marumaruitu Stream are thinner and at least four 5 m thick flows can be distinguished. The flows often have brecciated upper surfaces and may be underlain or preceded by tuffs. Olivine basalt lava is also seen to overlie a 20 m thick sedimentary conglomerate in some places (Fig. 3.24) and in turn overlies a Karioi basaltic lava flow (W17111) exposed in the waterfall 40 m from Ruapuke beach. The conglomerate is very clast-rich and contains abundant rounded boulders. Stipp (1968), Stipp et al. (1967) and Chappell (1964, 1970) interpret the conglomerate as indicating an oscillation in sea-level of some 20 m (65 ft) as both lavas appeared to have been deposited on a dry surface. Stipp (1968) dated the flows by K-Ar methods at 2.41 m.y. B.P. for the Karioi flow and 2.28 m.y. B.P. for the younger overlying Okete olivine basalt flow. However, evidence that the lavas did in fact flow over a dry surface is debatable and this should be considered in reference to these climatic change studies.

Karioi flows are also seen to overlie the Okete type olivine basalt flows on the Norther Cliffs of Papanui Pt (Section I) as well as underlie them. Thus the olivine basalt centre at Papanui Point erupted, probably localised along a north-striking fault, penecontemporaneously with the time Karioi volcano was active. This is consistent with the stratigraphic evidence seen in other coastal Okete olivine basalt lavas, and suggested both were active at similar times.

#### 3.7.4 Ruapuke Beach Road

This small centre is exposed north of Ruapuke Beach Road and directly west of the road north to Papanui Pt.

The small hill to the west of the road and to the east of a small tributary of the Ruapuke Stream has the bright red clay-loam soil typical of that formed on scoria cones, and is in sharp contrast to the yellow, lighter soils to the west and north formed on sands and those to the east on Karioi basaltic lavas.

Boulders of fine grained olivine basalt are found along the banks of this tributary and further down where it joins the main Ruapuke Stream. In situ lava is found 120 m up the tributary as a 6 - 8 m high remnant stack of lava (W17148).

A further outcrop of in situ lava is exposed right on the Ruapuke Beach Road but this weathered outcrop is coarse grained and texturally distinct and may be, as Player (1958) suggests, part of the Matawha Point centre 1 km further south. However it is considered more likely to be part of a separate centre which is now covered by the high coastal sand dunes south of the Ruapuke Beach Road.

There is little stratigraphic evidence to suggest whether this eruption was post or pre Karioi since there are no contact relations, although a deposit of lahar, with Karioi boulder is exposed on the south side of Ruapuke Beach Road 100 m past the olivine basalt in situ outcrop.

#### 3.7.5 Matawha Point

The olivine basalt centre at Matawha Point is exposed in 20 m high cliffs on the coast 3 km south of Papanui Pt. Two 6 - 8 m high lavas, dipping to the south-east, are exposed at beach level from the northern tip of the Point right around to the southern end. The lava flows show spheroidal weathering and appear to be more eroded than other Okete lavas on the coast. To the north and south the Point is covered by pleistocene sand dunes which are well exposed above the middle of the Point, along with pumice silts of the Kahu Group.

#### 3.7.6 Walmsely Hill

This centre is one of two which occur on the eastern flanks of Mt Karioi volcano, and is completely surrounded by Karioi lavas. Situated on Mr D. Walmsely's farm above the Toreparu Stream, it is recognised from a rise in topography above the gentle planezes of Karioi lavas.

In the field it is distinctive due to the contrasting soil types; the surrounding soils are yellow-brown loams formed from the Hamilton and other recent ashes, but the soils on the centre itself are bright red

coloured clay loams developed on olivine basalt.

Scoria or basaltic ash is not seen but some soil profiles are up to 2 m deep which indicates that weathered airfall deposits from this centre are probably present. In situ lava is found under this deep soil profile (W17101) and many residual boulders are found on the steep flanks of the centre where streams have dissected into the regolith.

Because of the freshness of the deposits and its topographic expression, this centre is believed to have erupted after the Karioi lavas were deposited.

### 3.7.7 Cornes Hill

The second of the two centres surrounded by Karioi lavas is situated at the end of Cornes Road, rising up to 500 m a.s.l. Again it is easily recognised topographically by forming a low angle cone which rises above the gently sloping planezes of the Karioi lavas. In area it is considerably larger than Walmsley Hill (which is 0.5 x 0.5 km) being about 1.3 x 0.75 km.

Only residual boulders of fresh Okete olivine basalt (W17104) have been found, along with some weathered brown rock outcrops and 3 m thick red soils probably formed on a scoriaceous and ash parent material.

It is not possible to determine whether the olivine basalt erupted before the Karioi lavas and hence flowed around it or whether the lavas erupted up through pre-existing Karioi lavas. On geomorphological grounds both are possible.

### 3.7.8 Waimaori Road

A number of Okete olivine basalt lava and scoria outcrops are exposed in the southern part of the mapping area, south of Waimaori Road.

The general topography, geomorphology and soil types distinguish the Waimaori Road area of olivine basalt deposits from the southernmost extent of the Karioi lavas. However, as with the Opotura and Te Mata areas, the separation and distinction of these deposits and centres is

out of the scope of this thesis and only outcrops of interest are discussed.

In the main branch of the Toreparu Stream large amounts of in situ olivine basalt lava (W17029) forming extensive rapids and waterfalls 500 m before the stream enters the Toreparu Swamp. This is a fine grained lava similar to Cornes Hill (W17104) and Ruapuke Beach (W17146).

Further up, on the northern side of the road, the Toreparu Stream has cut through a series of olivine basalt lava flows with a tuff in between (W17115). Some 30 m across the road more lava and also well-bedded scoria and ruff are exposed (Fig. 3.26).

### 3.7.9 Te Mata Basalts

To the east of Opotoru River the land rises quickly to over 150 m on the Mangatawhiri Road and all traces of Karioi lava are lost. Okete olivine basalt boulders, in situ lava, bedded scoria and ash are all in evidence especially on road cuttings. The deposits are exposed over several kilometres in all directions and probably many separate centres exist (see Fig. 2.2, Chapter 2).

### 3.7.10 Opotoru

The area immediately south of Raglan West township forms at least one other Okete Volcanic centre. In situ outcrop is limited but geomorphology and soils are again ideal indicators.

Weathered lavas and bedded tuffs are exposed on the Te Hutewai Road south of Raglan and in situ lava is confined to the foreshore of Omahina Creek arm of the Opotoru Estuary (W17118, W17119) and to the waterfalls flowing into the western side of the upper parts of the estuary (W17076, W17077). Lava outcrops tend to be small with no visible scoria and vary from fine grained to coarse grained types.

Stratigraphic evidence east of the Ahiawa Stream (Fig. 3.27) where Okete olivine basalt lavas surround Karioi lavas suggests that the olivine basalt centre is younger than Mt Karioi. The Opotoru clearly stands higher above the Karioi lavas to the west and has flowed westward surrounding a remnant outcrop of Karioi basalt lava (W17066) in the side of a bank.

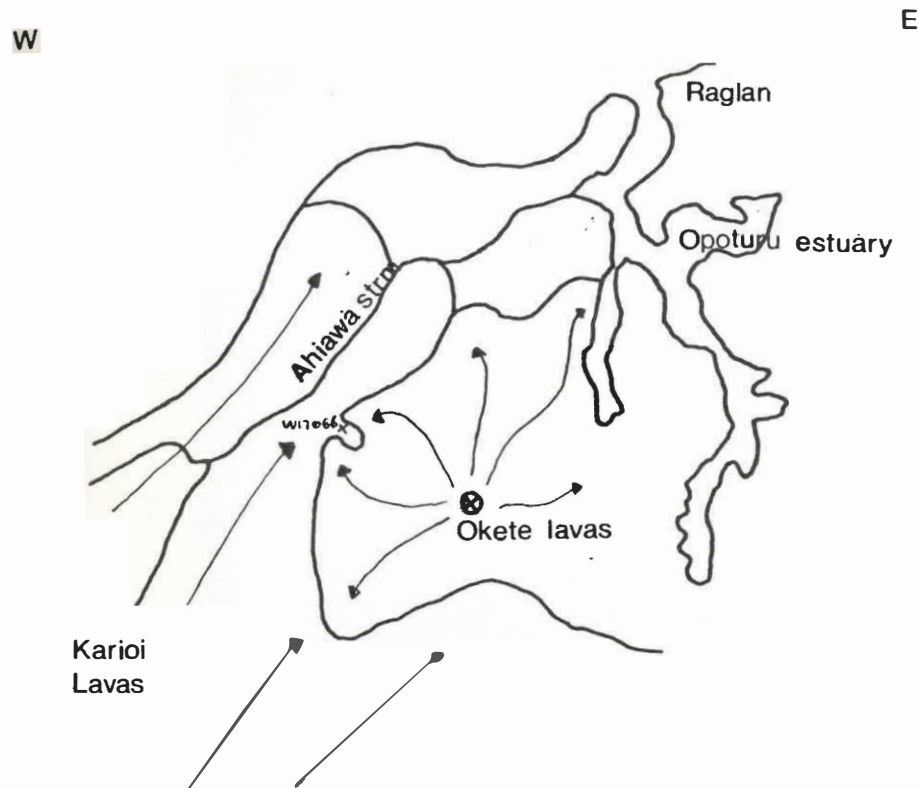


Fig. 3.27 - Oporuru Okete Volcanics olivine basalt centre showing direction of flow of lavas and 'enclosed' Karioi lava.

### 3.8 LAHARS

Lahar deposits (as defined by Mullineaux and Cradwell, 1962) outcrop in several places around Mt Karioi.

Lahars occur at Woody Head on the coastal cliffs overlying sedimentary conglomerate and volcanic breccias. The same deposit is also well exposed some 100 m inland on a road cutting above Big Cut Stream where 8 - 10 m high outcrops occur (Fig. 3.28). The lahars generally occur at the surface, overlying Karioi lavas but at Woody Head road cut (W17149), lahar also underlies lava.

Similar, but more clast-rich lahars outcrop on road cuttings above Manu Bay and on the eastern side of the mountain up the main tributary of the Oporuru Stream. On Mr T.L. Sweetman's farm near Te Mata, 5 km from Mt Karioi Trig, a cutting in a farm track exposes a lahar with boulders of chert, andesite and basalt.

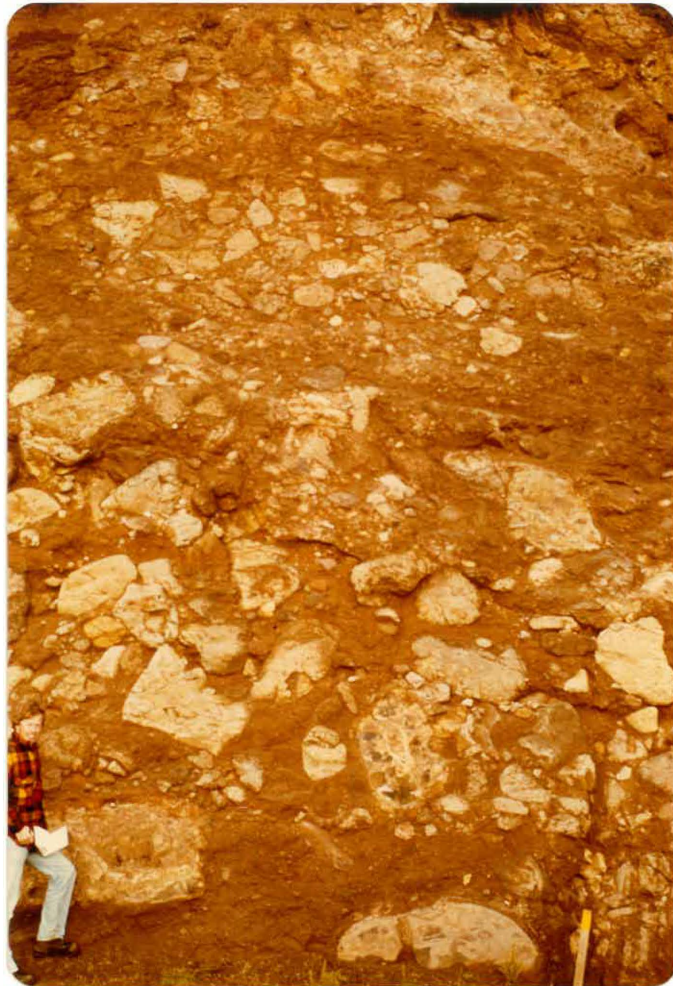


Fig. 3.28 - Lahar deposit in a road cutting at Manu Bay. Large angular blocks occur at the bottom which tend to grade upwards into smaller blocks.

The lahars are never extensive and can not be traced for any great distance up the flanks of the volcano. This is common of most lahar deposits, for example those on Mt Egmont (Neall, 1974) and is probably due in part to their comparative ease of erosion relative to hard compact lava flows, and also because it is in these higher areas of the mountain that such a mud and water filled deposit would originate and flow from.

The lahars are thick (generally more than 8 m) and are always found at the surface, on the stratigraphically upper parts of the sequence and contain clasts up to 1.5 m across (average 0.5 m) and appear in the field to be bimodal in their grain-size distribution with small 5 cm average sized boulders also abundant. The clasts are set in a fine matrix of crushed volcanic detritus. Clasts are often well weathered and outwardly have a soft appearance but corestones of fresh material are always found. The lahars are usually dominated by one rock type or lava flow type but with several accessory types also occurring. The percentage of clasts varies from 50 - 75%.

It would appear that most of the lahar deposits, particularly those on the coastal sides, occurred soon after and perhaps during the late stage of eruption when vegetation was limited and runoff from the mountain would be potentially high. An origin induced by heavy rain as suggested by Neall (1976) is envisaged for their emplacement.

### 3.9 SEDIMENTARY ROCKS

#### 3.9.1 Introduction

A detailed study of the sedimentary rocks of the area is beyond the scope of this thesis. Only a brief description of the nature and distribution of the Te Kuiti Group rocks, epiclastic sediments and Recent sediments can be given here.

### 3.9.2 Te Kuiti Group

These rocks are exposed in several areas and can be discussed conveniently in terms of five geographic regions.

#### (1) Raglan Oxidation Ponds

Glauconitic sandstone occurs in a 10 m high bank above the Raglan oxidation ponds and fossiliferous, calcareous sandstone and limestone boulders litter the western side. These boulders are probably material removed during construction of the ponds and hence probably stratigraphically underlie the glauconitic sandstone in the embankment.

#### (2) Opotoru Estuary

On the coastline of the estuary immediately south of the Raglan-West bridge there are numerous outcrops of flaggy limestone (W17121, W17122), a sandy limestone (W17124, W17125), and a massive blue-grey siltstone (W17123). The flaggy limestone occurs on several of the main promontaries in the estuary and occurs right at sea level or very close to it. Okete olivine basalt lava overlies and surrounds most of these outcrops. The siltstone crops out just outside the mapping area in the Kaitoke Creek arm of the estuary and is very obvious as a large 20 m high bank above the beach containing 15 m of siltstone with an overlying deposit of olivine basalt tuff. A limestone also occurs in the Kaitoke arm of the estuary but varies from the flaggy limestone in the rest of the estuary as it is silty, sandy and more massive.

These outcrops all occur at beach level and never together so that stratigraphic relations can only be inferred. The massive siltstone which is probably a stratigraphically lower unit than the other rocks (see Table 3.2), may occur at similar levels because of a north-south fault through the Kaitoke arm. The extent of these outcrops is limited (see geological map) and is certainly not as extensive as shown by Henderson and Grange (1926).

(3) Waimaori Road

A more extensive outcrop of limestone and sandstone occurs near the sharp bend in Waimaori Road, where it intersects the Waimaori Stream. The outcrops are very flaggy (Fig. 3.29) and range from 3 - 4 m to as much as 8 m in height close to the Waimaori Stream where caverns are present and the surrounding land has sinkholes and other typical Karst features.

(4) Coastal Outcrops

In several places along the coast at beach level, for example Woody Head, Papanuiti Bay, Te Toto Gorge grey mudstones occur which appear to be Tertiary in age. The most extensive outcrop occurs south of Woody Head (Section I) and is a blue-grey massive to finely bedded mudstone, exposed at beach level for over 30 m, where it is at least 4 m thick. Fresh-water springs are common throughout the outcrop and small faults are abundant. A more sandy and silty outcrop is exposed south of Papanuiti (Section J).

(5) Te Mata

In a small tributary of the Te Mata Stream immediately north of the Te Mata school are fossiliferous and calcareous sandstones. A greeny black calcareous, glauconitic siltstone also occurs. Te Kuiti Group beds are difficult to classify and fit into a stratigraphic sequence especially if only one or two limited outcrops of single lithologies occur in an area. Table 3.2 lists a possible stratigraphy for the Te Kuiti Group beds found in the mapping area. This has been deduced from the nature of the beds and from the literature discussing Te Kuiti Group rocks in nearby areas (for example Player, 1958; Kear, 1960, 1966; Kear and Schofield, 1959, 1964; Nelson, 1978).

TABLE 3.2 - Possible stratigraphy of Te Kuiti Group beds found in the Mt Karioi area (Classification after Kear and Schofield, 1959; and Nelson, 1978).

FORMATION	MEMBERS OR BEDS FOUND IN THE MT KARIOI AREA	LOCATION (see text)
TE AKATEA FORMATION	Calcareous mudstone Basal sandy limestone (Raglan limestone) Glaucinitic brown siltstone	Coastal outcrops Opotoru Estuary Oxidation Ponds
AOTEA FORMATION	Calcareous sandstone Glaucinitic sandstone Waitetuna limestone member (Kawhia limestone)	Oxidation Ponds " " and Waimaori Rd
WHAINGAROA SILTSTONE	Medium blue-grey, calcareous mudstone	Opotoru Estuary

### 3.9.3 Epiclastic Sediments

These sediments vary in their composition, grain size, distribution and degree of bedding and can be divided into a number of groups according to these factors.

#### Sedimentary Conglomerate

This is the most common type and is exposed in thicknesses varying from 1 - 50 m. They crop out extensively at coast level from south of Spray Bay to Gull Point and also at Woody Head Beach where they overlie olivine basalt lavas and underlie Karioi lavas. At Hills Flat (W17047 site) the deposit is at least 50 m thick although the angular basal surface of the conglomerate suggests it may be partly of slump origin.

The sedimentary conglomerates are generally massive and matrix-supported with clasts of olivine basalt and Karioi lavas, (Fig. 3.18 Section 3.7.2), and in some cases are clast dominant as at Papanui Pt and Bryant Home where boulder beds occur (Fig. 3.24, Section 3.7.3).

#### Well Bedded Sandy Sediments

Interbedded with the conglomerates on the coast in some cases (Section C and D), and further inland in others (Section E - Te Toto Gorge, Spray Bay, Woody Head to Papanuiti Point) are varying thicknesses (4 - 15 m) of well bedded sandy sediments containing much volcanic detritus.

In nearly all cases the deposits dip to the west at about  $10^{\circ}$ . They stratigraphically overlie Okete olivine basalts at the coast and are themselves overlain by Karioi basalts.

Individual beds are generally thin and may show conspicuous laminations (Fig. 3.30). Sediments range in size from silts to very coarse sands and small pebbles, and occasionally cobbles. The clasts are dominantly olivine basalt but Karioi rock fragments and augite crystals also occur.



Fig. 3.29 - Typically flaggy outcrop of limestone of the Te Kuiti Group, near Waimaori Road and Toreparu Stream.



Fig. 3.30 - Well bedded epiclastic sandstones and siltstones overlying poorly bedded and massive sandstones and conglomerates Te Toto Gorge coast.

Immediately south of Spray Bay (W17037, W17038) some finer sediments with less volcanic detritus occur which are cross-bedded (Fig. 3.31), contain pieces of charcoal, and have infilled an old fluvial valley.

#### Homestead Section

The sediments of this area are described together, even though lithologies are varied, because of the unique and large height and volume they occupy on this part of the coast.

Immediately south of a small stream that reaches the coast 500 m south of Papanuiti Pt, cliffs up to 100 m high expose large masses of bedded sediment (Fig. 3.32). These sediments continue south along the coast for 800 m but gradually have more and more Karioi lavas overlying them until 100 m from Papanui Pt Karioi lavas form the entire section.

The sedimentary rocks are sandstones, siltstones and conglomerates which show cross-bedding and exhibit channel and other sedimentary structures and would require a separate study to determine their detailed nature and depositional history. They do however appear to have been deposited at similar times to the other epiclastic sediments, although they are largely constituted of Karioi derived material in contrast to the other epiclastic sediments in which Okete olivine basalt often predominates.

The large quantity of sedimentary infill at this one place is likely to be associated with the presence of a large fault (see Section 3.11) which either uplifted the sediments or created a valley for their deposition. The age of the fault is uncertain but it appears that the latter alternative is more likely.

#### Recent Alluvial Sediments

More recent deposits of alluvial origin overlying Karioi lavas, occur in a number of places and are of three main types:



Fig. 3.31 - Well bedded fluvial sandstones and siltstones on the coast north of Hills Flat. Unit to the left of the geological hammer shows good cross bedding, and a deposit of charcoal to the left (by lens cap) can also be noted.



Fig. 3.32 - Homestead Cliffs - 100 m high cliffs of bedded epiclastic sandstones and siltstones and massive conglomerates. Pumiceous silts of the Kaihu Group occur in top right of the photo.

- (1) Sands and gravels which occur in several of the stream banks around Karioi, for example Hokonui Stream, Small Cut Stream. These deposits show moderate bedding and sorting. Some exhibit sharp changes in size distribution between individual units but generally a more gradual change is seen. Clasts are of Karioi lava type.
- (2) Conglomerates - these occur in several small streams on the eastern side of the mountain, for example Yearburys' and Adams' farms and are clast-rich boulder beds set in a fine mud size matrix of reworked ash and crushed lava. A variety of Karioi lava types are represented. It is likely that these represent flood type debris flows analogous to lahar deposits, that rushed off the upper slopes of the mountain during a storm event.
- (3) Fine-grained massive deposits occur up the Oporuru River and Te Hutewai Stream, particularly on Mr W. Roberts' farm. The outcrop here is 2 - 3 m high and occurs in a small gorge above the stream. It shows little bedding but sorting is moderate with small rock fragments and augite crystals dominating.

#### Summary

The epiclastic sediments are the most numerous of the various sedimentary deposits in the area. Their stratigraphic position amongst the Karioi and Okete lavas and their highly variable lithologies suggest that local and rapidly changing depositional environments must have existed along this section of the west coast from 2 to 3 m.y. B.P.

#### 3.9.4 Chert

The local farmers on the eastern side of the mountain have commonly found rounded chert pebbles ('moastones') just beneath the surface of the soil during ploughing. While none have been found in situ, x-ray and petrographic analysis of the pebbles indicates they are a cryptocrystalline fossiliferous variety of quartz. In thin-section

plant remains and possibly radiolarians were observed.

In a number of other places, however, large angular boulders of smooth brown cherts were found (see geological map). In one case in the bush above the Oporu Estuary near the Te Hutewai - Raglan road, the boulders were found in the clayey regolith by the outlet of a fresh water spring. In another (W17103) they were found in a tributary creek of the Te Mata Stream on Mr T. Sweetman's property with Te Kuiti Group rocks outcropping in the stream (see Section 3.9.2). A loose boulder of chert was also found in a lahar deposit 800 m up the creek towards Mt Karioi implying that a source must have occurred further up the mountain as well as perhaps at these described localities.

The significance of these chert boulders and their origin remain unclear. Since limestone underlies much of the region, diagenetic alteration and replacement of parts of the limestone after deposition is a possible origin (Pettijohn, 1975). However the Te Kuiti Group rocks do not contain chert nodules and the basal coal measures of the Te Kuiti Group are the only sediments in the Group which have siliceous cements (Nelson, 1973). The presence of nearby underlying Te Kuiti Group rocks in two of the areas where boulders occur makes this theory plausible but the presence of a boulder in a lahar and the rounded stones on the flanks of Mt Karioi would seem to rule out the above origin for all chert occurrences.

It is known that cherts may be associated with contemporaneous volcanic activity (Selly, 1976) and deposition of silica from geothermal activity should be considered a possible origin. A hot spring source high on the eastern side of the mountain could account for all the boulders and especially the rounded stones found in the regolith.

#### 3.9.5 Pleistocene Sands and Silts

These occur in numerous places throughout the area from above Bryant Home Beach in the north to Ruapuke Beach in the south.

The sands are generally orange-brown in colour and may show

cross bedding, mantle bedding, and other sedimentary forms. They are particularly prominent on Mr E. Tait's place on Bryant Home Beach and also south of Papanui Pt where large dunes occur.

Silts occur in a number of places as well. Firstly, within the sands above Bryant Home Beach a thin 10 cm (W17108) deposit occurs. South of the Homestead fault a much thicker (5 m - 7 m) deposit occurs (W17032, W17033) 100 m A.S.L. overlying the thick sedimentary deposits that crop out down to sea level.

Another outcrop occurs at Woody Head Beach (Section I) as a thin (1 m) white deposit of finely bedded silts exposed 2 - 10 m a.s.l. dipping to the north below Karioi basalt lavas but above a sedimentary conglomerate containing Karioi material. This suggests it was deposited during the period that Karioi was active and is Pliocene in age.

It is likely that all these deposits are part of the Kaihu Group as defined by Chappell (1970) and Pain (1976). Chappell (1970) states that pumiceous silts occur at several different altitudes in several of the formations of this Group. Both the sands and the silts are probably the result of shallow water and eolian deposition.

### 3.10 STRUCTURAL ASPECTS AND FAULTING

#### 3.10.1 Introduction

The regional aspects of faulting and structure were broadly discussed in the regional geology section of Chapter Two (Section 2.1).

This section discusses the faults found in the mapping area itself. It also describes the present mountain shape and relates this to erosion, original shape and volume of erupted material. Structural features on the mountain such as possible crater position and rotational slumps on the coast are also mentioned.

### 3.10.2 Shape, Volume and Degree of Erosion

If it is assumed that:-

- (a) The present height of Mt Karioi is close to the original height during its eruptive period (which appears likely due to the presence of the breccias and dykes on the upper ridges),
- (b) The base-level of Mt Karioi is approximately sea level,
- (c) The mountain had an original cone shape,
- (d) The radius of the cone was 5.5 km (distance from the summit to furthest extent of lavas in the east and south) and thus the angle of cone is  $8^{\circ}$ ,

then a volume of  $24 \text{ km}^3$  of erupted material can be calculated.

The present shape of the mountain is convex with the upper slopes having angles of  $17^{\circ}$ , decreasing in middle slopes to  $12^{\circ}$ , and on the lower sides to  $4^{\circ}$ . Comparing this shape with the assumed shape (above) implies that up to half of the mountain or erupted material has been eroded away.

While the rivers and streams are deeply dissected and many boulders are found on the upper surfaces of the mountain and abundant volcanic detritus is present in the epiclastic sediments, the planezes of the mountain (the main ridges such as at Tait, Te Toto etc) from which the present shape was calculated are unlikely to be greatly eroded, certainly not to the extent that as much volume again was originally present above the shape of the mountain today.

The assumed shape would also imply that the lahars, which are always found on the surface of Mt Karioi, were recent events deposited after the erosion of half the volume had concluded. While lahars often occur as recent deposits on a volcano, this is not suggested by their weathered outcrop appearance.

Also from the angle of slope above Woody Head of the present profile ( $10 - 12^{\circ}$ ), and considering the height of the cliffs it can be calculated that the lavas continued out originally at least 300 m past

the present coastline. This seems entirely reasonable but if the radius of 5.5 km of the assumed cone shape (calculated from the east side of the mountain) is projected to the west, a figure of 1 to 1.5 km of extra land is obtained. This latter distance appears most unlikely as it would suggest that considerable erosion would have subsequently occurred. Whether Jackson's Reef 3 km offshore of Woody Head represents such a lava flow, or perhaps is a separate volcanic vent, is uncertain.

All this evidence would seem to indicate that the assumed cone shape is incorrect and that the original shape of the mountain was asymmetrical in cross-section and more convex in nature as it is today. Taking this and the following factors into consideration:-

- (a) The volume and thickness of the epiclastic sediments and the early olivine basalt lavas presumed to lie under Mt Karioi,
- (b) The fact that the Te Kuiti Group is found up to 15 m a.s.l. in the north and 35 m a.s.l. in the south,

then the amount of erupted material must be considerably less than  $24 \text{ km}^3$  and probably in the region of  $10 \text{ km}^3$ .

### 3.10.3 Crater Structure

Hochstetter (1864 p122) stated "we can recognise the former crater in a basin-like valley opening to the north embraced by its jagged peak".

However there is little evidence in the eroded nature of Mt Karioi today to suggest where a former crater might have been. It may be possible that Central Ridge which runs east - west is one side of the lip of a former crater. With the presence of large masses of volcanic breccia at Tamahine O Karewa Peak which must be close to source, the former crater may well be in the basin Hochstetter (1864) describes. If it was, flows were directed more to the west and southeast than to the north as the northern limit of the lavas is a lot closer than in the other directions.

### 3.10.4 Coastal Geomorphology

The coastline is typically of two types:-

- (a) High vertical cliffs right on the coast, or
- (b) Sloping, vegetated bays with cliffs set back from the coast in a semi-circular fashion.

The former can be explained by the natural processes of marine erosion. The origin of the latter, which occurs in a number of places on the coast, is uncertain but may be the result of large-scale rotational slumping and subsequent erosion by marine and alluvial action.

Such an origin gains credibility when one looks at Hills Flat, an unusual geomorphological feature which is a combination of both (a) and (b) from above (Fig. 3.34). Cliffs occur on the coast but also inland in a semi-circular fashion. The lavas on the coast are also dipping back to the east indicating that rotational slumping took place (Fig 3.35).

Epiclastic sediments appear at coastal level to the north and south of Hills Flat and may have been a potential failure plane. Such sediments also occur at Te Toto Gorge where one of the semi-circular bays occur. Faulting may well have provided the impetus for such slumping to occur. A large fault is thought to occur at Te Toto vent site which if projected south would run close behind the middle of the semi-circular basin at Spray Bay and Hills Flat.

#### 3.10.5 Faulting

Faults are seen in many places on the coastal sections and around other locations on the mountain, occurring both in the volcanic and sedimentary rocks. The location and description of fault directions and displacements is summarised in Table 3.3.

The faults are of two major types:-

- (1) Small faults with limited displacements (cm to m) which generally strike in a northwesterly or northeasterly direction (see Fig. 3.3).
- (2) Large inferred faults with large displacements ( 100 m) striking approximately north-south.

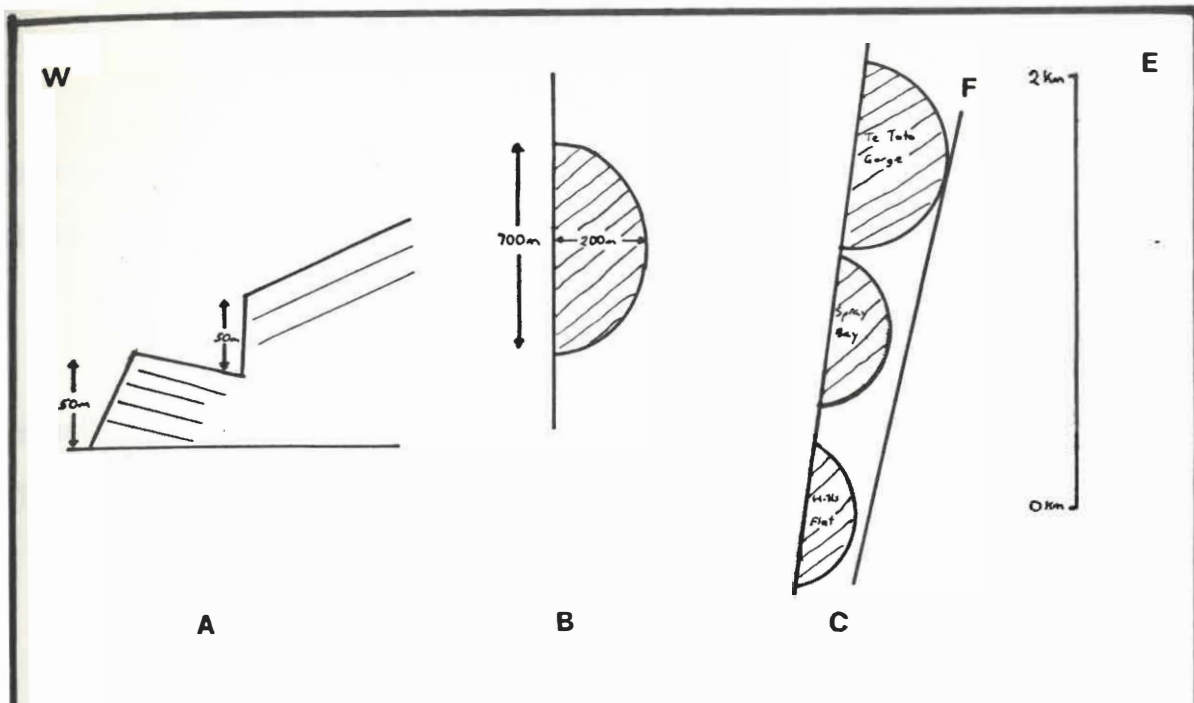


Fig. 3.33 - Hills Flat rotational slump feature

- A. horizontal profile
- B. vertical 'bird's eye' view
- C. expanded vertical view showing relation to other slump features and Te Toto Fault.



Fig. 3.34 - Hills Flat rotational slump looking north.

### Small Faults

These are common right throughout the area. In the epiclastic sediments the faults usually have displacements of several centimetres while the displacement in the volcanic rocks is usually several metres.

### Large Faults

These are inferred only, from stratigraphic and geomorphological grounds.

#### (1) Te Toto Gorge Fault

This fault strikes NNE from behind Hills Flat up to Te Toto vent site. Evidence is seen at Te Toto Gorge where lavas on the coastal side (west) of the faults are thin (1 - 2 m) but directly east of the fault they are considerably thicker (8 m). This fault is also important in explaining the geomorphological features of Hills Flat, Spray Bay and Te Toto Gorge as discussed in the last section (Section 3.10.4).

#### (2) Homestead Fault

The large cliffs (up to 150 m) of sedimentary deposits that occur directly south of a small stream, south of Papanuiti Pt are likely to be of such thickness as a result of faulting. As mentioned previously this may be the direct result of uplift or perhaps due to deposition in a faulted valley area.

A fault is seen above the stream and an associated dyke of Karioi olivine pyroxene basalt (W17036) has come up along this fault.

Shearing and slickensiding are prominent in the broken and shattered country rock of Karioi lavas (Fig. 3.12). This fault strikes almost north - south and if it continues, it may be associated with the olivine basalt vent above Jacksons Cut (see Chapter 3.7.2).

A small fault branching off this main fault is seen in the upper sediments of the cliffs immediately south of the stream and suggests that the stream is cutting down along a fault plane.

TABLE 3.3 - Location and direction of faults observed or inferred in the Mt Karioi area.

LOCATION (or fault name)	DIRECTION	DISPLACEMENT	LITHOLOGIES AFFECTED
<u>Tait Section</u>	005/70E 114/67S	1.5 m 2.5 m	Karioi lavas and tuffs " " " "
<u>Te Toto Gorge</u>			
a) southern cliffs	?	0.02 m	Epiclastic sediments
b) western cliffs	126/80SW	4 - 5 m	Karioi lavas and tuffs
<u>Te Toto Fault</u>	008/?	large (?)	Major fault through Karioi lavas
<u>Spray Bay</u>	058/80N	0.5 m	Karioi lavas
<u>Hills Flat</u>	128/45N 055/50SE 122/50SW 85/50S	1.0 m ) ) 0.30 m )	Karioi lavas and tuffs Epiclastic sandstones
<u>Section I</u>	112/75S many others of similar strike	) 0.05 - ) 0.5 m )	Te Kuiti Group siltstone Te Kuiti Group siltstone
<u>Homestead Fault</u>	009/? 076/?	large (?) ?	Major fault and dyke Minor fault up creek in epiclastic sediments
<u>Beach North of Papanui Pt</u>	092/34S 130/?	0.20 m 2.0 m	Pumiceous silts Karioi lavas and tuffs

### Summary of Faulting

The faulting in the Mt Karioi area would appear to be consistent with the regional geology and orientation of faults in the whole South Auckland region.

The major period of regional faulting is known to be post-Oligocene and essentially pre-Karioi. This is seen in the south of the mapping area for instance at Taranaki Point where a post-Kaawa formation fault displaces Kaawa and tertiary rocks. Volcanism was then localised along the fault.

## CHAPTER FOUR

## PETROGRAPHY

4.1 INTRODUCTION AND CLASSIFICATION

The lavas of the Mt Karioi area all contain plagioclase, augite, and opaques; most lavas also contain significant amounts of olivine and the andesitic rocks tend to contain hornblende and hyperthene. Phlogopite and apatite are accessory minerals.

The lavas have been divided into four groups on textural and chemical grounds, and the petrography will be discussed under these headings:

- (1) The Karioi basalts (less than 52 wt %  $\text{SiO}_2$ ) are subdivided into two
  - (a) the porphyritic basalts with abundant large phenocrysts in a coarse grained groundmass
  - (b) the coarse grained rocks with little or no groundmass.
- (2) Basaltic andesites - these have a porphyritic texture with a fine grained groundmass and contain 52-55 wt %  $\text{SiO}_2$ .
- (3) Andesites - Karioi andesites contain more than 55 wt %  $\text{SiO}_2$  and have a typical andesitic texture with a dominance of plagioclase phenocrysts set in a fine grained groundmass.
- (4) The olivine basalts from the Okete Volcanics are easily separated from Karioi lavas by the high percentage of groundmass and olivine phenocrysts, and low amounts of plagioclase. They are typically fine grained and often have a pilotaxitic texture. Generally they have less than 47 wt %  $\text{SiO}_2$ .

The petrography of the volcanic breccias and tuffs are described separately. Xenoliths occur in all lava types and are discussed with each rock group.

Modal analyses of the rocks varies with each group and average modal analyses are presented in Table 4.1 (Appendix I has complete data). However, while the modal analyses are generally characteristic for each group, graduations between groups occur, so that a classification based solely on any modal analysis is not of great value, and a classification based more on textural criteria has been found to be more useful, both from field work and thin-section studies.

## 4.2 KARIOI BASALTS

The Karioi basalts make up the bulk of the lavas on Mt Karioi. They can be divided into two types:

- (1) coarse grained doleritic textured basalts, and
- (2) Porphyritic basalts.

### 4.2.1 Coarse Grained Basalts

Coarse grained basalts are abundant in the mapping area, particularly on the eastern side of Mt Karioi, but are not as common as the porphyritic basalts. Stratigraphically, they occur at all levels throughout the lava sequence.

Essentially they have an almost doleritic type of texture with large phenocrysts of plagioclase, olivine and clinopyroxene, smaller phenocrysts of tabular pyroxene, subhedral opaques, apatite and occasionally phlogopite. Hypersthene occurs in some rocks. Alteration products of olivine such as serpentine, iddingsite, chlorite or bowlingite are common.

The lavas vary both in the size of the minerals and in the amount of large "phenocrysts" and small "groundmass" crystals. However, all the minerals are large enough to be point counted and no groundmass is recorded.

TABLE 4.1 - Average modal analyses of major lava types (to nearest 0.5%).

Mineral Present ↓	Rock Type →	I Karioi Basalt		II Karioi Basaltic Andesite		III Karioi Andesite	IV Okete Olivine Basalt (average only)
		(a) Coarse Grained	(b) Porphy- ritic	(a) Olivine	(b) Hornblende		
Groundmass		-	43.0	43.5	48.0	50.0	72.0
Plagioclase		56.0	36.5	32.0	33.5	34.0	6.0
Clinopyroxene		23.0	13.5	15.5	6.0	6.0	6.5
Orthopyroxene		0.5	-	0.5	0.5	2.5	-
Olivine		8.0	5.5	5.0	-	-	13.0
Hornblende		-	-	1.0	9.0	5.0	-
Opques		7.0	1.5	3.0	3.0	2.5	1.5
Alteration Products (Iddingsite etc)		4.0	-	-	-	-	1.0
Phlogopite		0.5	-	trace	-	-	-
Apatite		1.0	-	-	-	-	trace

#### 4.2.2 Porphyritic Basalt Lavas

Porphyritic basalts are the most common lava types on Mt Karioi. They are distinguished by the large size of the phenocrysts and their porphyritic texture (Fig. 4.1). Phenocrysts make up a considerable volume of the rock (57 modal %) and are distinctive in hand specimen and thin-section. Plagioclase predominates, generally being about 1.5mm long but may occur up to 5 mm in length e.g. W17026, W17027. Clinopyroxene occurs as large (up to 6 mm) subhedral to euhedral phenocrysts and often shows glomeroporphyritic and poikilitic textures.

Olivine is also an abundant phenocryst phase and is often altered to iddingsite or other alteration products. Opaques are not as abundant in these rocks as in other rock types (1.5 modal %) but vary in their size and may be anhedral or euhedral. Hornblende phenocrysts occur only in a few rocks (e.g. W17056), as reaction rims or partially resorbed phenocrysts.

The groundmass is usually medium to coarse grained with plagioclase, clinopyroxene and opaques and olivine, alteration products of olivine, and glass may be present. Intergranular groundmass textures are predominant but intersertal textures occur in some rocks (e.g. W17036, 17044).

An unusual Karioi basalt occurs at Tauranga Trig (Section A) as a 13 m thick lava flow; it is fine grained with a pilotaxitic groundmass of plagioclase laths, granular clinopyroxene, abundant opaques and also chlorite and serpentine. This lava is characterised by the low proportions of olivine in the rock (3.0%) and the predominance of plagioclase (65 - 80 modal % of total phenocrysts) which occurs as subhedral crystals up to 1.5 mm in size. Clinopyroxene only occurs in limited amounts, olivine is generally completely altered iddingsite, and titanomagnetite forms anhedral crystals. An unusual red-brown form of apatite is present in small amounts (see Chapter 5.9).

### 4.3 BASALTIC ANDESITES

#### 4.3.1 Introduction

Basaltic andesites are generally lighter in colour and contain more plagioclase than the basalts. They frequently contain hornblende or hypersthene phenocrysts, and have a more fine grained andesitic type texture.

Henderson and Grange (1926) and later Player (1958), referred to many rocks in the Mt Karioi area as olivine andesites. However, chemically these rocks contain less than 54 wt %  $\text{SiO}_2$  and have plagioclase compositions more sodic than  $\text{An}_{55}$ , and are here grouped as basaltic andesites. These rocks are difficult to distinguish in the field from the andesites and basalts, and while Cox et al (1979) classified basaltic andesites as rocks between 52 - 55 wt %  $\text{SiO}_2$  it would seem that the texture and phenocryst types in thin-section are just as important in any classification. In this study W17084 which has only 50.19 wt %  $\text{SiO}_2$  is not classified as a basalt but rather as an olivine basaltic andesite because of its textural features.

The basaltic andesites all contain plagioclase and clinopyroxene as the main phenocrysts and have been subdivided into:

- (1) Olivine basaltic andesites, and
- (2) Hornblende basaltic andesites.

Hypersthene may also be present but is not a modally significant phase, and phlogopite occurs as small flakes in some lavas.

#### 4.3.2 Olivine Basaltic Andesites

Olivine basaltic andesites have a similar modal analyses to the porphyritic Karioi basalts (Table 4.1) but differ in containing hornblende, hypersthene and traces of phlogopite. The phenocrysts tend to be smaller compared with the basalts, with augite and plagioclase generally being less than 2 mm in length, and olivine crystals averaging 0.3 - 0.5 mm. Olivine may be unaltered or show an alteration to iddingsite. Titanomagnetites may be associated with the olivines or

with hornblende and range from small (0.2 mm) anhedral to larger (0.4 mm) subhedral phenocrysts.

Hornblende is usually altered or resorbed. Rims of hornblende phenocrysts are often isotropic and the cores may show a range of degree of resorption. Totally resorbed phenocrysts of hornblende sometimes can only be recognised by their relict outline. Hornblende often shows an alteration to a mass of fine grained opaque grains. Phlogopite is often associated with hornblende, particularly in the cores of partially resorbed phenocrysts (e.g. W17053, W17095), and hypersthene occurs in some rocks as small euhedral tabular crystals.

The groundmass is generally medium grained and intersertal with abundant interstitial glass. Opaques and augite may interstices between plagioclase laths producing an intergranular groundmass.

#### 4.3.3 Hornblende Basaltic Andesites

Hornblende basaltic andesites are characterised by containing significant hornblende phenocrysts which constitute approximately 9 modal % of the rock. Hypersthene and rarely phlogopite may also occur.

This group of rocks is part of a graduation of lavas from basalt to andesite which is shown in Table 4.2.

TABLE 4.2 - Karioi Lavas - a graduation from basalt to andesite

	Basalt	Olivine Basaltic Andesite	Hornblende Basaltic Andesite	Andesite
Modal % Groundmass	43	43.5	48	50
Modal % Olivine	7	5.5	-	-

The trend from the basalts through the basaltic andesites to andesites shows an increase in the modal % groundmass while the modal % olivine phenocrysts decreases. Table 4.2 suggests that the olivine basaltic

andesites are more related to the basalts than the andesites and the hornblende basaltic andesites are more related to the andesites, with intermediate stages between the two main rock types.

Hornblende phenocrysts range up to 5 mm in size and show less resorption compared with the olivine basaltic andesites, with only limited alteration on the rims or minor resorption of the cores.

Glass is generally present in the groundmass, which varies in texture from intersertal (W17083) to intergranular (W17096).

#### Xenoliths

Xenoliths, presumably cognate, of coarse equigranular gabbro or theralite type textures, were common at two sites, on Central Ridge (W17096) and on Whale Bay Ridge (W17099).

On Central Ridge the lava is a hornblend basaltic andesite containing abundant hornblende phenocrysts and the xenoliths (W17097) have a hypidiomorphic-granular texture and a predominance of subhedral and euhedral plagioclase phenocrysts. Anhedral opaques and subhedral green-yellow brown hornblende also occur.

W17099 is also an inclusion from a hornblende basaltic andesite and shows a hypidiomorphic-granular to allotriomorphic-granular texture (Fig. 4.3). Anhedral hornblende is the dominant phase and plagioclase, augite and opaques are minor.

#### 4.4 ANDESITES

Contrary to what several authors have suggested (e.g. Stipp, 1968: 200, 202) true andesites are rare in the Alexandra Volcanics Group. The only substantial occurrence of andesitic rocks in the Alexandra Volcanics is on Mt Karioi where andesites are found as dykes and lavas on the main ridges.

The Karioi andesites contain no olivine and are dominated by plagioclase phenocrysts set in a fine grained groundmass (Fig. 4.2). Hornblende and hypersthene may also occur as phenocrysts and textures

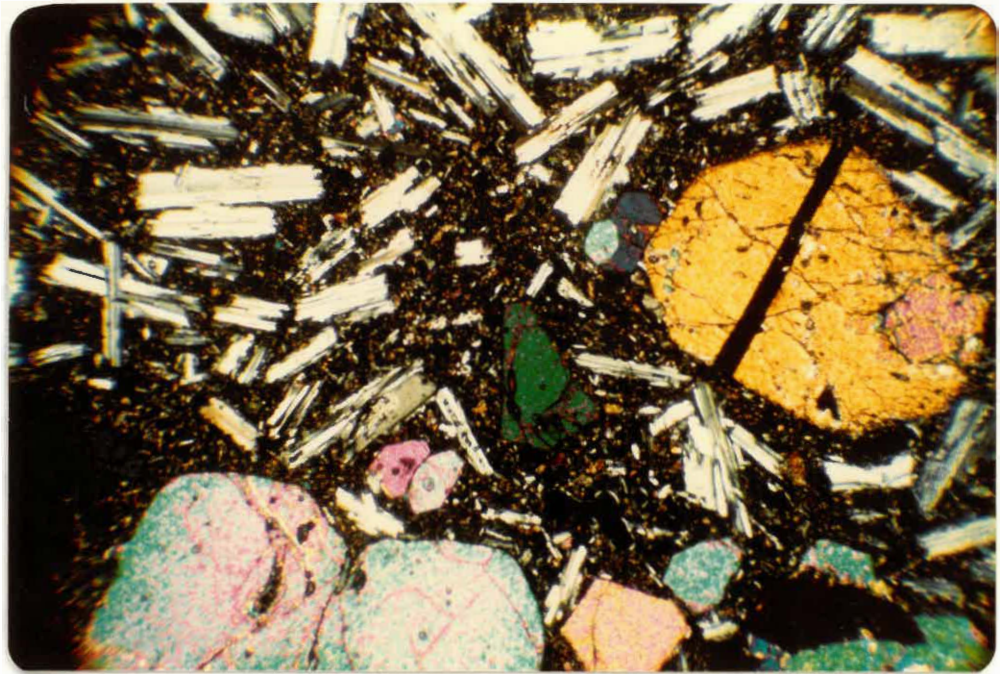


Fig. 4.1 - Typical Karioi porphyritic basalt lava (W17080) with large crystals of plagioclase (abundant white laths), clinopyroxene (twinned orange mineral to the right) and olivine (blue and green minerals at the bottom) set in a coarse groundmass. Crossed nicols (32x).

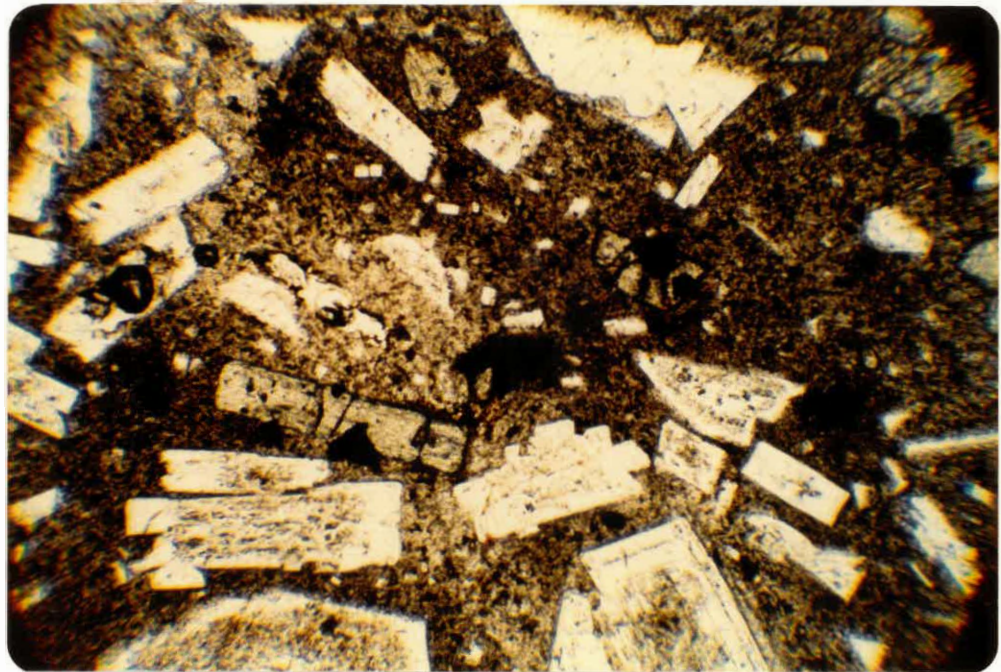


Fig. 4.2 - Karioi andesite lava (W17082) with large white partially resorbed plagioclase phenocrysts, euhedral hypersthene (middle left) and opaques set in a fine grained often intersertal groundmass. Crossed nicols (60x).

vary from porphyritic to glomeroporphyritic.

An average modal analysis is shown in Table 4.1 and indicates the predominance of groundmass (38 - 60 modal %) percentage over the phenocrysts. The groundmass contains mainly plagioclase, opaques, and glass and textures range from intergranular to intersertal.

Plagioclase predominates over clinopyroxene (plagioclase constitutes 68 modal % of total phenocrysts) and generally occurs as euhedral crystals up to 2 mm in length and shows resorption by glass in some cases. Clinopyroxene mainly occurs as small phenocrysts but larger phenocrysts up to 2 mm, more typical of the Karioi basalts, may be present. Clinopyroxenes often show a poikilitic texture with inclusions of plagioclase, opaques or hypersthene. Hornblende is common (5 modal %) in some andesites; generally occurring as small phenocrysts. Larger phenocrysts (up to 4 mm) are present in some instances and may show limited resorption of the rims.

The hornblende andesite from Jacksons Rock (W17057, W17059) has up to 19 modal percent hornblende and shows little resorption. The phenocrysts average 1.5 mm in length but megacrysts may reach 8 mm. This sample is clearly different from the one Henderson and Grange (1926) describe (Analysis No. 6) which contains hornblende that has been completely resorbed. Olivine is also present. The rock has 52.99 wt %  $\text{SiO}_2$  and could best be described as an olivine hornblende basaltic andesite.

Hypersthene andesite outcrops in two places (W17016, W17082) as lavas. Hypersthene forms small (up to 0.4 mm) tabular euhedral crystals, and is often associated with opaque phenocrysts and may also show a glomeroporphyritic texture with clinopyroxenes and opaques.

#### Xenoliths

The lava at Jacksons Rock (W17057, W17059) contains many cognate xenoliths which can clearly be seen in hand specimen. The xenoliths range from 0.5 to 4 mm in size and vary in texture from being fine to coarse grained equigranular gabbro textured material e.g. W17058, W17060

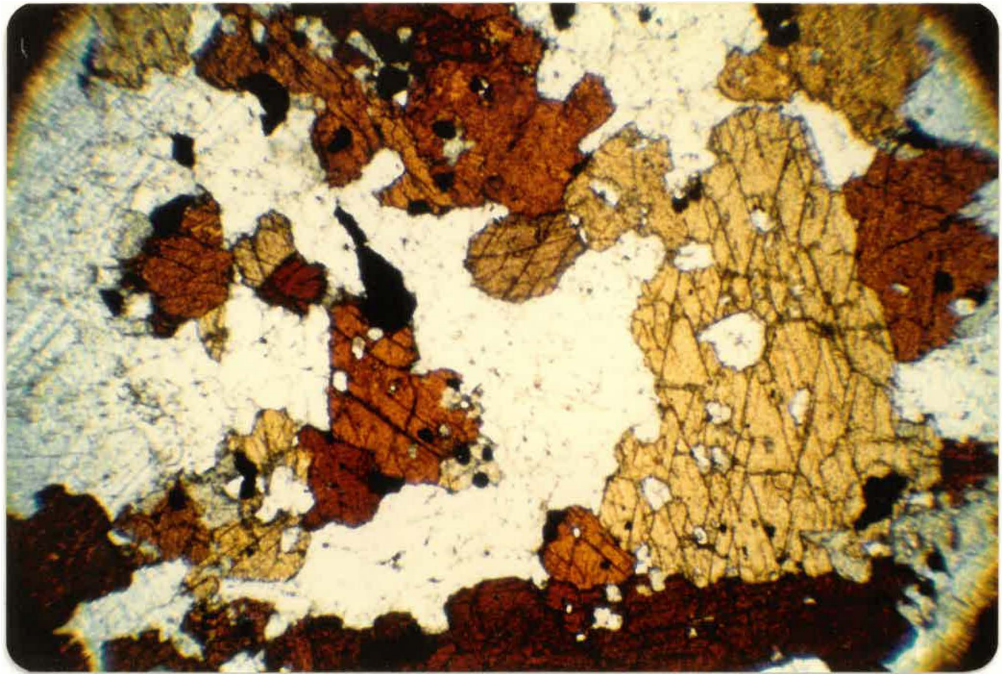


Fig. 4.3 - Cognate xenolith (W17099) from a Karioi basaltic andesite. Dominated by reddy-brown amphibole (Kaersutite) and plagioclase, minor clinopyroxenes and opaques. Crossed nicols (32x).

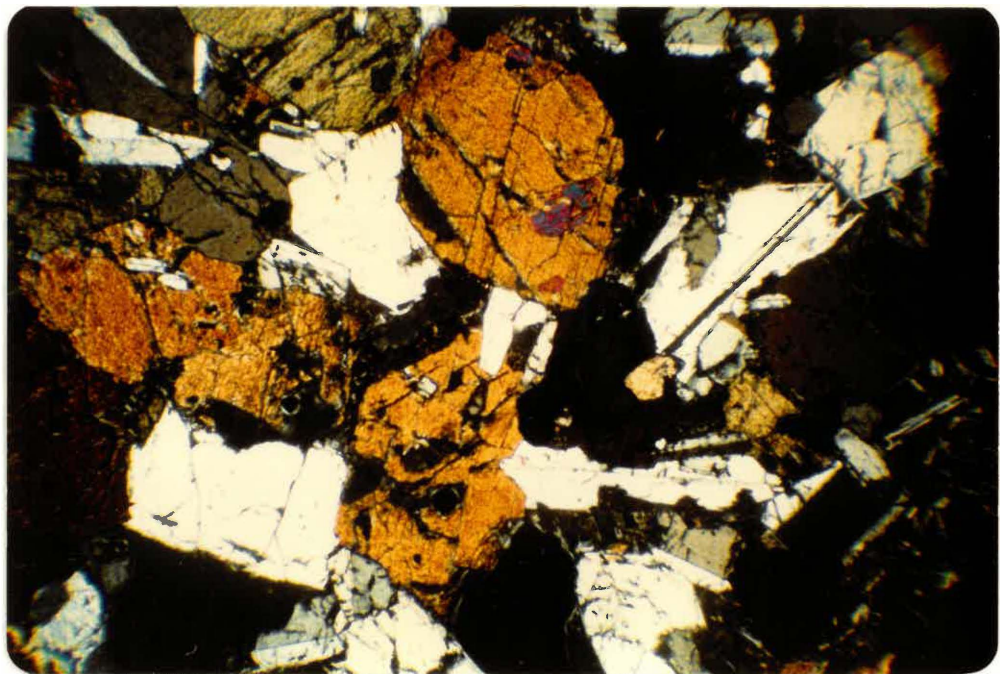


Fig. 4.4 - Cognate xenolith (W17058) from a Karioi andesite (W17057), Jacksons Rock. Coarse grained with plagioclase and clinopyroxene dominating. Crossed nicols (32x).

(Fig. 4.4). The minerals present are the same as in the host hornblende andesite lava.

#### 4.5 OKETE OLIVINE BASALTS

The typical Okete type olivine basalt has small phenocrysts of olivine set in a fine grained groundmass of euhedral tabular pyroxenes, plagioclase laths, and opaques. However, the texture and mineralogy of the Okete Volcanics may vary considerably.

The olivine basalts found in the mapping area have been divided into 5 different types on petrographic grounds, with the grain size and amount of groundmass being the diagnostic features. Generally the lavas from one centre are found to be similar (as Player, 1958, suggested from his limited study of these rocks). Lavas from different centres may be distinctive but often are of similar types e.g. Walmsley Hill and Cornes Hill.

Modal analyses of the five types are listed and described in Table 4.2. Types II and III have been further subdivided according to grain size. The typical Okete Volcanics lava (W17145, from Okete Quarry, R.M. Briggs in prep.) is Type III(b), a fine grained pilotaxitic lava.

##### Type I

This type outcrops mainly as thin lavas south of Tait section (see 3.7.2.), and in hand specimen shows common olivine phenocrysts, and may contain quartz xenoliths.

Type I basalts are porphyritic with phenocrysts of plagioclase, olivine and augite set in a medium grained groundmass (Fig. 4.5). It differs from the other Okete olivine basalts by the significant amounts of clinopyroxene (1.5 modal %, cf. 4 - 5 modal % in other types). This is similar to the porphyritic Karioi basalts but differs in the amount of groundmass (58 modal % cf. 43 modal %), abundance of olivine (14.0% cf. 5.5 modal %), and the smaller size of the phenocrysts.

TABLE 4.3 - Representative modal analyses of Okete Volcanics olivine basalts.

TYPE	I	II		III		IV	V
Description Mineral	Plagioclase, olivine & augite in medium grained groundmass	Coarse grained equigranular with no groundmass		Coarse grained lava with pilotaxitic groundmass		Fine grained groundmass with many opaques	Glassy groundmass with no plagioclase phenocrysts
		large	small	large	small		
sample examples	W17022 W17039 W17112	W17001 W17049 W17065 W17105	W17043 W17035	W17012 W17047 W17054	W17106 W17119 W17127	W17029 W17093 W17101 W17131	W17042 W17089 W17128
Groundmass	58.0	-	-	79.0	76.5	69.5	82.0
Plagioclase	13.0	51.0	39.0	-	-	4.0	-
Clinopyroxene	14.5	25.0	24.0	5.0	4.0	6.0	2.5
Orthopyroxene	-	-	-	-	-	-	may occur eg W17089
Olivine	14.0	19.0	16.5	15.0	13.0	19.0	15.0
Alteration products	may occur	may occur	15.5	may occur	1.0	may occur	may occur
Opaques	0.5	5.5	5.0	1.0	5.5	1.5	0.5
Apatite	trace	trace	trace	trace	trace	-	-
Phlogopite	-	may occur	-	-	-	-	-

### Type II

Type II olivine basalt lavas occur at Papanui Point (see Chapter 3.7.3.), Fields' and Benseman's farms (3.7.11) and Te Toto southern point (3.8.2). They have a coarse grained doleritic texture which is similar to the coarse grained Karioi basalts but can be distinguished by the amount of modal olivine (19% cf. 8%). A groundmass is essentially lacking and the rocks are comprised of crystals of plagioclase, olivine, augite and opaques. Alteration products of olivine are common and apatite is an accessory mineral. Clinopyroxene usually forms small euhedral or subhedral crystals, which are subophitic, and occur between the larger euhedral plagioclase laths. Subhedral olivines are usually large, titanomagnetites may be anhedral or subhedral and in some cases show a skeletal habit. All the phenocrysts are variable in size and some lavas show an overall fine grain size. The Type II basalts may be subdivided on this basis (see Table 4.3).

### Type III

The most common textural type of the Okete Volcanics is that with a pilotaxitic groundmass (Fig. 4.6). These may occur in many places in the mapping area e.g. Te Toto Gorge, Matawha Point, Spray Bay Coast, Oporuru and Ruapuke Beach.

Olivine is the dominant phenocryst phase and occurs as subhedral phenocrysts up to 1.5 mm in length. Clinopyroxenes are small and often show a glomeroporphyritic texture. Anhedral and skeletal titanomagnetites, apatites and alteration products of olivine may also be present. Plagioclase is confined to small laths within the groundmass. The groundmass makes up the majority of the rock (76-79 modal %) and is generally fine grained, with plagioclase laths, augite and opaque crystals being the main constituents. Alteration products of olivine may be present in some lavas (e.g. W17043).

The Type III basalts have been subdivided in Table 4.3 into two types depending on the size of the minerals in the groundmass. In some

cases the plagioclase laths and pyroxenes are small and in others they are much larger, and the flowage features more obvious.

#### Type IV

This type resembles Type III olivine basalts with phenocrysts of olivine, augite, and opaques set in porphyritic groundmass. However, in this case the groundmass is not pilotaxitic, but very fine grained and contains an abundance of small anhedral opaques. Plagioclase and augite occur in small amounts.

Type IV basalts are found at Bryant Home Point, Walmsley Hill and Cornes Hill, Toreparu Stream, Spray Bay and Oporu Estuary and are therefore common to many centres.

#### Type V

While many of the rocks in the other groups contain some glass and intersertal textures may occur, they usually have intergranular textures or a combination of both. However, a few rocks have a vitrophyric groundmass, for example the lavas at Te Toto Southern point, some clasts from the pyroclastic vent deposit at Bryant Home Beach, and in some boulders from the eastern side of the mountain.

#### Xenoliths

Xenoliths were only seen in thin section in one rock from Papanui Point where a coarse grained gabbro textured inclusion (W17002) was discovered in a Type II olivine basalt lava (W17001). The inclusion had a hypidiomorphic - granular texture of plagioclase, augite, olivine and opaques, and is probably a cognate xenolith with similar composition to the host lava.

Quartz xenoliths were seen in some of the olivine basalts at Tait's Section (Type I lavas) but could not be extracted for sectioning.

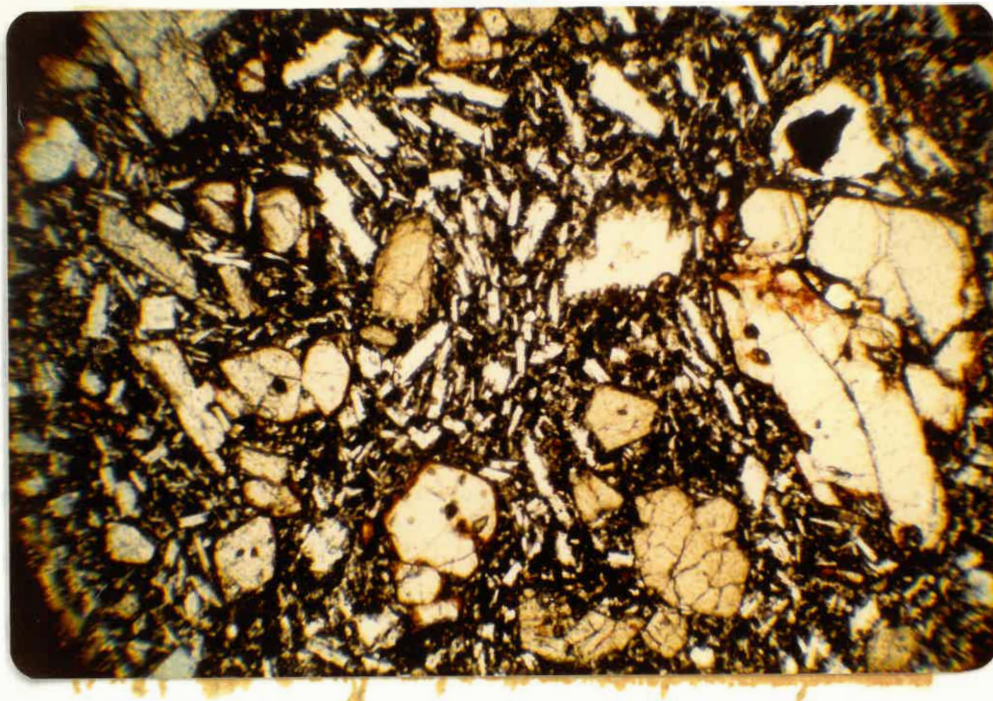


Fig. 4.5 - Okete olivine basalt Type I textured lava (W17022), with large phenocrysts of euhedral olivine (for example on the right hand side) which show minor alteration to iddingsite on their rims and euhedral clinopyroxene set in a medium grained groundmass of plagioclase laths, clinopyroxenes and opaques. Plane polarised light (32x).

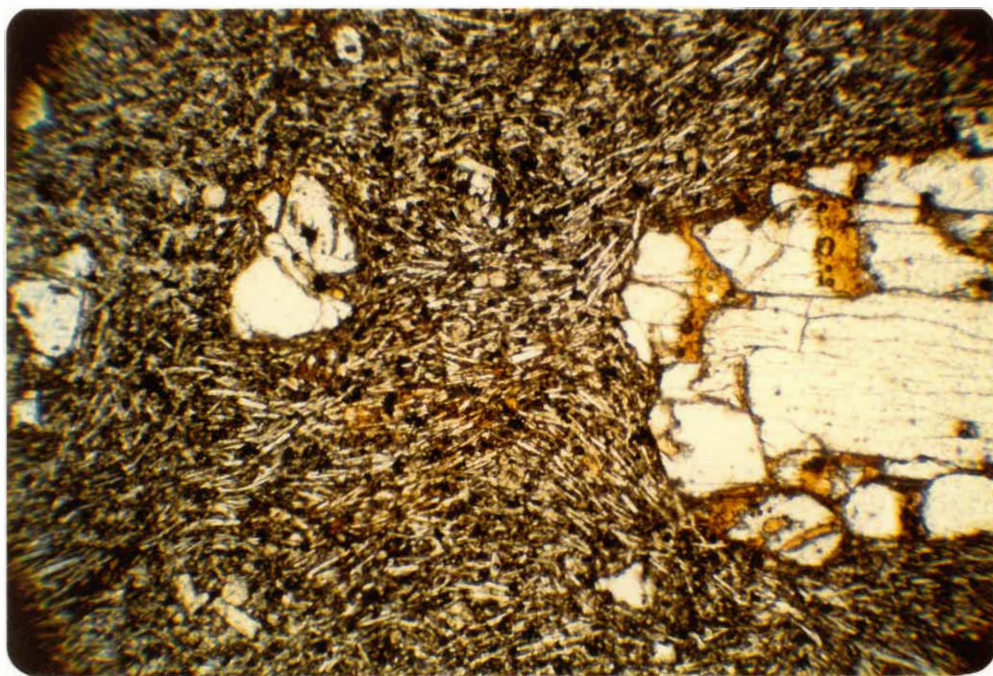


Fig. 4.6 - Okete olivine basalt lava (W17012). This is a typical Type II fine grained lava with large phenocrysts of olivine (minor alteration to iddingsite) set in a pilotaxitic groundmass. Plane polarised light (32x).

## 4.6 VOLCANIC BRECCIAS AND TUFFS

A number of thin sections were made of the volcanic breccias and tuffs of the Mt Karioi area. The volcanic breccias and non indurated tuffs which could not be sectioned were crushed, wet sieved into two size fractions (  $1.5\phi$  and  $1.5 - 3.0\phi$ ) and mounted in Canada Balsalm.

### 4.6.1 Volcanic Breccias

A number of samples from Papanuiti Point (W17030, W17031, W17055) of volcanic breccia from the presumed Okete olivine basalt vent site, were examined. They have abundant phenocrysts of plagioclase, augite and olivine set in a palagonitic groundmass. The presence of yellow palagonite, supports the origin of a submarine volcanic eruption as suggested in Chapter 3.7.2 for this volcanic breccia. Small rock fragments (averaging 1 mm) were also observed in one rock (W17055) and these also have a glassy groundmass. Augite is the dominant phenocryst and occurs as small euhedral to subhedral phenocrysts. Plagioclase occurs as small laths and olivine may also be present. Red "staining" from oxidation occurs in patches of the groundmass and calcite may also be prominent particularly in W17055.

W17062 and W17134 from a volcanic breccia of similar nature above the road near Jacksons Cut also contain augite and olivine phenocrysts and plagioclase laths. The groundmass is almost entirely made up of glass and calcite.

The presence and textural nature of the calcite in these two volcanic breccias indicate that cementation after deposition has occurred and would account for their extremely hard, indurated nature.

The volcanic breccia at Tamahine Peak (W17074) on the upper ridges of Mt Karioi contains phenocrysts of augite, plagioclase and rock fragments (up to 2 mm) set in a groundmass of palagonite. The rock fragments are of the Karioi porphyritic basalt type, and contain common plagioclase laths (up to 1.2 mm long), granular augite (up to 2 mm), minor small olivine (less than 0.4 mm), and titanomagnetite. Considering

the mineralogy and composition of both the breccia and the rock fragments within the breccia, it is likely that the volcanic breccia was the result of a basaltic, rather than andesitic, eruption from the main volcanic edifice of Mt Karioi.

#### 4.6.2 Tuffs

A number of non-indurated tuffs and volcanic breccias (e.g. W17010, W17011, W17034) were examined to determine whether they contained similar mineral assemblages to the lavas which overlie them, and this was confirmed in each case. The lavas were all Karioi basalts, containing plagioclase, pyroxenes, olivine and titanomagnetite, and similar minerals were found in the tuffs and tuff breccias.

## CHAPTER FIVE

## MINERALOGY

5.1 INTRODUCTION

The minerals from representative rock samples of the Karioi and Okete Volcanic Formations were examined in thin-section and chemically analysed to determine their optical properties and composition.

Chemical analysis of some selected minerals was undertaken with the use of the the Geology Department, University of Auckland, microprobe following the procedures of Bence and Albee (1968). Data was processed by computer at the University of Waikato. Details of methods and results are presented in full in the appendices but average compositions and end member data is presented in the text and in Fig 5.1.

5.2 PLAGIOCLASE

Plagioclase feldspar is present in virtually all the volcanic rocks of the mapping area. It is the dominant phenocryst in all the Karioi rocks, and some of the Okete type rocks. It occurs as phenocrysts, ranging in size from 0.2 to 3 mm and as small groundmass crystals. In the plagioclase-rich Karioi porphyritic basalts, the phenocrysts are lath-like, up to 2.5 mm in length, and generally form small squat tabular prisms (0.5 by 0.2 mm in size). The crystals in the coarse grained basalts are similar to those in the plagioclase-rich porphyritic basalts and form elongated laths. In the andesites the phenocrysts are variable in length but tend to be tabular (Fig. 4.4).

The plagioclase phenocrysts usually possess euhedral and subhedral outlines. Euhedral shapes are shown clearly in the coarse grained rocks. Some of the phenocrysts in the andesites may be resorbed and show corroded and rounded outlines.

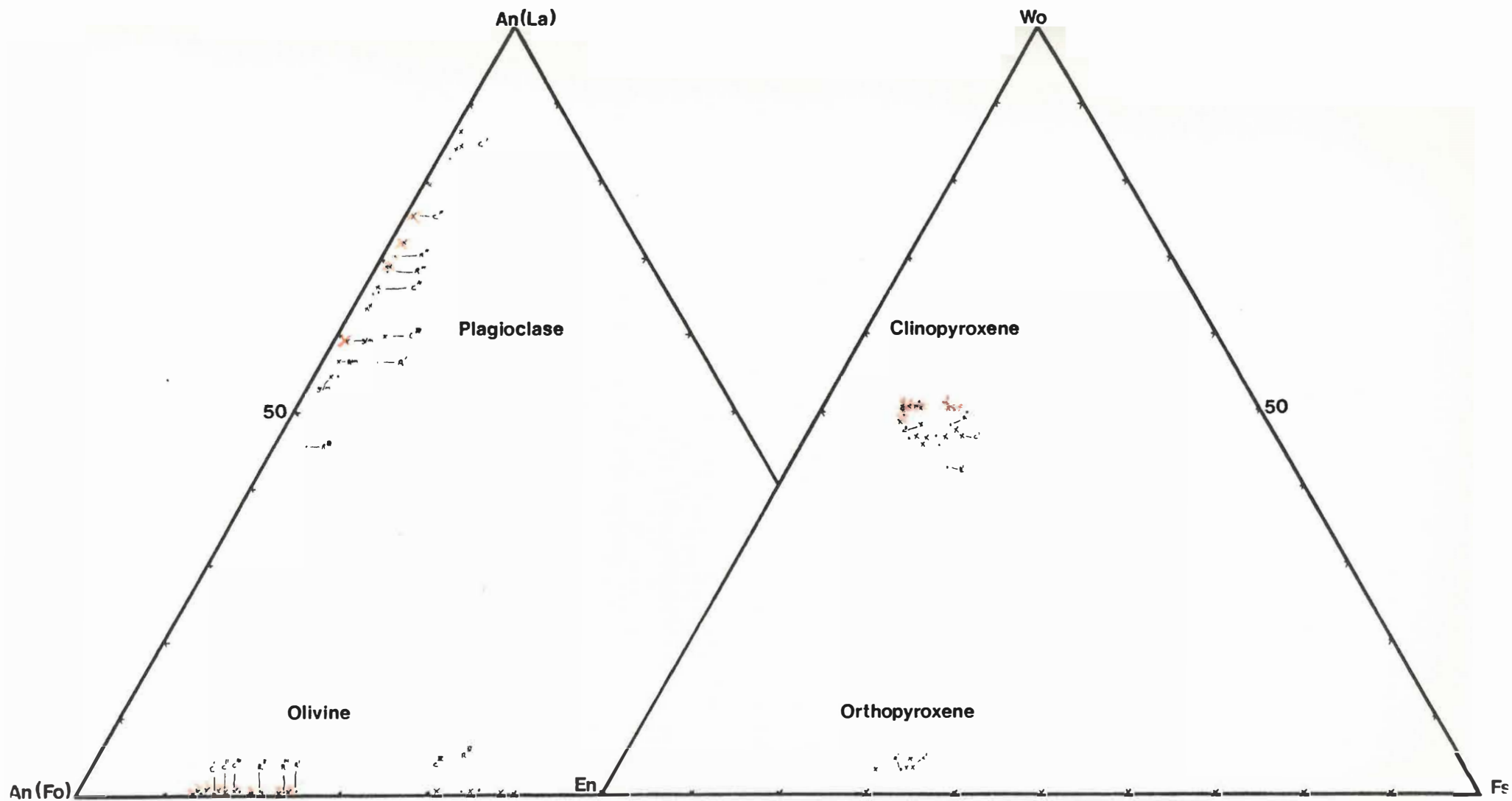


Fig. 5.1 - Mineral Compositions (Plagioclase, Olivine, Clino and Orthopyroxenes) (mol. %) g/m refers to groundmass, x or c to core, . or r to rim. Okete Volcanics are in red.

Resorption occurs mainly in the andesites or basaltic andesites but may occur in the Karioi basalts. It is generally limited in effect to the cores of phenocrysts. However, in some rocks resorption pervades almost the entire crystal, for example W17116 (Fig. 5.2).

Inclusions of small apatite and pyroxene crystals occur in most phenocrysts. Twinning appears to have been on Carlsbad and albite twin laws (Fig. 5.3). Albite twinning is the most common especially in the basalts, but is less frequent in the andesites where some phenocrysts show little or no twinning, and zoning is usually pronounced.

The composition of the feldspars is generally calcic but ranges from  $An_{85}$  -  $An_{55}$  and falls in the labradorite and bytownite compositional fields. The Okete types are, on the whole, more calcic than the Karioi volcanics and range between 70 - 80% (Fig. 5.1).

Zoning is common in some crystals. In one phenocryst (W17040) the composition ranges from  $An_{85}$  -  $An_{56}$  from core to rim which is the entire range of the composition of all the plagioclases examined. Reversed zoning was observed in one crystal (W17027) but only to a limited degree ( $An_{66}$  -  $An_{68}$ ). Groundmass plagioclase compositions ( $An_{58}$  -  $An_{55}$ ) tended to be more sodic than core and rim values.

Generally the large phenocrysts in the porphyritic basalts show a limited degree of alignment. The Okete Volcanics tend to show strong flow alignment, with the small plagioclase laths in the groundmass showing a pilotaxitic texture. In the basaltic andesites, andesites and some of the basalts, where the phenocrysts are smaller and tabular, alignment of the plagioclase due to flow is rarely observed.

### 5.3 ORTHOPYROXENES

Orthopyroxene phenocrysts occur mainly in the andesites, (W17016, W17082) some basaltic andesites (W17083, W17084, W17090, W17091), and are rare in the Karioi coarse grained and porphyritic basalts (W17023, W17029). Orthopyroxene is never abundant and only occurs as small euhedral to

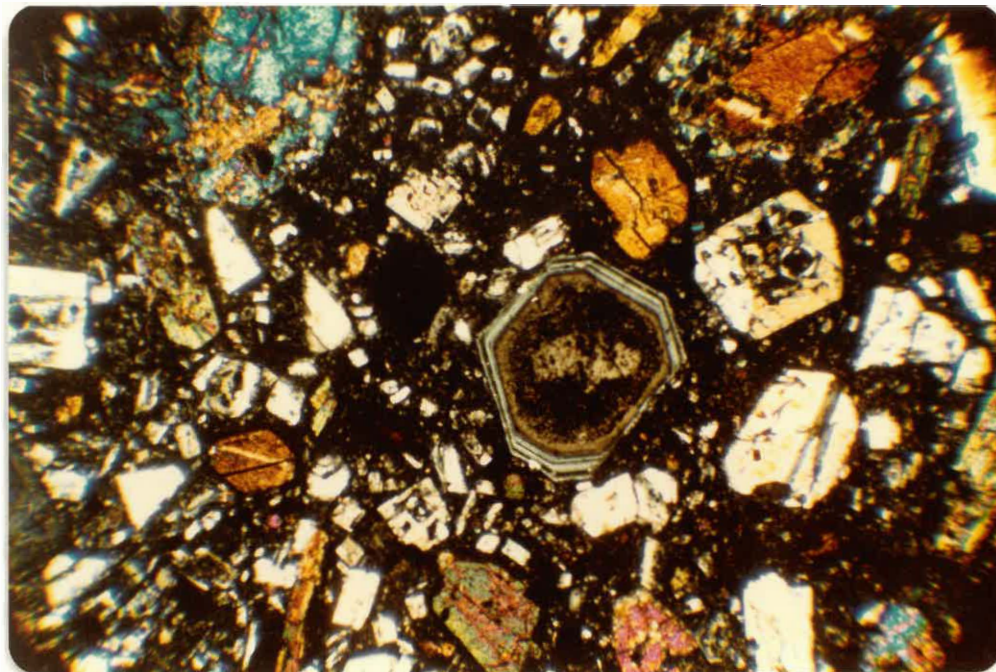


Fig. 5.2 - Zoned plagioclase which is almost completely resorbed except for the rim, in a Karioi andesite (W17059), Jacksons Rock. Crossed nicols (60x).

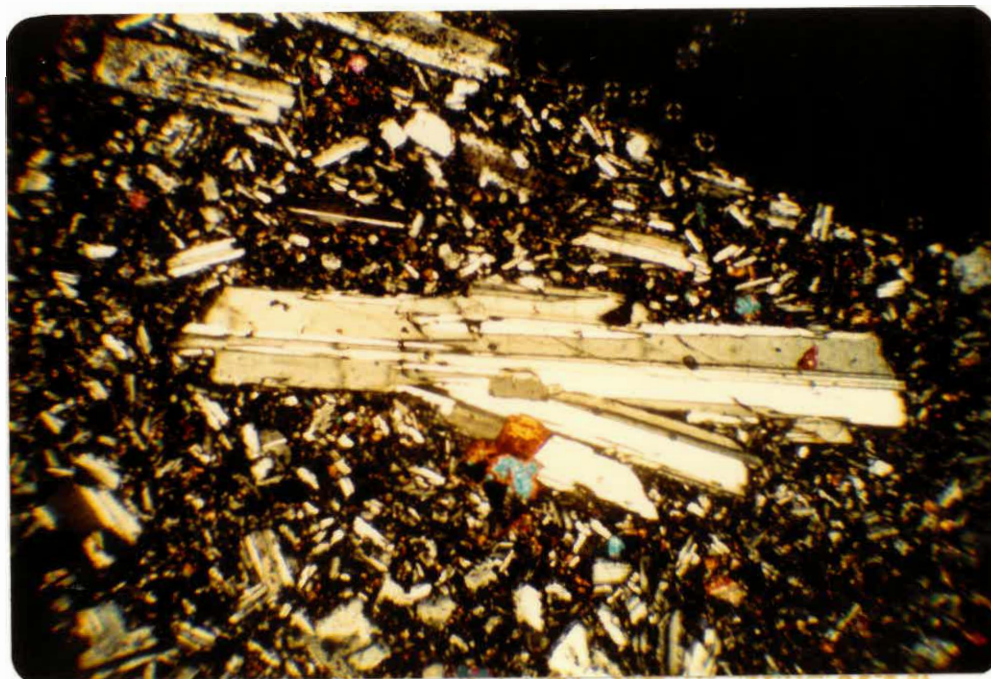


Fig. 5.3 - Plagioclase showing carlsband and albite twinning with inclusions of apatite (small dark mineral right centre) and clinopyroxene, in a Karioi porphyritic basalt (W17027). Crossed nicols (32x).

subhedral tabular prisms, generally 0.3 mm long (see Fig. 4.2).

Pleochroism is not common but the larger crystals are weakly pleochroic from pale pink to pale green. Most phenocrysts show an embayed outline indicating some resorption has taken place. Inclusions of opaques are common.

Orthopyroxene frequently shows a glomeroporphyritic texture which may be in association with either titanomagnetites which are more common, or clinopyroxene phenocrysts (Fig 4.2).

Orthopyroxene compositions range from  $En_{70}$  -  $En_{66}$  (from microprobe data) and according to the nomenclature of Poldervaart (1947) they fall into the hypersthene compositional field.

#### 5.4 CLINOPYROXENE

Clinopyroxenes occur in all the volcanic rocks of the area as large and small phenocrysts and as granular crystals in the groundmass.

The range in size is extremely variable. Phenocrysts in the porphyritic basalts are up to 10 mm in length and width (for example W17028) and are clearly and characteristically seen in hand specimen. More commonly they occur as smaller (0.5 - 0.7 mm) phenocrysts. Generally they show little or no pleochroism, but some phenocrysts were distinctly pink (for example W17146) and may be titaniferous.

The crystals are generally subhedral and are commonly glomeroporphyritic, appearing as clusters within opaques and olivines (Fig. 5.4).

Inclusions of opaques, apatite, plagioclase, phlogopite, and alteration products of olivine all occur in clinopyroxenes, with opaques being the most prominent. Intergrowths may also occur between individual clinopyroxene phenocrysts (Fig. 5.5).

The composition of the clinopyroxenes is unusual and Karioi clinopyroxenes are distinctive from those of the Okete volcanics (Fig. 5.1). The Karioi types lie in the salite field of Poldervaart

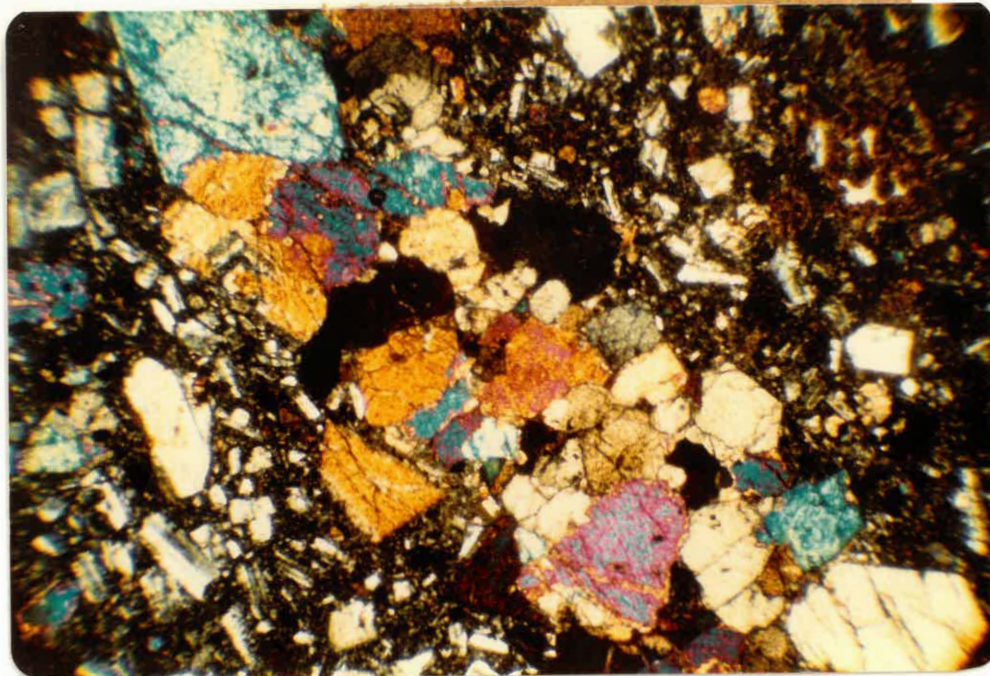


Fig. 5.4 - Clinopyroxenes showing glomeroporphyritic texture in a Karioi olivine basaltic andesite (W17067). This texture is common throughout the various rock types in the mapping area. Crossed nicols (60x).

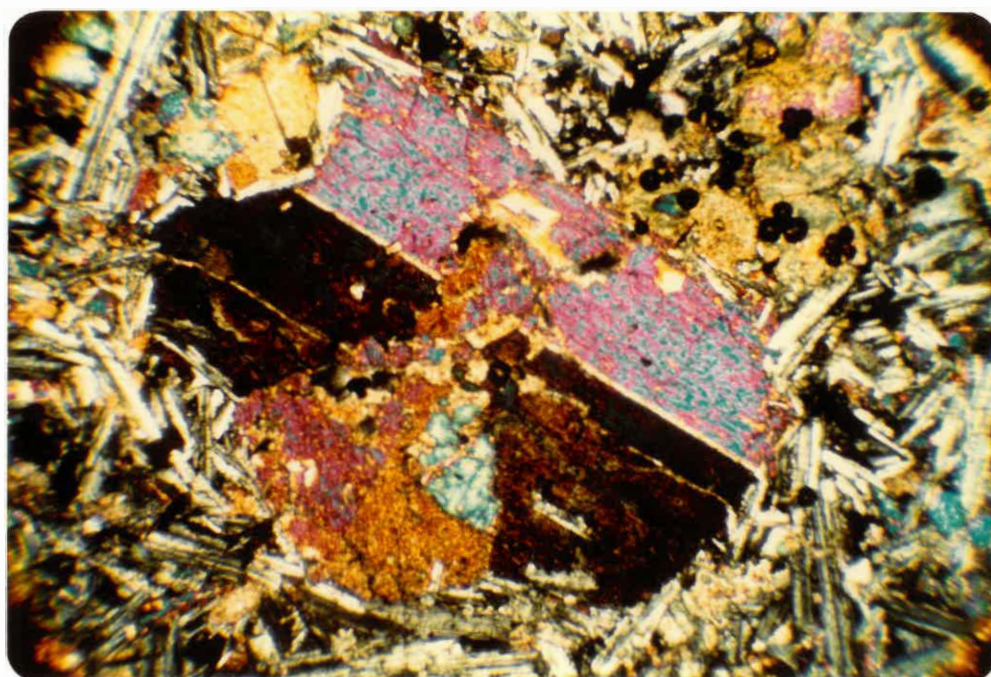


Fig. 5.5 - Large zoned and intergrown clinopyroxene in a coarse grained Karioi basalt (W17050). Highly birefringent bowlingite occurs in top right and is common in this rock. Crossed nicols (32x).

and Hess (1951) with compositions of  $Wo_{45} En_{45} Fs_{10}$  -  $Wo_{40} En_{50} Fs_{20}$  and the Okete values lie on the sollastonite side of the salite boundary with values of  $Wo_{50} En_{42} Fs_8$  -  $Wo_{52} En_{52} Fs_{15}$ .

The differences in composition between Karioi and Okete Volcanics clinopyroxenes is presented in Table 1 and shows that Okete clinopyroxenes are relatively silica and iron poor but richer in  $TiO_2$ ,  $Al_2O_3$ , CaO and MgO.

TABLE 5.1 - Analysis of Representative Clinopyroxenes

Analysis	W17083 (Karioi Volcanics)		W17046 (Okete Volcanics)	
	Phenocryst Core	Phenocryst Rim	Phenocryst Core	Phenocryst Rim
SiO <sub>2</sub>	55.04	56.54	51.50	51.08
TiO <sub>2</sub>	0.42	0.31	1.31	1.53
Al <sub>2</sub> O <sub>3</sub>	2.00	1.76	5.44	6.25
FeO	9.80	10.24	5.76	6.49
MnO	0.49	0.52	0.07	0.10
MgO	11.13	12.38	13.16	12.81
CaO	20.28	18.77	23.23	23.07
Na <sub>2</sub> O	0.32	0.24	0.35	0.41
K <sub>2</sub> O	0.00	0.00	0.00	0.00
TOTAL	99.50	100.77	100.82	101.74

Zoning is common and is clearly visible in many of the large phenocrysts. Chemically they tend to get less calcic and more iron rich from core to rim.

Twinning is also common with both simple and multiple twinning occurring (Fig. 4.4).

## 5.5 OLIVINE

Olivine is present in all rocks except hornblende basaltic andesites and andesites. It occurs mainly as phenocrysts but occasionally in the groundmass. The phenocrysts are generally subhedral and range in size from 0.3 - 3.0 mm (see Fig. 4.5).

The phenocrysts are typically prismatic but may be subhedral and tabular. They show a gradation in alteration, commonly to iddingsite and less commonly to bowlingite, serpentine and chlorite. Alteration is common on the rims but invades along fractures and in some cases olivine may be completely altered. These alteration products may also occur in the groundmass representing totally altered groundmass olivines.

Compositions of olivines vary between the Okete and Karioi types: Okete Volcanics have olivine compositions from Fo<sub>87</sub> - Fo<sub>74</sub> and the Karioi Volcanics range from Fo<sub>59</sub> - Fo<sub>50</sub>. Representative olivine compositions of cores and rims for Okete Volcanics are presented in Table 5.2. Both the Okete and Karioi Volcanics are comparable with the South Auckland Basalts which range from Fo<sub>85</sub> - Fo<sub>55</sub> (Rafferty and Heming, 1979).

The Okete and Karioi Volcanics show some zoning with rims more fayalitic than the cores, for example, W17035 ranges from Fo<sub>84</sub> in the core to Fo<sub>74</sub> in the rim.

Inclusions of opaques and pyroxenes are common in olivine phenocrysts. Olivine may also show a glomeroporphyritic texture which may be in association with pyroxenes and opaques. This association with opaques is quite common, particularly in the Okete olivine basalts.

TABLE 5.2 - Representative Olivine Compositions

Analyses	Okete Volcanics (W17035)	
	Phenocryst Core	Phenocryst Rim
SiO <sub>2</sub>	30.84	41.31
TiO <sub>2</sub>	0.00	0.00
Al <sub>2</sub> O <sub>3</sub>	0.00	0.02
FeO	17.06	21.00
MnO	0.14	0.29
MgO	51.29	35.23
CaO	0.16	0.29
Na <sub>2</sub> O	0.00	0.00
K <sub>2</sub> O	0.00	0.00
TOTAL	99.51	98.13

## 5.6 HORNBLLENDE

Hornblende phenocrysts frequently occur in both the basaltic andesites and andesites, and as resorbed phenocrysts in the Karioi basalts (W17036).

Hornblende commonly forms subhedral to euhedral crystals averaging 0.5 - 1.0 mm in size but may be up to 11 mm in length.

Hornblende usually shows pleochroism from green to straw brown. An amphibole, possibly kaersutite, pleochroic from yellow-orange to red brown, occurs in a xenolith in W17099.

The hornblendes all have reaction rims, usually composed of many minute granular opaques. Resorption varies from almost total (for example W17053) where only the general relict outline of the phenocryst remains, to partially resorbed phenocrysts with opaque rims and patches of phenocryst remaining in the core, and to some only slightly resorbed phenocrysts with reaction rims for example, W17057 (Fig. 5.6, 5.7). Phlogopite and augite are often associated with partially resorbed phenocrysts, commonly restricted to the cores.

Composition of selected hornblendes were determined by microprobe (see Table 5.3) and the end-members were recalculated following the procedures presented by Deer et al. (1969). Since the microprobe cannot determine the oxidation state of iron or water contents, the results have been calculated on an anhydrous basis based on 23 oxygens, following Hurlbutt and Klein (1977). Although not strictly correct in terms of amphibole structure, similar and comparable results to full analysis may be obtained.

From molecular proportions, the composition of W17083(2) was found to be CaO 30%, MgO 44%, FeO 26%. Its composition varies from the average hornblende (Deer et al., 1969) and tends to be intermediate between hornblende and a more titanium-rich oxy-hornblende or kaersutite.

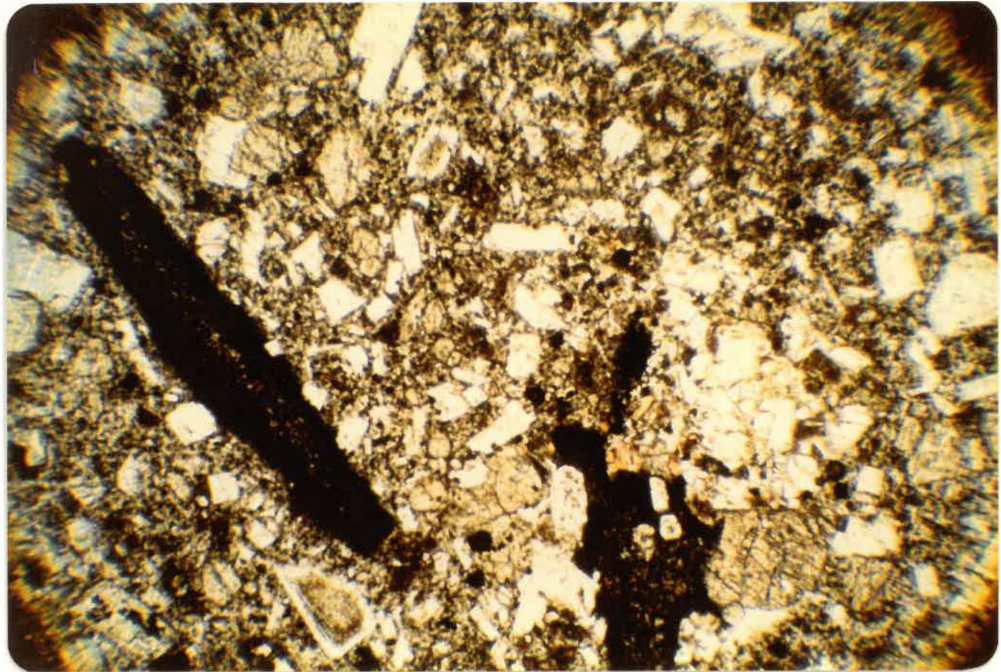


Fig. 5.6 - Almost completely resorbed tabular hornblende phenocrysts (left) in a Karioi olivine basaltic andesite (W17067). Phlogopite occurs above the reabsorbed hornblende (centre) as small brown flakes. Plane polarised light (32x).

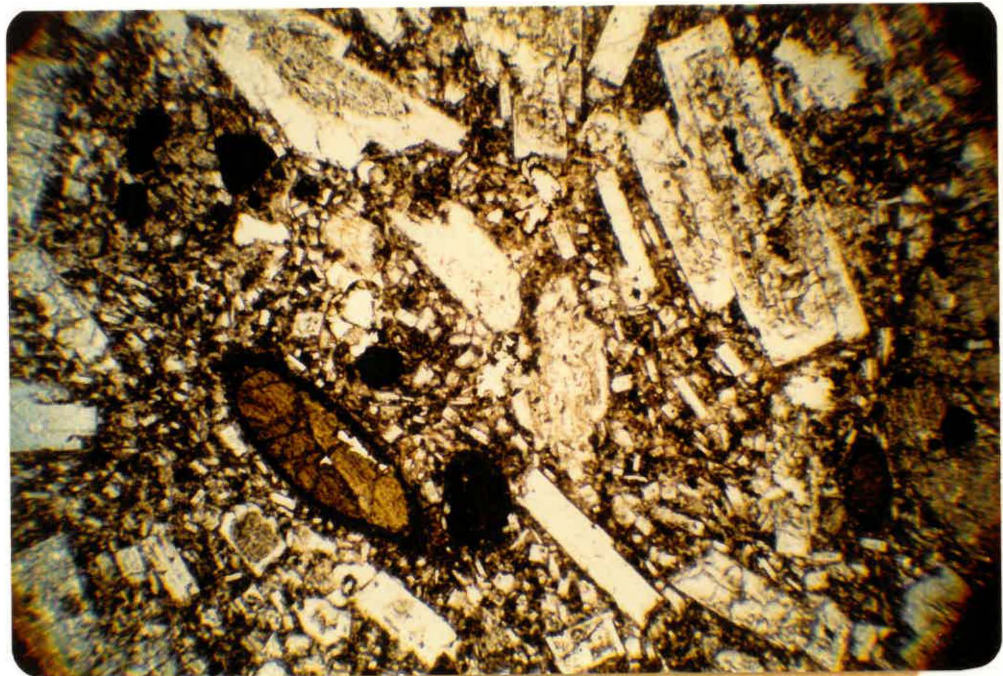


Fig. 5.7 - Partially resorbed hornblende with embayed outline in a hornblende basaltic andesite (W17083). Partially resorbed plagioclase are also prominent in a medium grained groundmass. Plane polarised light (32x).

TABLE 5.3 - Compositions of core and rim of hornblende from a hornblende basaltic andesite.

REPRESENTATIVE ANALYSES			RECALCULATION OF W17083 (2)	
Oxide	W17083 core (1)	W17083 core (2)	No of ions in formula	
SiO <sub>2</sub>	43.01	44.03	6.3745	) 8.00
TiO <sub>2</sub>	2.27	3.34	0.3642	
Al <sub>2</sub> O <sub>3</sub>	13.47	12.40	2.0496	
FeO	13.07	12.94	1.5676	) 5.01
MnO	0.12	0.19	0.0235	
MgO	12.61	12.19	2.6307	) 2.67
CaO	11.64	11.52	1.7868	
Na <sub>2</sub> O	1.50	2.71	0.7621	) 2.67
K <sub>2</sub> O	1.10	0.63	0.1183	
TOTAL	98.80	99.95		
End members for W17083 (2)		0.2054	CaO	29.85%
		0.3024	MgO	43.95%
		0.1802	FeO	26.20%
		<u>0.6880</u>		

### 5.7 MICAS

Henderson and Grange (1926) mention a straw coloured mica (anomite) in one rock (analysis number 11). Anomite is a 2M polymorph of biotite (Deer et al., 1969) but the mineral has never been found by the present author in any rock in the Raglan - Pirongia area. The rock is described as a coarse grained basalt by Henderson and Grange (1926), and is probably from the Karioi Volcanics, but it has not been located. However, micas of two different types have been observed in the mapping area.

### 5.7.1 Phlogopite

Rare flakes of phlogopite occur in some of the Karioi basalts, olivine basaltic andesites, and in some of the Okete lavas, as small anhedral flakes 0.1 - 0.3 mm in length, which are pleochroic from pale yellow to dark red-brown (Fig. 5.8).

Compositions of representative micas are shown in Table 5.4. W17092 (1) appears to be phlogopite and similar analyses have been obtained from micas in rocks from the Pirongia Volcanics (R.M. Briggs pers. comm.).

### 5.7.2 Muscovite

The second mica analysis on Table 5.4 is from a coarse grained Karioi basalt and appears to be muscovite, which is high in SiO<sub>2</sub>. Optically the mineral appeared to be pleochroic and of the phlogopite type, but possibly very thin layers of muscovite may occur interleaved with phlogopite. Muscovite was not identified petrographically in any rock.

TABLE 5.4 - Representative mica analyses from Karioi Volcanics.

Analyses	Phlogopite W17092(1)	Muscovite W17092(2)
SiO <sub>2</sub>	41.59	66.30
TiO	5.69	0.13
Al <sub>2</sub> O <sub>3</sub>	11.39	19.77
FeO	9.22	0.38
MnO	0.66	0.00
MgO	17.78	0.01
CaO	0.00	0.58
Na <sub>2</sub> O	0.63	4.10
K <sub>2</sub> O	8.96	8.09
TOTAL	95.32	99.37

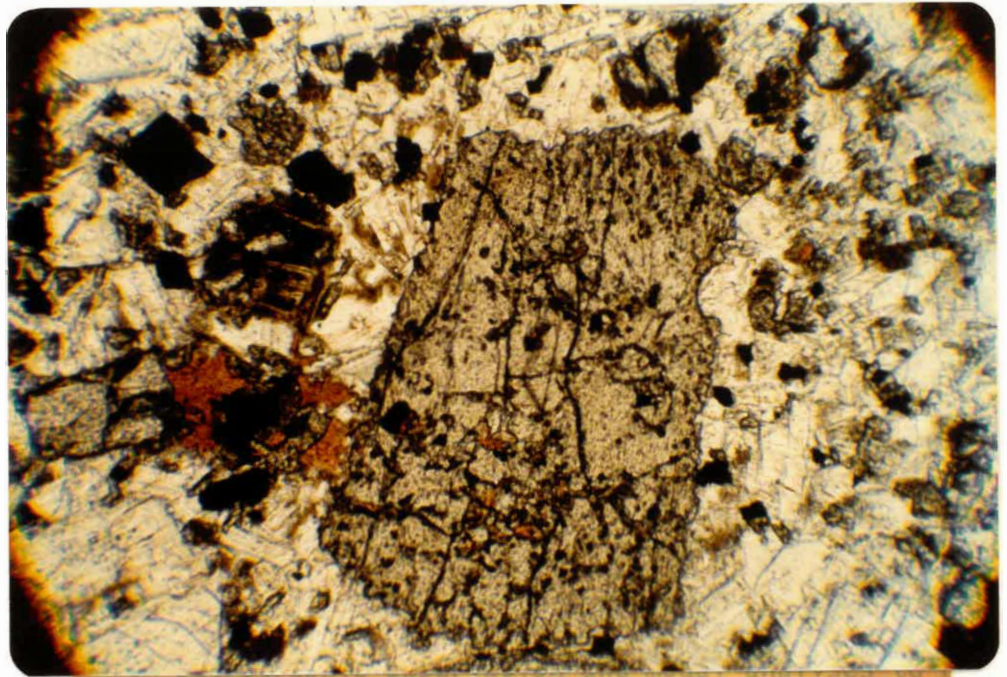


Fig. 5.8 - Typical coarse grained Karioi basalt (W17092) with reddy-brown flakes of phlogopite and a large clinopyroxene which shows inclusions of phlogopite and opaques and titanomagnetite are set in coarse grained groundmass of plagioclase, clinopyroxene and minor apatite needles. Plane polarised light (60x).

## 5.8 TITANOMAGNETITES

From petrographic characteristics, polished section examination and microprobe analysis, it is likely that all the opaques in the Karioi and Okete Volcanics are titanomagnetites. They have considerable  $TiO_2$  and iron, and are  $Cr_2O_3$  and  $V_2O_3$  bearing. Ilmenite was not observed in any of the polished sections.

The titanomagnetites are found in all lava types as both phenocrysts and smaller crystals in the groundmass, and as inclusions in pyroxene and olivine phenocrysts. Generally they occur as anhedral to subhedral granules (Fig. 5.9) but skeletal varieties may be present and are most common in the olivine basalts and coarse grained Karioi basalts (Fig. 5.10). Phenocrysts are varied in size and average 0.1 - 0.2 mm but may be up to 0.5 mm in the coarser grained Karioi basalts.

## 5.9 APATITE

Small (less than 0.1 mm) euhedral, prismatic crystals of apatite occur as inclusions in plagioclase phenocrysts and in the groundmass. Apatite appears from petrographic observation and modal analyses to be most common but as an accessory mineral in the coarse grained Okete Volcanics although this may only be due to the factor of their larger size in these rocks.

An unusual red-brown mineral with high relief, straight extinction, low order birefringence and basal cleavage occurs in W17108. This mineral was not seen in any other rock in the mapping area; however, analysis by electron microprobe on a similar mineral in a Pirongia Volcanics lava suggests that the mineral is apatite (R.M. Briggs, pers. comm.).

## 5.10 CALCITE

Calcite (identified from XRD analysis) occurs in a number of rocks as irregular interstitial pools in the groundmass (Fig. 5.11) in both lavas and volcanic breccias. In a Karioi porphyritic basalt (W17024), it is



Fig. 5.9 - Skeletal opaques in a coarse grained Karioi basalt (W17052). Olivine phenocrysts which have now been partially altered to brownish bowlingite and serpentine occur at top right. Plane polarised light (60x).

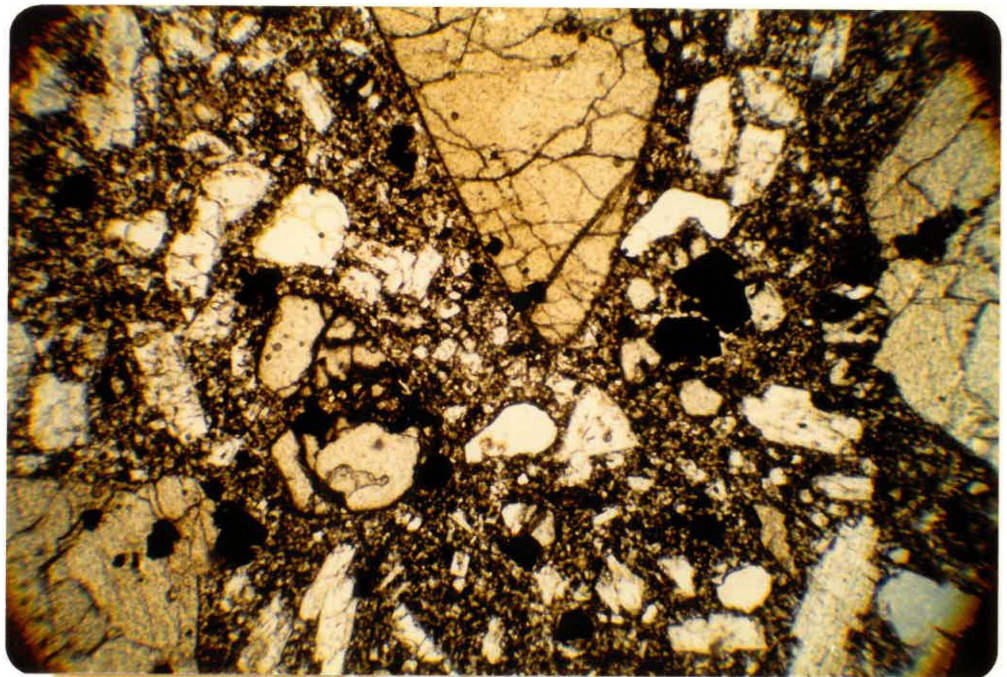


Fig. 5.10 - Common association of subhedral opaques with olivine (left centre) and clinopyroxene (right centre) in a Karioi porphyritic basalt (W17051). Plane polarised light (32x).

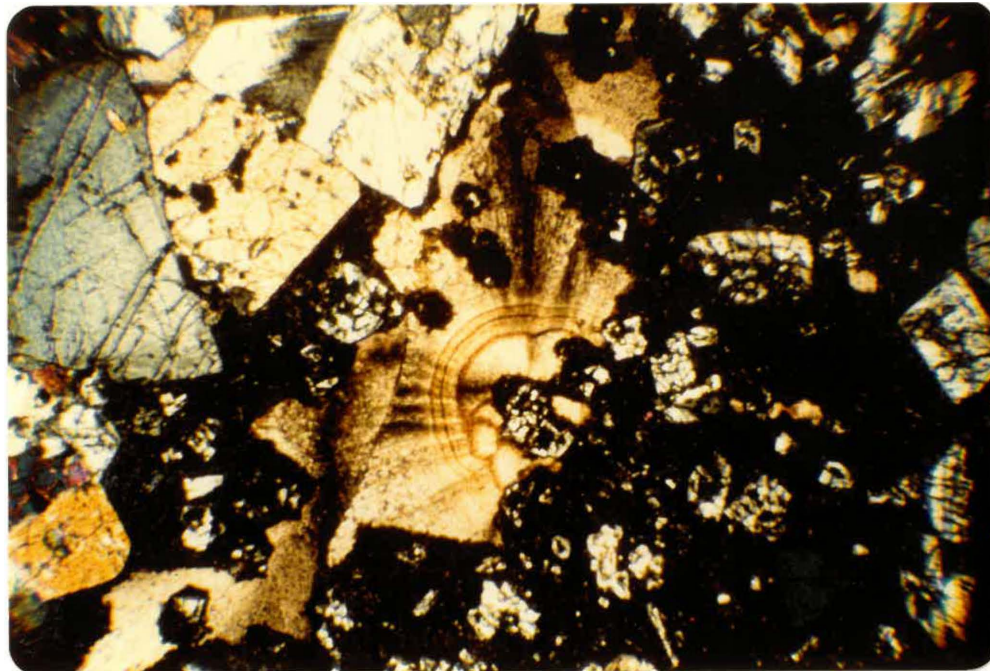


Fig. 5.11 - Calcite pools in the intersertal groundmass of an olivine basaltic andesite (W17102). Calcite shows a fibrous nature and has brown bands perpendicular to these fibres. Cognate xenolith inclusions occur top left. Crossed nicols (32x).

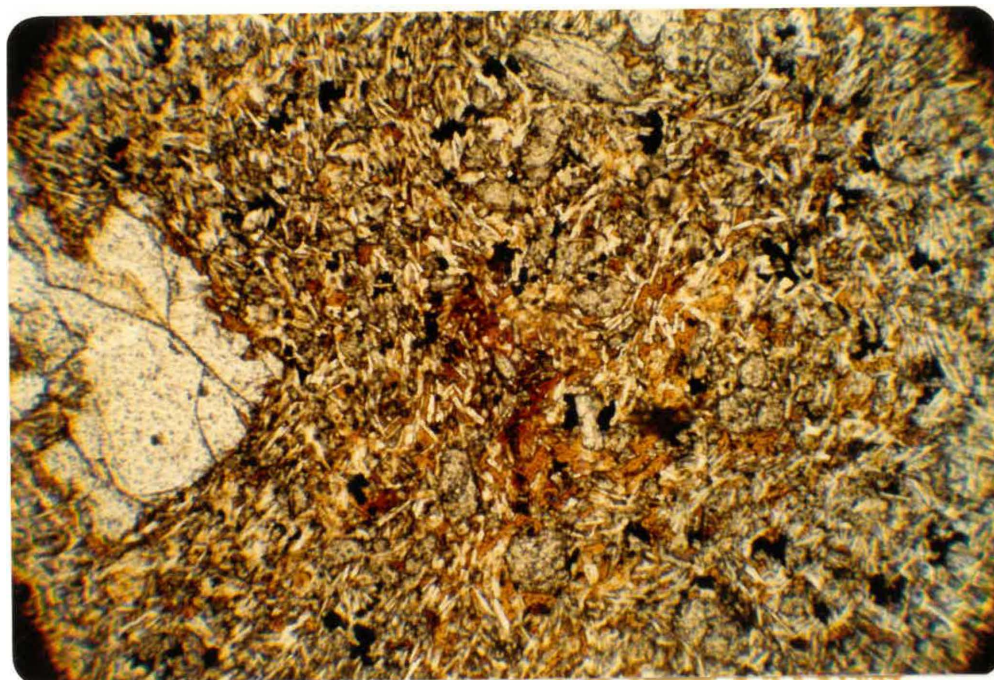


Fig. 5.12 - Reddy orange iddingsite dominating the fine grained groundmass of a pilotaxitic Type III Okete olivine basalt lava (W17043). An olivine phenocryst to left shows only minor alteration. Plane polarised light (60x).

common and shows brown concentric bands perpendicular to the fibrous nature of the material. It is more abundant in the volcanic breccias (W17055, W17134).

#### 5.11 ALTERATION PRODUCTS

Iddingsite and other alteration products of olivine (bowlingite, serpentine and chlorite) are common in the Karioi and Okete basalts. These minerals occur in the Ngatutura, South Auckland (Rafferty, 1977) and Auckland olivine basalts (Searle, 1961) and are common olivine alteration products (Shelley, 1975).

Iddingsite is the most prevalent, and is a common product of deuteric alteration, altering both the groundmass and phenocrystic olivines (Fig. 5.12). It shows a variety of colours ranging from orange to red-brown to dark red. In one rock (W17036) iddingsite was almost isotropic and occurred in concentric, alternating yellow and red bands.

The other alteration products of olivine, i.e. bowlingite, serpentine and chlorite, commonly occur in the groundmass particularly in the coarse grained lavas. In W17052 for instance, large amounts of bowlingite and serpentine have partially altered the rims and invaded olivine phenocrysts along fractures, and also form patches in the groundmass. The highly birefringent bowlingite is also present in spherical amygdules of about 2 mm diameter which are plainly visible in hand specimen. Some of these alteration products were also observed in small amounts along fractures and cleavages of clinopyroxenes.

#### 5.12 GLASS

Glass was observed in the groundmass of most of the andesites, some of the basaltic andesites and in two olivine basalts. However, glass is usually not seen in large quantities in the Karioi lavas and most of the groundmass textures are intergranular or intersertal.

Glass is more prevalent in the Type V Okete olivine basalts (Chapter 4.5) where the groundmass is vitrophyric. In plane polarised light an intersertal texture with large masses of brown glass and small plagioclase laths is observed.

The groundmass of the volcanic breccias (Chapter 4.6) is almost totally brown glass or palagonite.

## CHAPTER SIX

## PETROCHEMISTRY AND PETROGENESIS

6.1 INTRODUCTION

Thirteen new analyses have been determined for the Karioi and Okete Volcanics and are presented in Table 6.1. These were analysed by X-ray fluorescence at the Analytical Facility, Geology Department, Victoria University of Wellington and analytical methods are discussed in Appendix II. Ten previously published results are presented in Table 6.3.

6.1.1 Norm Calculations

CIPW norms were calculated by the PDP 11/70 computer at Waikato University (see Appendix II) and are presented in Table 6.2 and 6.4.

Results from CIPW calculations can be calculated in weight or cation percents (the Barth Niggli Katanorm of Chayes and Metais, 1964). Results from the two systems are generally similar but iron mineral values are smaller in the cation norm and more relative to modal data (Irvine and Baragar, 1971). Because of this, and their general suitability to graphical projection the CIPW norms in this thesis are presented as cation percents.

The  $\text{Fe}_2\text{O}_3/\text{FeO}$  ratio can appreciably affect the norm as Coombs (1963) demonstrated. The effect is greater for those lavas which plot close to the "critical plane of silica undersaturation" in Yoder and Tilley's (1962) basalt tetrahedron diagram (Rafferty, 1977). If the ferric iron is reduced hy is increased at the expense of ol, and ab at the expense of ne, and a more undersaturated norm is produced (shown in Coombs, 1963: 233; and Rafferty, 1977: 95).

TABLE 6.1 - MAJOR ELEMENT ANALYSES OF SELECTED ROCKS IN THE MT KARIOI REGION (WT %)

Location of samples and descriptions of rock types are given in Table IV.1. LOI and FeO were determined by S.G. Matheson (see Appendix II). Analyst: K. Palmer, Victoria University.

TYPE	KARIOI VOLCANICS							OKETE VOLCANICS					
	W17016	W17027	W17040	W17085	W17084	W17085	W17092	W17007	W17012	W17039	W17046	W17029	W17145
SiO <sub>2</sub>	56.50	49.72	49.37	52.13	50.02	48.49	47.19	47.34	45.87	44.89	45.21	43.57	43.47
TiO <sub>2</sub>	1.01	2.16	0.94	0.84	1.26	0.92	0.92	1.74	1.85	2.07	1.94	2.11	2.34
Al <sub>2</sub> O <sub>3</sub>	17.55	17.95	16.67	17.77	16.53	18.55	16.10	13.53	13.03	13.28	12.98	12.20	11.76
Fe <sub>2</sub> O <sub>3</sub>	3.07	3.07	3.56	3.83	3.95	2.44	2.34	1.97	3.61	4.89	1.95	3.40	1.56
FeO	3.97	7.02	5.89	4.46	4.59	6.93	7.38	8.35	7.57	6.30	8.88	8.66	10.07
MnO	0.14	0.18	0.19	0.15	0.15	0.17	0.17	0.18	0.18	0.20	0.17	0.18	0.21
MgO	3.15	3.75	6.32	3.61	5.89	5.37	7.32	10.73	10.78	10.33	10.92	12.91	13.45
CaO	6.60	8.19	11.04	7.54	8.35	9.95	11.21	10.54	9.97	10.88	10.42	10.68	10.19
Na <sub>2</sub> O	3.66	3.77	2.44	5.26	5.64	3.41	2.77	2.67	2.29	2.54	4.56	1.38	3.32
K <sub>2</sub> O	2.21	1.78	2.34	1.50	1.64	1.23	1.44	1.15	0.88	0.58	1.03	0.98	1.18
P <sub>2</sub> O <sub>5</sub>	0.41	0.51	0.32	0.24	0.35	0.22	0.23	0.36	0.41	0.45	0.41	0.46	0.63
LOI	1.58	1.59	1.72	1.84	1.84	1.94	2.16	1.05	2.23	2.48	1.57	2.94	0.95
TOTAL	99.85	99.69	100.80	99.17	100.21	99.62	99.23	99.61	98.67	98.89	100.04	99.47	99.13
DI (Wt%)	52.69	42.42	34.42	51.77	48.91	34.96	29.22	27.75	24.58	24.92	31.43	17.47	25.04
A (Wt%)	36.55	28.62	23.26	36.23	33.53	23.94	19.81	15.36	12.61	12.66	20.45	8.64	15.21
F (Wt%)	43.84	52.04	45.99	44.43	39.34	48.35	45.74	41.50	44.69	45.41	39.61	44.13	39.32
M (Wt%)	19.61	19.34	30.75	19.35	27.13	27.71	34.45	43.14	42.90	41.92	39.94	47.24	45.47

TABLE 6.2 - CIPW NORMS (CATION %) OF SELECTED ANALYSED ROCKS IN MT KARIOI REGION  
Location of samples and rock descriptions are given in Table IV.1

TYPE	KARIOI VOLCANICS							OKETE VOLCANICS					
	W17016	W17027	W17040	W17083	W17084	W17085	W17092	W17007	W17012	W17039	W17046	W17029	W17145
Qtz	8.19	-	-	-	-	-	-	-	-	-	-	-	-
Or	13.33	10.79	13.98	9.01	9.65	7.41	8.73	6.83	5.37	3.55	6.03	5.98	6.95
Ab	33.56	34.74	22.03	44.23	30.80	28.48	19.03	20.29	21.25	23.60	10.18	12.80	6.57
An	25.46	27.51	27.95	20.79	14.88	32.31	27.95	21.64	23.44	23.93	11.80	25.01	13.66
Ne	-	-	0.08	2.27	11.77	1.65	3.89	2.28	-	-	18.24	-	13.89
Di	4.19	8.62	20.28	12.52	19.27	13.26	22.05	22.83	19.93	23.12	29.42	21.31	26.11
(Wo)	2.10	4.31	10.14	6.26	9.64	6.63	11.03	11.42	9.97	11.56	14.71	10.66	13.06
(En)	1.58	2.73	7.67	4.70	8.21	4.30	7.68	8.66	8.09	10.21	11.06	8.63	9.95
(Fs)	0.51	1.58	2.47	1.56	1.43	2.33	3.34	2.75	1.88	1.35	3.65	2.03	3.10
Hy	9.67	6.03	-	-	-	-	-	-	6.42	0.56	-	4.22	-
(En)	7.30	3.82	-	-	-	-	-	-	5.21	0.50	-	3.42	-
(Fs)	2.37	2.21	-	-	-	-	-	-	1.21	0.07	-	0.80	-
Ol	-	4.84	9.91	5.42	7.04	12.50	14.04	20.86	16.14	15.98	18.78	22.97	26.63
(Fo)	-	3.06	7.49	4.07	5.99	8.12	9.79	15.83	13.09	14.11	14.12	18.59	20.30
(Fa)	-	1.78	2.42	1.35	1.05	4.39	4.25	5.03	3.04	1.87	4.66	4.38	6.33
Mt	3.28	3.29	3.77	4.07	4.11	2.60	2.15	2.07	3.90	5.29	2.02	3.67	1.63
Il	1.44	3.09	1.32	1.19	1.75	1.31	1.31	2.44	2.66	2.98	2.68	3.04	3.25
Ap	0.88	1.09	0.68	0.51	0.73	0.47	0.49	0.76	0.89	0.97	0.85	0.99	1.31

TABLE 6.3 - PREVIOUSLY PUBLISHED WHOLE ROCK MAJOR ELEMENT ANALYSES (WT%)

H + G = Henderson and Grange (1926)

K, V = Rodgers *et al.* (1975)

Location of samples and descriptions of rock types are given in Table IV.2

TYPE	KARIOI VOLCANICS						OKETE VOLCANICS				
	H+G 5	H+G 6	H+G 7	H+G 10	H+G 11	H+G 9	H+G 13	H+G 14	H+G 17	K	V
SiO <sub>2</sub>	59.63	52.99	53.54	49.49	49.99	50.16	45.69	46.69	44.04	45.08	46.25
TiO <sub>2</sub>	0.60	1.31	1.20	1.10	1.26	2.16	2.09	2.44	2.44	2.56	2.10
Al <sub>2</sub> O <sub>3</sub>	17.69	16.45	16.72	16.93	17.84	17.45	12.95	12.69	12.47	11.34	12.22
Fe <sub>2</sub> O <sub>3</sub>	3.75	5.29	4.41	4.79	4.45	3.79	5.92	2.46	2.60	2.91	3.00
FeO	2.29	3.84	4.27	5.78	4.89	6.57	5.96	9.79	9.85	6.81	9.28
MnO	0.17	0.15	0.12	0.15	0.15	0.14	0.16	0.17	0.18	0.00	0.16
MgO	2.03	4.24	4.06	5.43	4.50	3.72	10.58	10.79	11.63	12.83	10.38
CaO	6.70	7.78	7.94	10.38	8.53	8.19	11.02	9.18	10.70	9.33	9.43
Na <sub>2</sub> O	3.94	3.33	2.84	2.75	2.92	3.86	2.41	3.02	2.52	2.69	3.53
K <sub>2</sub> O	2.03	2.05	1.70	1.11	1.96	2.05	0.94	1.24	1.10	0.93	1.66
P <sub>2</sub> O <sub>5</sub>	0.22	0.44	0.15	0.25	0.37	0.53	0.52	0.44	0.57	0.96	0.53
H <sub>2</sub> O <sup>+</sup>	0.41	0.78	1.30	0.60	1.50	0.35	0.90	0.39	0.84	3.72	1.10
H <sub>2</sub> O <sup>-</sup>	0.71	1.40	1.36	0.94	1.41	0.63	0.80	0.70	1.11	0.72	0.59
TOTAL	100.17	100.05	99.61	99.70	99.77	99.60	99.94	100.00	100.05	99.88	100.23
DI (Wt5)	58.88	46.51	46.51	31.28	39.91	44.78	25.95	30.73	23.45	28.26	33.32
A (Wt%)	45.52	28.69	26.27	19.44	26.07	29.56	12.98	15.60	13.07	13.83	18.64
F (Wt%)	43.02	48.69	50.23	53.23	49.89	51.83	46.03	44.87	44.95	37.14	44.09
M (Wt%)	14.46	22.61	23.50	27.34	24.04	18.61	40.99	39.52	41.99	49.03	37.27

TABLE 6.4 - CIPW NORMS OF PREVIOUSLY PUBLISHED ANALYTICAL DATA (CATION %)

H+G = Henderson and Grange (1926, p70) but volatiles and minor trace elements were ignored and totals recalculated to give comparable figures to Table 6.2. K + V = Rodgers *et al.* (1975), and are Okete olivine basalts from Kirikiripu Quarry and Bridal Veil Falls respectively. See Table IV.2 for sample sites and rock descriptions.

	KARIOI VOLCANICS						OKETE VOLCANICS				
	H+G 5	H+G 6	H+G 7	H+G 10	H+G 11	H+G 9	H+G 13	H+G 14	H+G 17	K	V
Qtz	12.72	5.94	8.74	1.38	3.46	-	-	-	-	-	-
Or	12.17	12.48	10.48	6.74	11.94	12.37	5.66	7.36	6.59	5.67	9.86
Ab	35.89	30.81	26.60	25.39	27.03	35.41	22.04	22.26	12.67	24.93	17.07
An	24.95	24.61	29.06	31.44	30.71	24.76	22.15	17.50	19.74	16.64	12.67
Ne	-	-	-	-	-	-	-	3.00	6.16	-	8.88
Di	5.86	9.76	8.81	15.87	2.74	10.57	24.07	20.32	24.25	19.74	24.72
(Wo)	2.93	4.88	4.41	7.93	1.37	5.29	12.04	10.16	12.13	9.87	12.36
(En)	2.75	4.62	3.72	6.16	1.11	3.62	11.11	7.55	9.17	8.66	9.26
(Fs)	0.18	0.27	0.68	1.77	0.26	1.67	0.93	2.61	2.95	1.21	3.10
Hy	3.13	7.88	9.43	11.92	14.48	4.36	2.16	-	-	1.04	-
(En)	2.94	7.45	7.97	9.25	11.70	2.98	1.99	-	-	0.91	-
(Fs)	0.19	0.43	1.46	2.67	2.78	1.38	0.17	-	-	0.13	-
Ol	-	-	-	-	-	4.27	13.54	22.62	23.18	23.08	19.59
(Fo)	-	-	-	-	-	2.92	12.50	16.80	17.54	20.25	14.67
(Fa)	-	-	-	-	-	1.35	1.05	5.82	5.64	2.83	4.92
Mt	3.98	5.70	4.81	5.15	4.80	4.05	6.30	2.59	2.76	3.14	3.15
Il	0.85	1.88	1.74	1.58	1.81	3.07	2.97	3.42	3.45	3.68	2.94
Ap	0.47	0.95	0.33	0.54	3.04	1.13	1.11	0.92	1.21	2.07	1.11

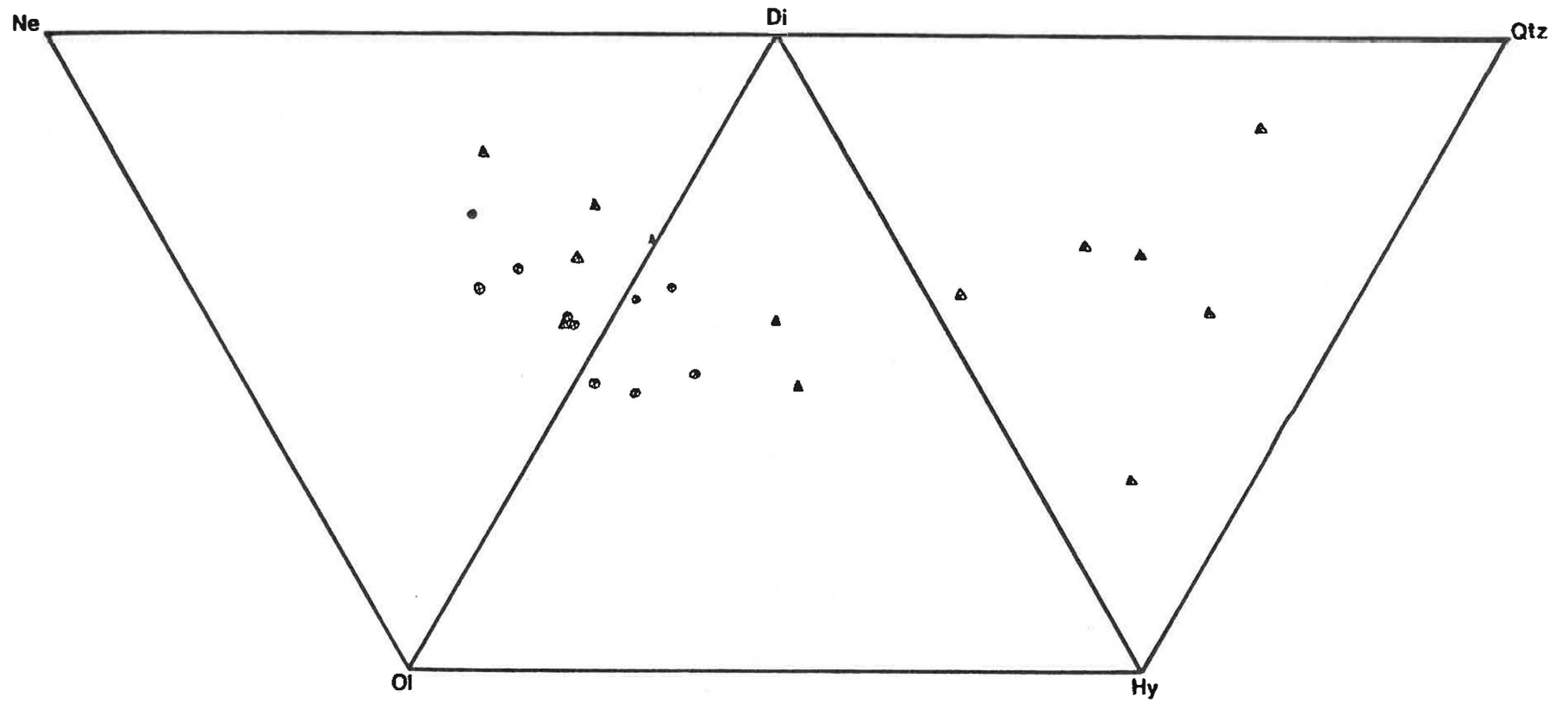


Fig. 6.1 - Basalt tetrahedron cation norms after Coombs (1963). Okete Volcanics (⊙) and Karioi Volcanics (△).

Coombs (1963) reduced all calculated analytical values of  $\text{Fe}_2\text{O}_3$  to 1.5% and converted the excess to FeO. (Chayes (1966) rejected analyses with  $\text{Fe}_2\text{O}_3/\text{FeO}$  ratios greater than 0.6 and Irvine and Baragar (1971) set an upper limit for  $\text{Fe}_2\text{O}_3$  of ( $\% \text{Fe}_2\text{O}_3 = \% \text{TiO}_2 + 1.5$ ) with the excess converted to FeO. Rafferty (1977) chose a ratio of  $\text{Fe}_2\text{O}_3/\text{FeO}$  of 0.2.

The aim of any adjustment should be to come as close as possible to the primary composition of the rock. The secondary oxidation and alteration of minerals for example iddingsitisation of olivine, will affect the original ferric to ferrous ratio in the rock. Thus the adjustment of this ratio should counter such effects. However in the selection of the rocks analysed in this thesis, those with alteration products and oxidation effects were rejected and since a wide range of rocks from basalts to andesites is involved one single adjustment factor is probably inappropriate. All the basalts have  $\text{Fe}_2\text{O}_3$  less than the FeO and generally the ratio is less than 0.6. Considering then the many varying adjustment factors that could be used, it would appear that any 'adjusted' norm is no more representative than a 'natural' norm. Rafferty (1977) in fact suggested that the difference between the two is small, and the original  $\text{Fe}_2\text{O}_3$  and FeO values have therefore been used in the norm calculations.

### 6.1.2 Nomenclature

The nomenclature adopting for describing the Karioi and Okete Volcanic lavas according to their norm values is essentially that of Green and Ringwood (1967) and Coombs and Wilkinson (1969). A list of analysed rocks in the Karioi region, using this classification, is presented below.

#### (1) Basanitoids

(normative olivine, normative nepheline 75% but no modal nepheline)

*Karioi*: W17084 (Whale Bay Ridge)

*Okete*: W17145 (Okete Quarry), V (Bridal Veil Falls), W17046

(Te Toto Gorge), H + G 17 (Pangonui Inlet)

V and W17084 could also be further described as nepheline hawaiites

and the others of this group as basanites if modal nepheline was present.

(2) Alkali Olivine Basalt

(normative olivine, normative nepheline <5%)

*Karioi*: W17040 (Hills Flat), W17083 (Whale Bay Ridge), W17086 (Te Toto Ridge), W17092 (Opotoru River)

*Okete*: W17007 (Te Toto Gorge), H + G 14 (Wharauoa Plateau)

(3) Olivine Basalt

(normative olivine and normative hypersthene <3%)

*Okete*: K (Kirikirpu), H + G 13 (Whale Bay), W17039 (Hills Flat coast)

(4) Olivine Tholeiite

(normative hypersthene and olivine)

*Karioi*: H + G 9 (Tait Section), W17027 (Tait Section)

*Okete*: W17012 (Papanui Pt), W17029 (Toreparu Stream)

(5) Quartz Tholeiite

(normative quartz and normative hypersthene)

*Karioi*: H + G 5 (Karioi Trig), H + G 6 (Jacksons Rock), H + G 7 (Opoturu River), H + G 10 (South of Whale Bay), W17016 (Millward Ridge)

## 6.2 MAJOR ELEMENT CHEMISTRY

The lavas of the Mt Karioi region are of two main types:

- (1) The Karioi Volcanics which range in silica from 47 - 59 wt% and contain low  $TiO_2$ , FeO, MgO and CaO and high  $Al_2O_3$ .
- (2) The Okete Volcanics range from 43 - 47 wt%  $SiO_2$  and have high  $TiO_2$ , FeO, MgO and CaO and low  $Al_2O_3$ .

### 6.2.1 Karioi Volcanics

The lavas from Mt Karioi show a range in silica (47 - 59 wt%  $SiO_2$ ) and can be classified as basalts, basaltic andesites and andesites on this basis.

The major chemical distinctions between the Karioi and Okete Volcanics separate well on Harker variation diagrams and are shown in Figs 6.2 - 6.6.

The Karioi Volcanics are distinctly low in  $TiO_2$  (except W17027, H + G 9) and higher in  $SiO_2$  than the Okete Volcanics (Fig 6.2). The highest  $TiO_2$  values in the group occur in the basalts while the lowest values are found in the andesites (W17016, H + G 5).

In Fig. 6.3 a distinct trend of decreasing FeO with increasing  $SiO_2$  occurs. The highest value of FeO (7.38%) is found in the most basaltic rock of the group (47.19 wt%  $SiO_2$ ) while the lowest value of FeO (2.29 wt%) is found in the least basic rock (59.63 wt%  $SiO_2$ ).  $Al_2O_3$  is high in the Karioi Volcanics ranging from 16 - 18 % and is clearly distinct from the lower values of the Okete Volcanics.

In Fig. 6.4 ( $MgO$  v  $SiO_2$ ) a trend of decreasing wt% MgO with increasing  $SiO_2$  occurs. The highest MgO value (7.32 wt%) is found in the most basic rock (47.19 wt%) and the lowest value (2.03 wt%) in the most acid rock (59.6 wt%  $SiO_2$ ). Calcium also shows a similar trend but this is not as distinct as with magnesium.

$K_2O$  appears to be relatively high in both the Karioi and Okete Volcanics. Following the nomenclature of Taylor (1969) and Whitford *et al.* (1979) the Karioi Volcanics can be classified as calc-alkaline and high - K calc-alkaline rocks (Fig. 6.5)

The alkalis ( $Na_2O$  and  $K_2O$ ) range from 3.9 - 7.25% and show a general increase with  $SiO_2$  (Fig. 6.6). The Karioi Volcanics generally lie in the alkaline field of Irvine and Baargar (1971), close to the subalkaline boundary. However from the basalt tetrahedron norm diagram of Yoder and Tolley (1962) they clearly show a wide range in chemical nature from distinctly alkaline ne normative rocks to saturated quartz normative rocks. Plotted on the AFM diagram (Fig. 6.7) they do not show iron enrichment and tend to advance to the alkali apex from the Fe/Mg side of the diagram as part of a calc-alkaline trend. On a  $SiO_2$  versus FeO

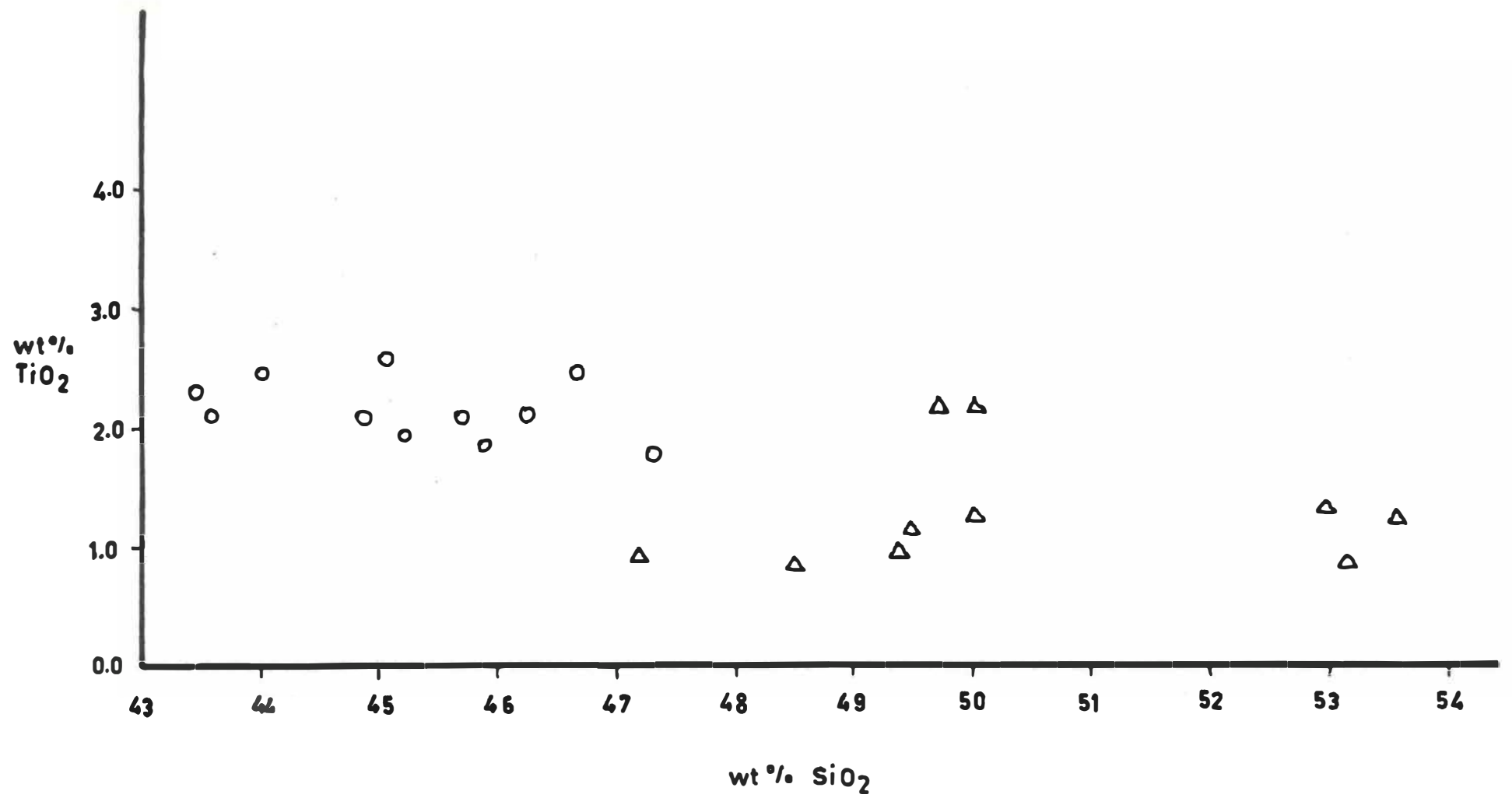


Fig. 6.2 - Harker variation diagram of TiO<sub>2</sub> (wt%) versus SiO<sub>2</sub> (wt%). Symbols as for Fig. 6.1.

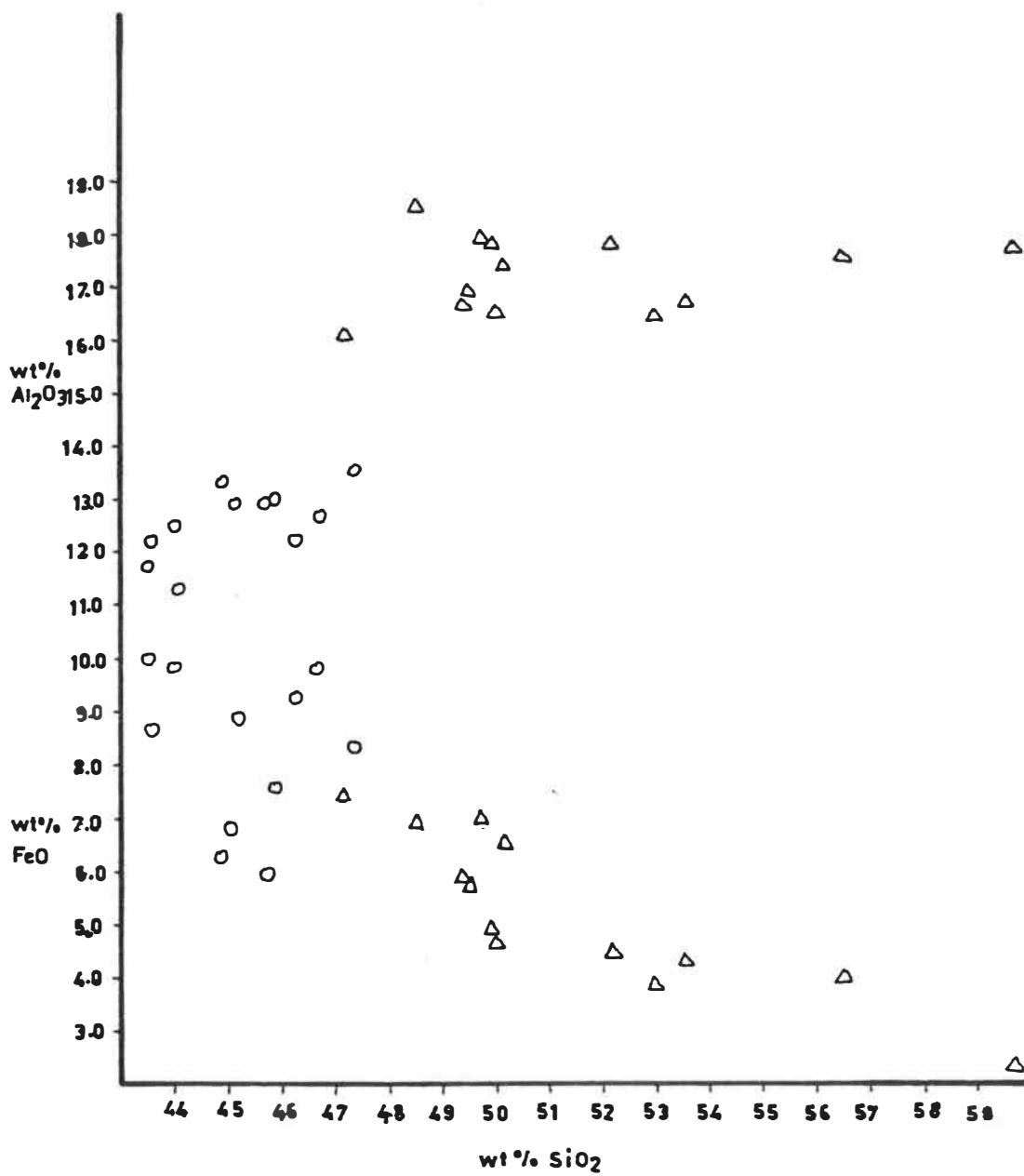


Fig. 6.3 - Harker variation diagram of FeO (wt%), Al<sub>2</sub>O<sub>3</sub> (wt%) versus SiO<sub>2</sub> (wt%). Symbols as for Fig. 6.1.

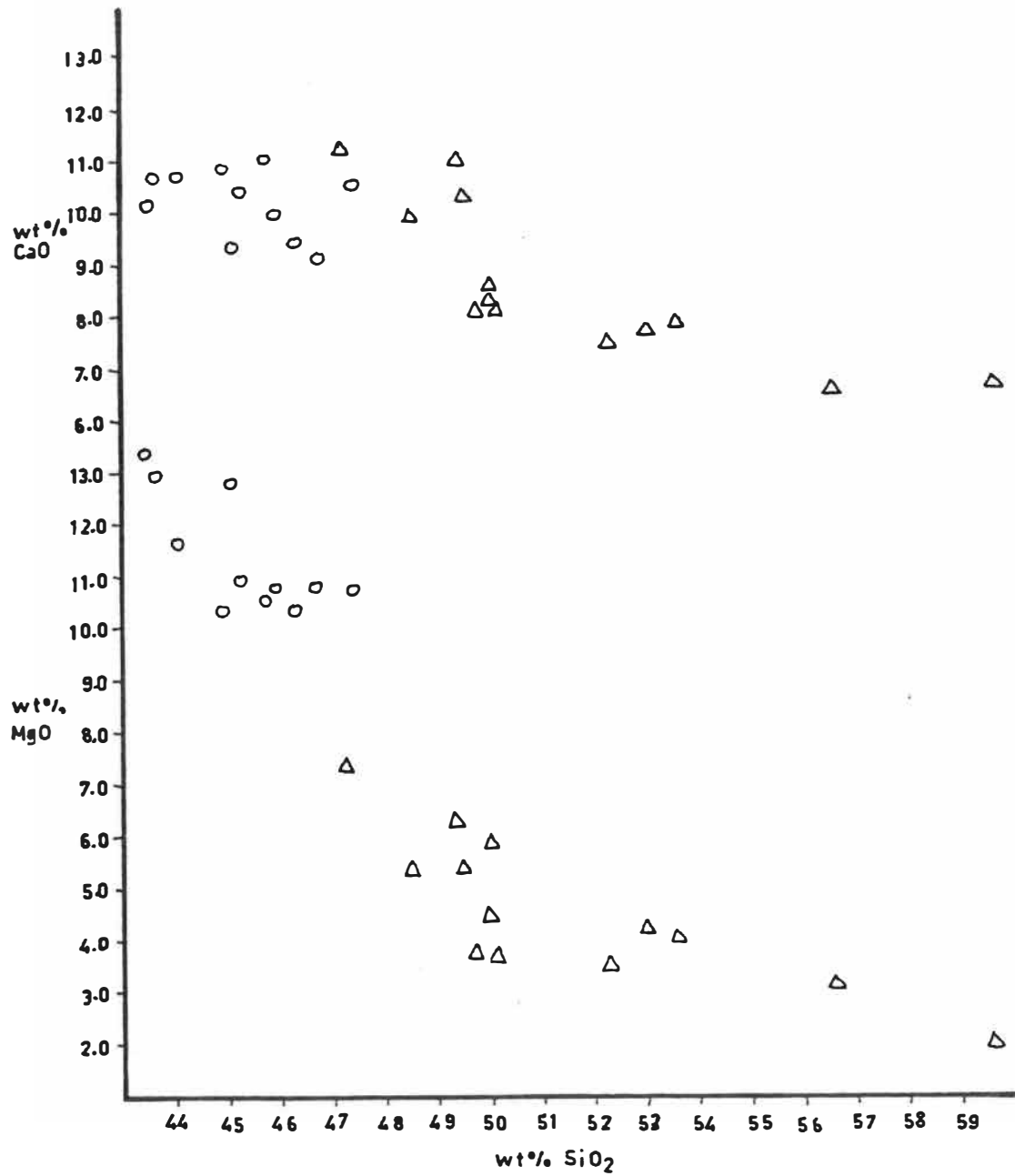


Fig. 6.4 - Harker variation diagram of CaO (wt%), MgO (wt%) versus SiO<sub>2</sub> (wt%). Symbols as for Fig. 6.1.

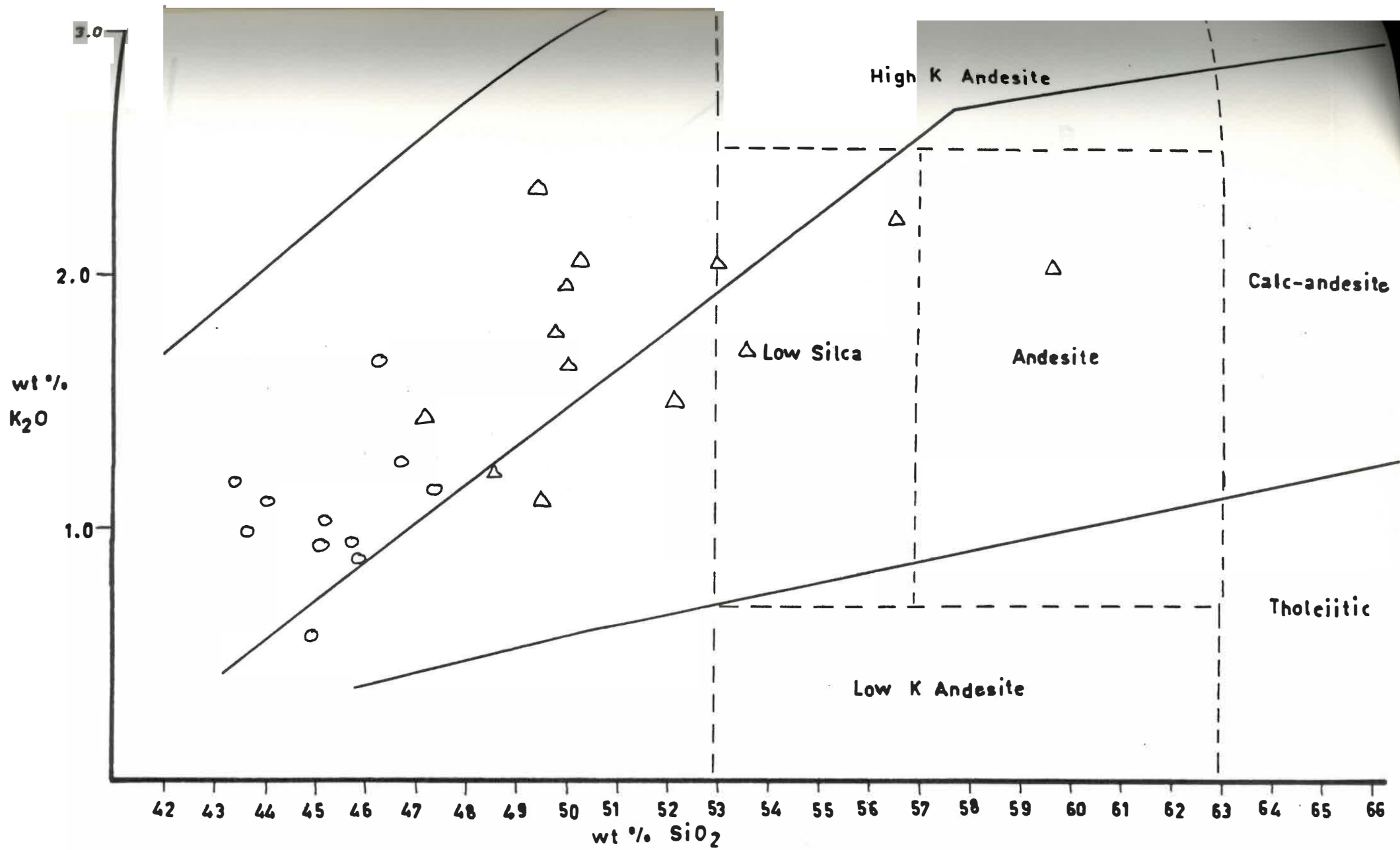


Fig. 6.5 - Harker variation diagram of K<sub>2</sub>O (wt%) versus SiO<sub>2</sub> (wt%) with classification of Taylor, 1969 (-----) and Whitford et al., 1979 (———). Symbols as for Fig. 6.1.

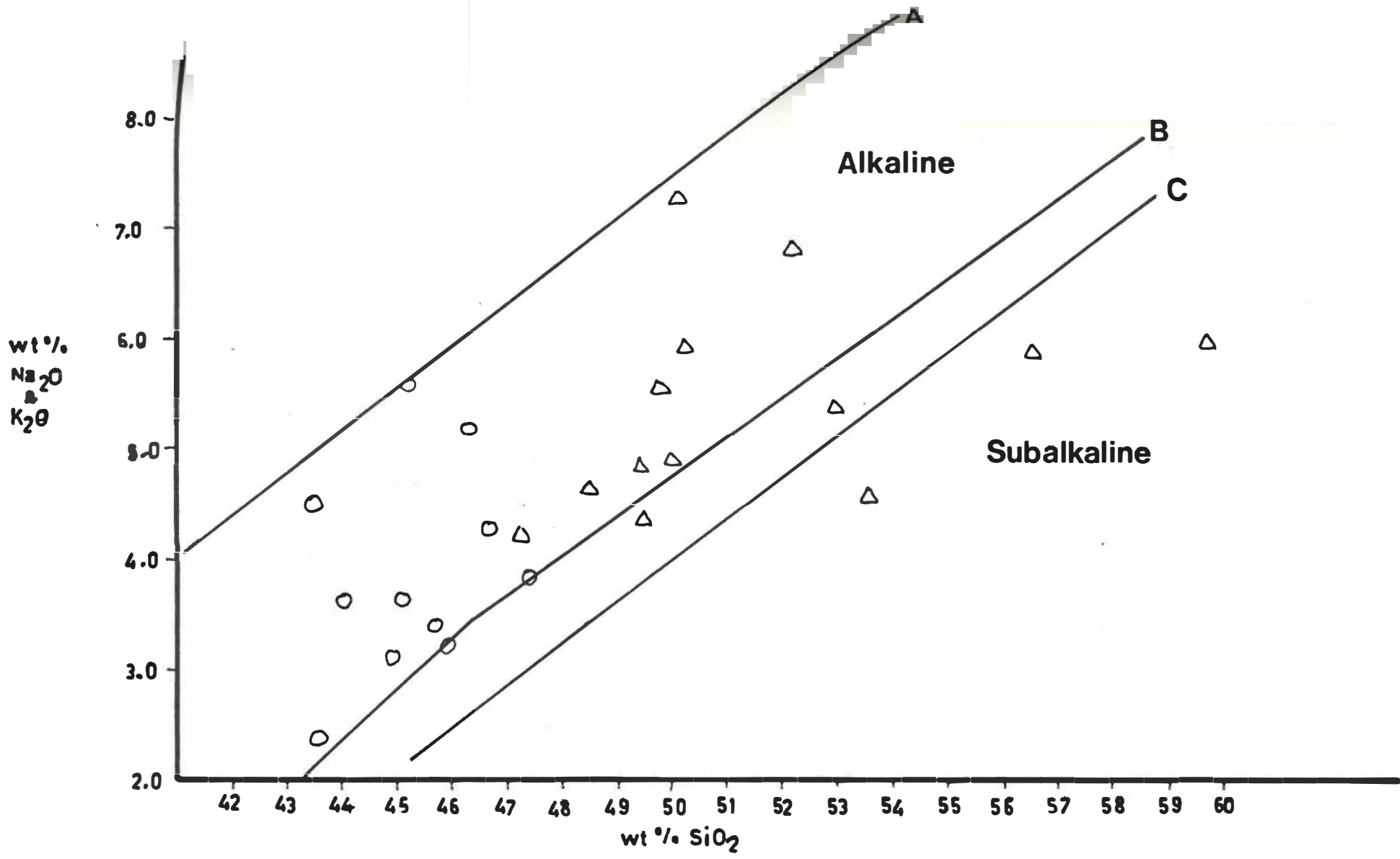


Fig. 6.6 - Alkalis SiO<sub>2</sub> diagram with Saggerson and Williams (1964) strongly mildly alkaline boundary (A), Irvine and Baragar (1971) alkaline - subalkaline boundary (B) and MacDonald and Katsura (1964) alkaline - tholeiitic boundary (C). Symbols as in Fig. 6.1.

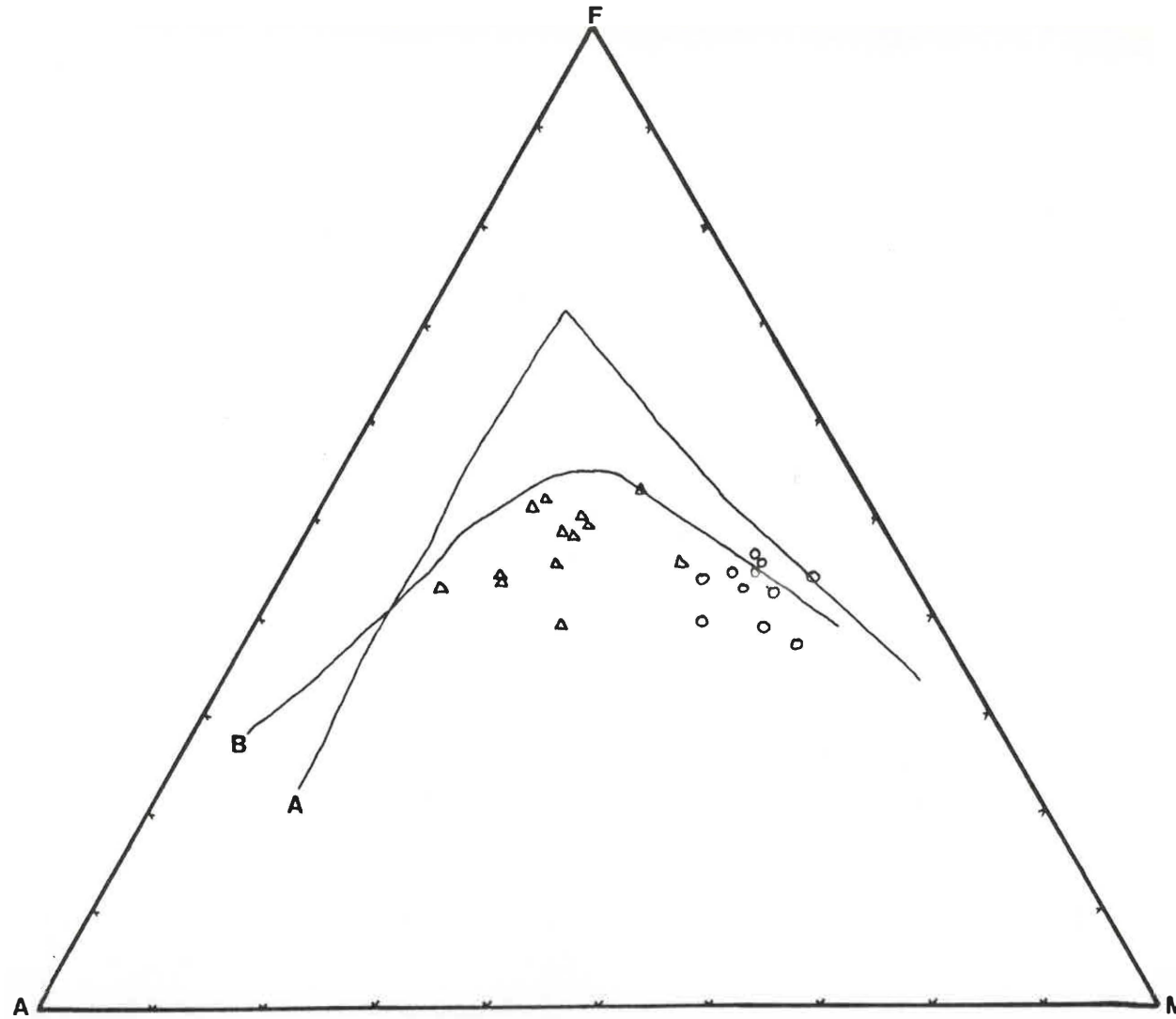


Fig. 6.7 - AFM Diagram (wt% oxides) where F = Fe<sub>2</sub>O<sub>3</sub> + FeO, M = MgO and A = Na<sub>2</sub>O + K<sub>2</sub>O. Okete Volcanics (○) and Karioi Volcanics (△). Boundaries as for Fig. 6.6.

diagram the Karioi rocks show a depletion in iron as  $\text{SiO}_2$  increases. The Karioi Volcanics appear then from their chemical nature, to be calc-alkaline in type and show a differentiation trend from basanitoids to alkali olivine basalts, basaltic andesite and andesites.

### 6.2.2 Okete Volcanics

This group of volcanics is notably more basic than the Karioi rocks and range from 43 - 47%  $\text{SiO}_2$ .

$\text{TiO}_2$  is higher than in the Karioi Volcanics and is always greater than 1.70%. Values tend to decrease slowly as the rocks become more acidic and the most acidic rock of the group (47.30 wt%  $\text{SiO}_2$ ) has the lowest  $\text{TiO}_2$  value (1.74 wt%).

$\text{FeO}$  varies from 6.0 to 10.0 wt% and shows no relation to  $\text{SiO}_2$  content although iron values tend to be higher than in the Karioi Volcanics (Fig. 6.3).  $\text{Al}_2\text{O}_3$  is lower in the Okete Volcanics than in the Karioi Volcanics (Fig. 6.3) and ranges from 11.0 to 13.5 wt%. Values increase slowly with increasing silica content.

$\text{MgO}$  is high in the Okete Volcanics (10 - 13.4 wt%) and clearly distinct from Karioi values (Fig. 6.4)  $\text{MgO}$  tends to decrease as the  $\text{SiO}_2$  content decreases.  $\text{CaO}$  is also high (9 - 11%) but shows no relation to  $\text{SiO}_2$  content.

The Okete Volcanics clearly tend to have less alkalis ( $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ ) than the Karioi Volcanics which is probably related to their lower  $\text{SiO}_2$  values but no clear cut relationship exists (Figs 6.6 and 6.7). They are alkaline in nature and lie in the alkaline field of Irvine and Baragar (1971) (Fig. 6.6). On the basalt tetrahedron of Yoder and Tilley (1962) (Fig. 1) the rocks lie immediately to both sides of the critical plane of undersaturation and can be described as basanitoids, alkali olivine basalts and olivine basalts.

The Okete Volcanics plot quite distinctly and closely on an AFM plot (Fig. 6.7) but show no clear trends of enrichment or depletion.

### 6.3 TRACE ELEMENT CHEMISTRY

Trace elements were calculated by X-ray fluorescence along with the major elements at the Analytical Facility, Geology Department, Victoria University of Wellington, by Mr Ken Palmer and are shown in Table 6.5. The two volcanic types, Karioi and Okete, do show some differences and trends and these will be discussed element by element.

#### Rubidium and Barium

Rubidium and Barium are found mainly in feldspars and feldspathoids (Prinz, 1967). These elements both follow the K content of the lavas and thus the Okete Volcanics with low  $K_2O$  (<1.25 wt%) have low Rb and Ba values. The Karioi lavas with a higher  $K_2O$  (>1.25% generally around 2%) have higher Rb and Ba values (Fig. 6.8). A Karioi andesite lava (W17016) with the highest K value (2.21 wt%) has the highest Rb and Ba values.

#### Strontium

Strontium values are similar in both volcanic types. Sr in basaltic rocks is mainly distributed in Ca rich minerals such as plagioclase (Prinz, 1967), but the strontium values in both groups do not show a clear distinction in relation to calcium (Fig. 6.9).

Stipp (1968) presents a graph of rubidium versus strontium using olivine basalts (Okete type) from Papanui Pt which he assumed were Karioi in type, and 'andesites' from Mt Karioi which are in fact mainly basaltic andesites. He also plotted data from other volcanics in the North Island (Auckland, Pukekohe, Egmont, South-West Coast) and from this information distinguished the volcanic fields (Fig. 6.10). However with the addition of values from this thesis and the correction of his data into Okete and Karioi types the points are scattered and do not cluster in separate fields, for example the Okete volcanics overlap the Pukekohe, Auckland and Karioi fields, and Karioi rocks are found outside Stipp's Karioi field and some lie in the Egmont field.

Of more interest was the conclusion by Stipp (1968) from  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios that the 'basalts' of Mt Karioi (actually Okete olivine basalts) and the 'andesites' of Mt Karioi (basaltic andesite and andesites) have individual and distinct ratios which suggests that simple derivation of one group from the other group by fractional crystallisation is most unlikely.

#### Zirconium

Zirconium values are higher overall in Okete Volcanics but individual values are not distinct from the Karioi Volcanics. Zirconium tends to decrease with less basic members in the Okete Volcanics (Fig. 6.11) but in the Karioi Volcanics increases with less basic members.

Following the plot of Pearce and Cann (1973) (zirconium v titanium) the two volcanic types are distinct but only because of the distinct differences in titanium. Zirconium shows no systematic change with varying titanium content.

#### Nickel

Nickel is often enriched in olivine, and olivine normative tholeiites and nepheline normative alkaline basalts tend to have the highest nickel values of basaltic groups (Prinz, 1967). Since the Okete Volcanics are alkaline and have higher modal olivine values, it is not surprising that the Okete Volcanics can clearly be separated from the Karioi Volcanics on the basis of nickel values. A plot of wt% MgO versus nickel (ppm) shows a very distinct separation (Fig. 6.12) and the Okete Volcanics are well grouped around 300 ppm and have high MgO values, while the Karioi Volcanics show a range of lower decreasing nickel and magnesium values. This would suggest that some fractionation of olivine has occurred within the Karioi Volcanics but not within the Okete Volcanics.

#### Vanadium

Vanadium is higher in the Okete lavas than the Karioi lavas and the two groups plot distinctly on a vanadium versus wt% FeO diagram. The Karioi Volcanics show a clear straight-line trend on this graph (Fig. 6.13) and this may indicate fractionation within the group (c.f. Cole, 1978).

TABLE 6.5 - TRACE ELEMENT ANALYSES OF SELECTED KARIOI AND OKETE VOLCANICS (ppm)  
 Location of samples sites and descriptions of rock types are given in Table IV.2.  
 Analyst: K. Palmer, Victoria University

	KARIOI VOLCANICS							OKETE VOLCANICS					
	W17016	W17027	W17040	W17083	W17084	W17085	W17092	W17007	W17012	W17039	W17046	W17029	W17145
Ba	908	430	520	558	648	370	568	375	354	323	312	359	331
Sr	652	646	466	467	585	423	448	470	502	542	542	856	640
Zr	166	178	106	126	154	60	79	122	126	150	153	165	196
Nb	26	32	3	14	27	<2	4	21	27	33	53	40	50
Pb	10	11	14	3	3	4	4	8	8	10	4	<2	8
Th	14	6	8	nd	nd	nd	nd	6	4	<2	nd	nd	<2
Rb	97	41	88	52	36	36	46	25	18	7	20	19	26
Y	21	28	31	18	22	20	22	21	21	24	23	23	25
S	<10	1210	115	nd	nd	nd	nd	15	20	45	nd	nd	35
Zn	61	104	69	83	87	92	74	89	96	90	101	103	100
Cu	49	63	74	53	45	186	80	84	77	88	86	94	74
Ni	21	29	38	12	78	26	40	239	304	263	244	341	407
V	144	247	292	201	234	297	294	254	239	285	250	267	241
Cr	27	23	69	25	248	49	131	664	582	419	411	672	647
Ga	nd	nd	nd	20	19	20	15	nd	nd	nd	15	18	nd

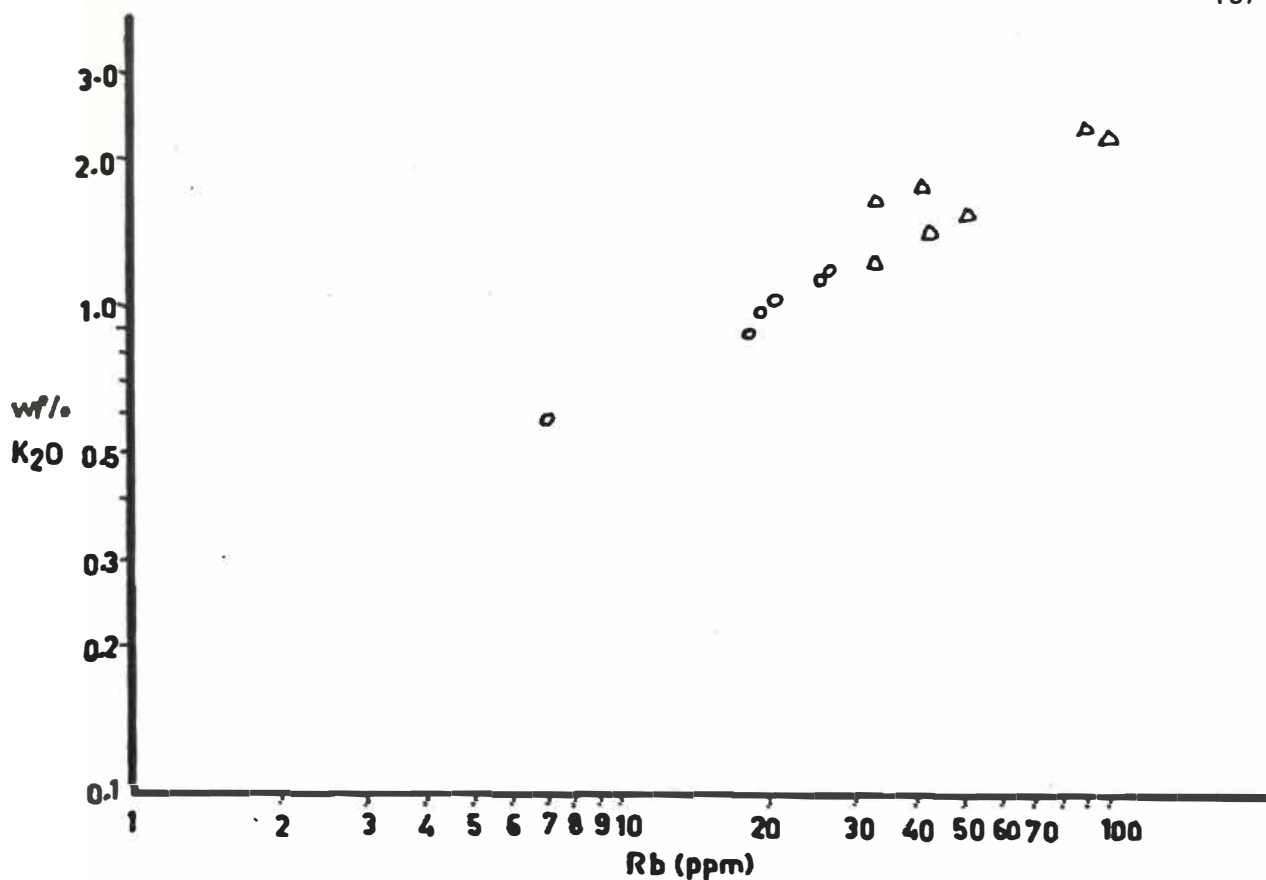


Fig. 6.8 - Log-log plot of potassium (wt%) versus rubidium (ppm) for Karioi ( $\Delta$ ) and Okete ( $\circ$ ) Volcanics.

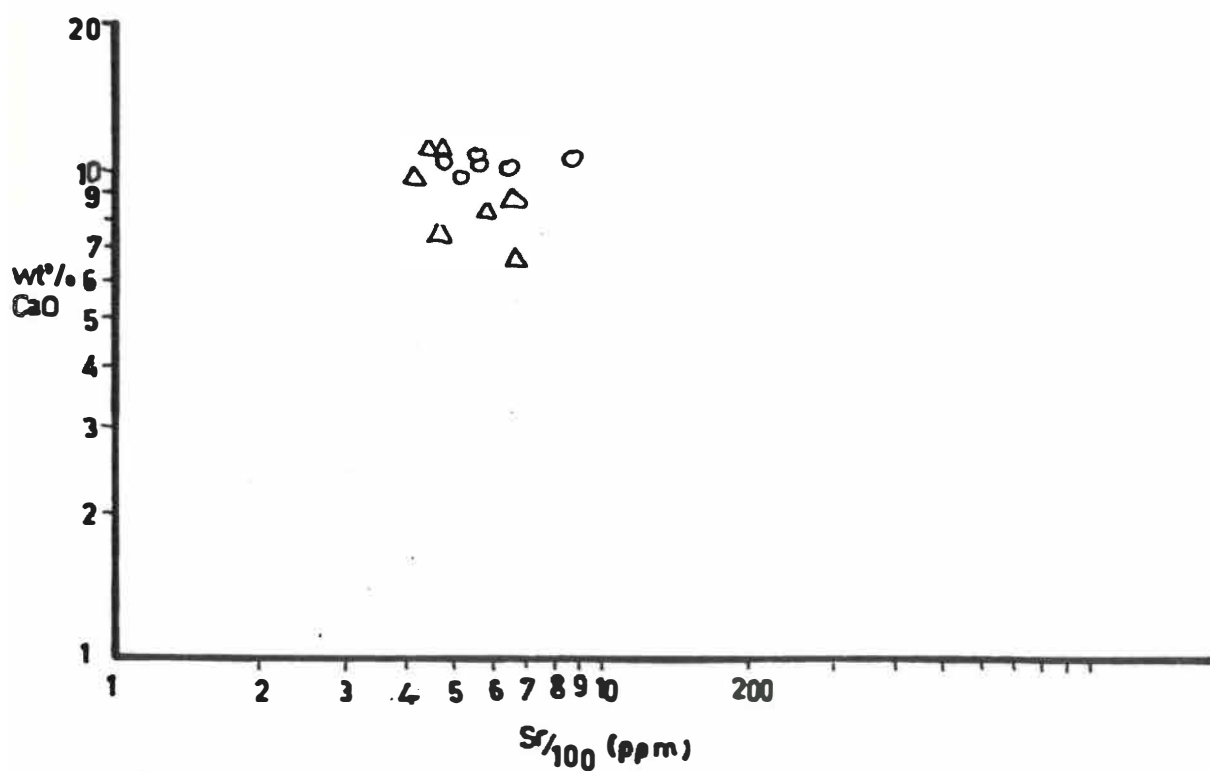


Fig. 6.9 - Log-log plot of calcium (wt%) versus strontium (ppm) for Karioi Volcanics ( $\Delta$ ) and Okete Volcanics ( $\circ$ ).

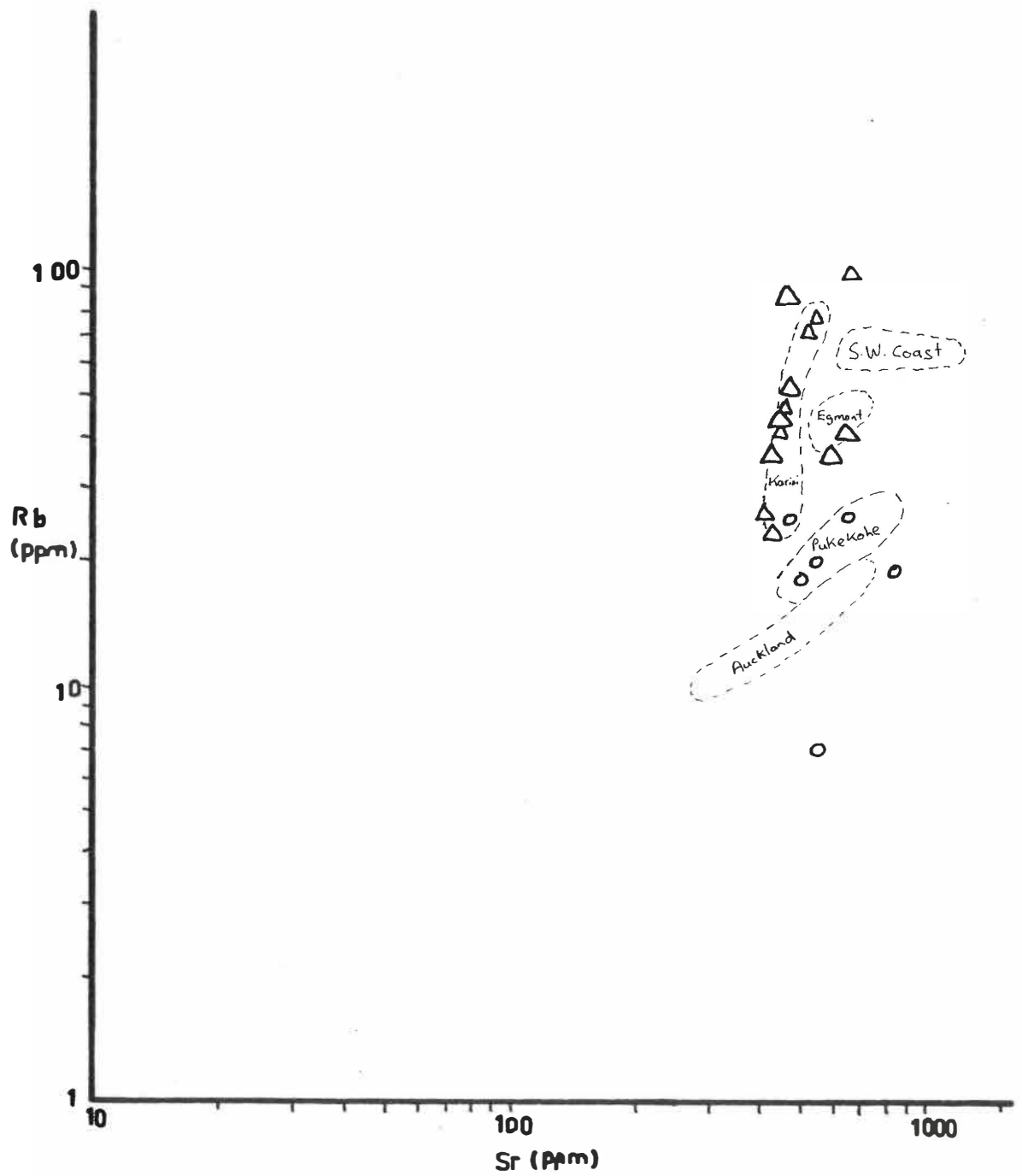


Fig. 6.10 - Log-log plot of rubidium (ppm) versus strontium (ppm) of the Karioi and Okete Volcanics. Symbols as for Fig. 6.8 with Stipps' (1968) volcanic fields in dotted lines.

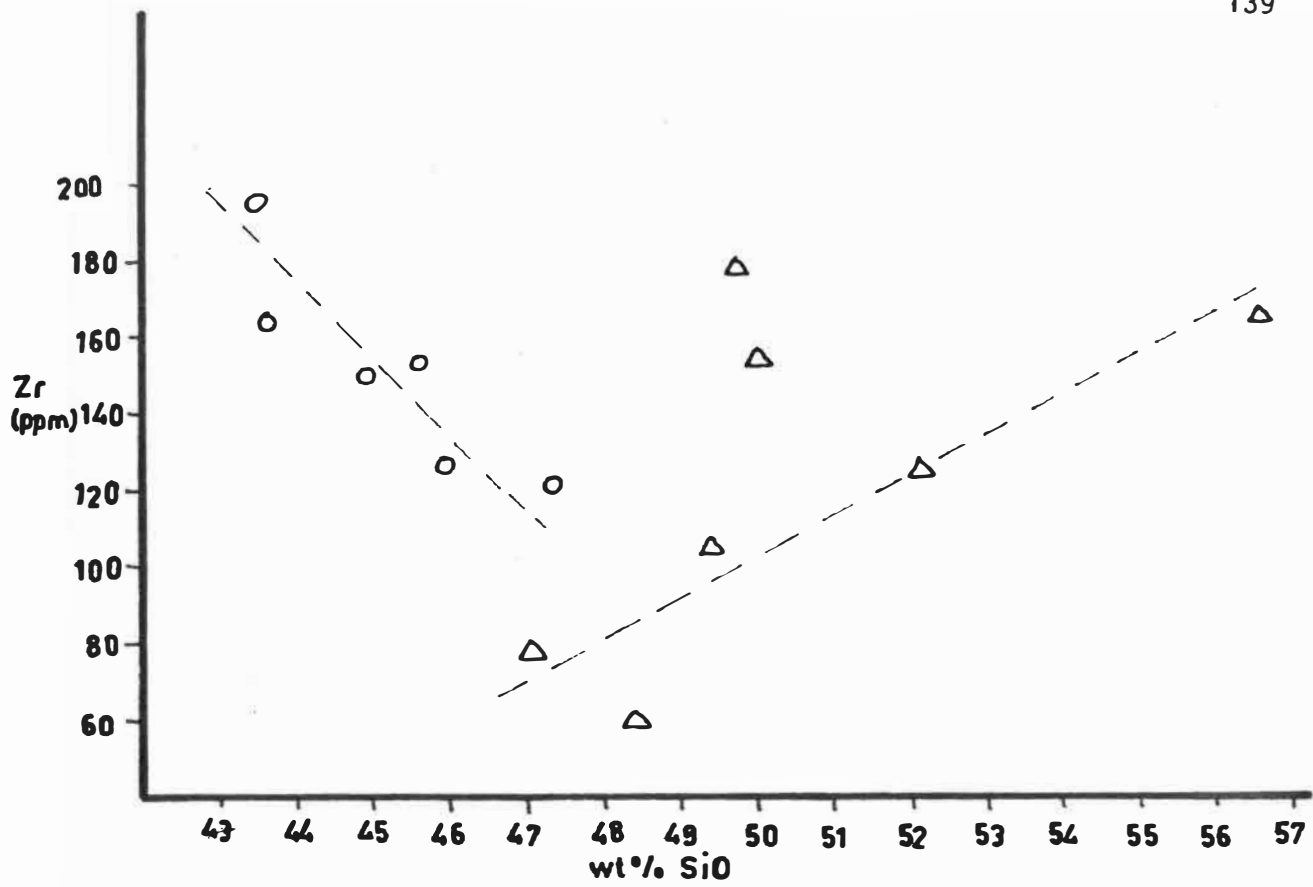


Fig. 6.11 - Plot of zirconium (ppm) versus SiO<sub>2</sub> (wt%). Symbols as for Fig. 6.8.

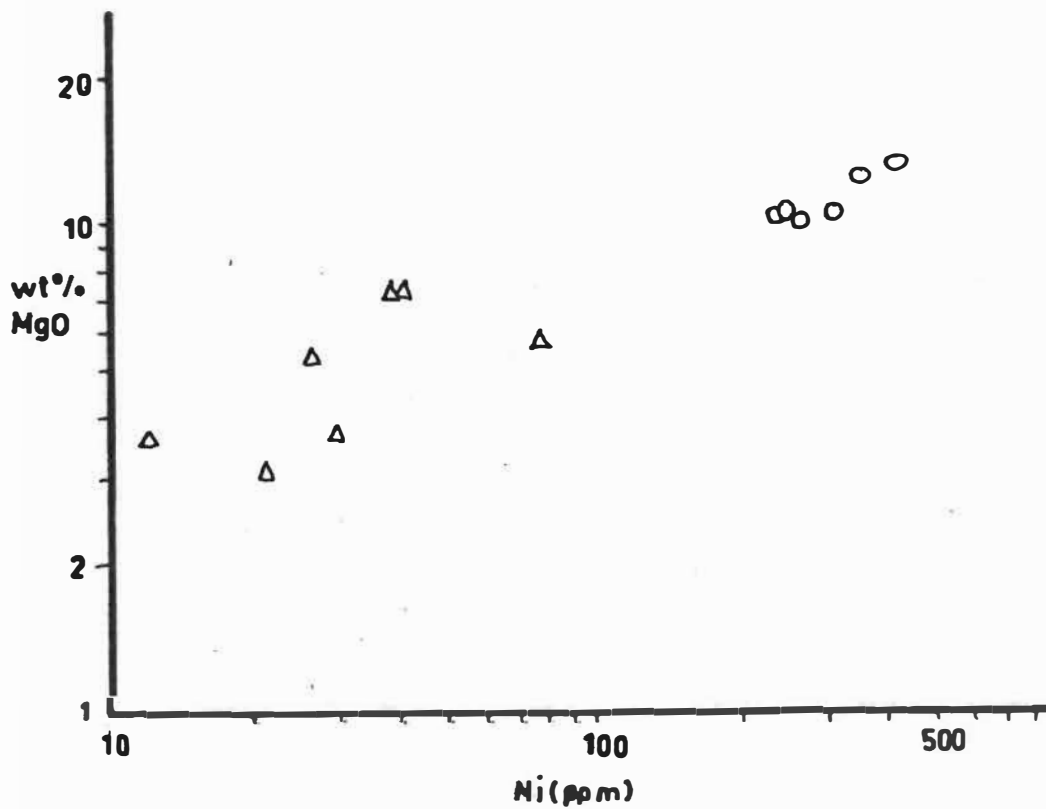


Fig. 6.12 - Log-log plot of magnesium (wt%) versus nickel (ppm). Symbols as for Fig. 6.8.

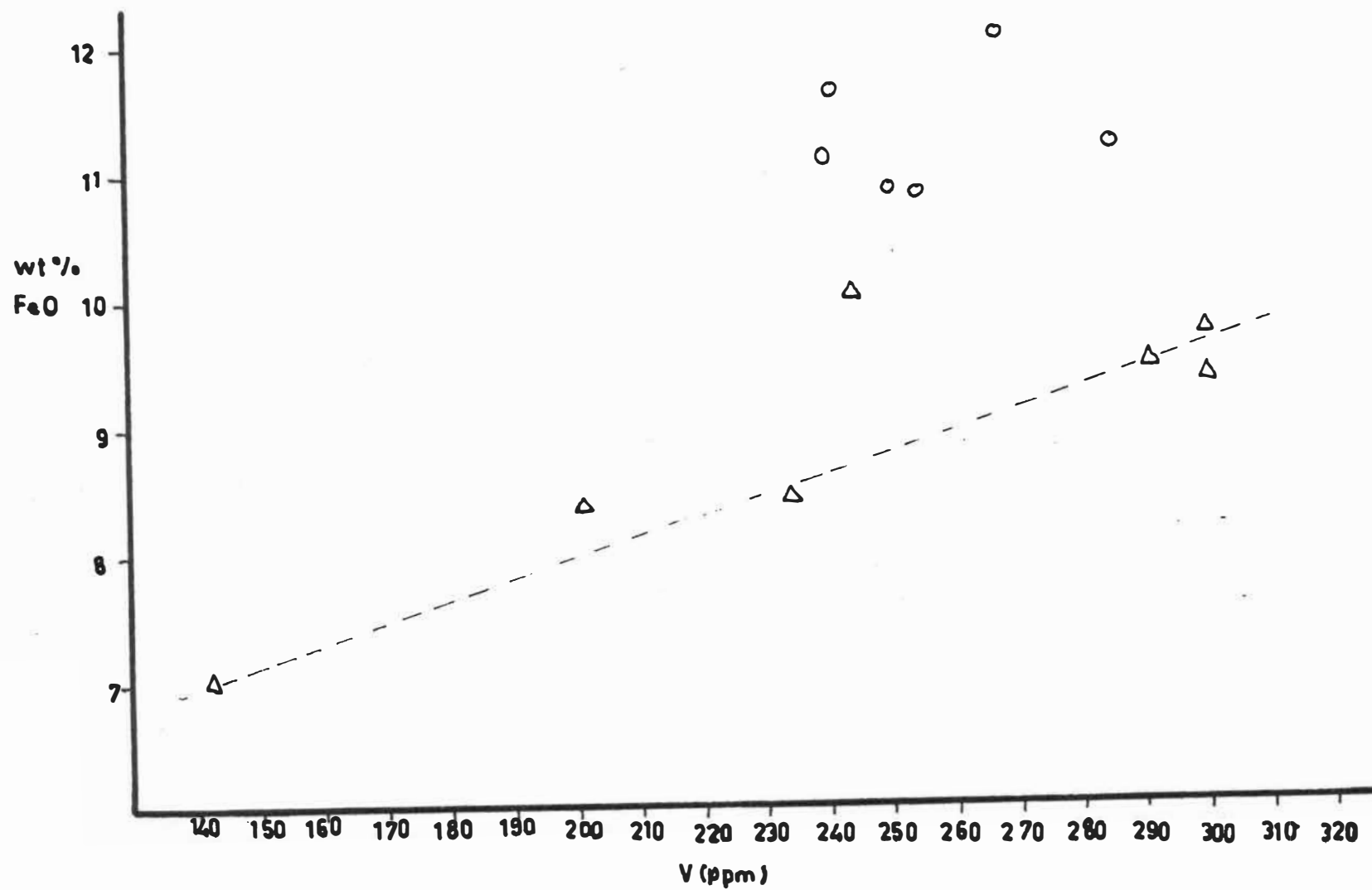


Fig. 6.13 - Plot of FeO (wt%) versus vanadium (ppm). Symbols as for Fig. 6.8.

### Chromium

Chromium content is very distinctive between the two types and perhaps the best trace element to distinguish the two groups. The Karioi Volcanics show distinctly low values (23 - 248 ppm) while the Okete Volcanics are much higher (411 - 672 ppm). This difference may well be the reflection of the differing titanium contents of the two groups and also the distinctively higher modal olivine values in the Okete Volcanic lavas.

### Summary of Trace Elements

Several ternary plots of Pearce and Cann(1973) were also used in an attempt to determine the tectonic setting of the rocks using trace element analyses. Following their methods (see Pearce and Cann, 1973 Fig. 6) the points were first plotted on a Ti, Zr, Y<sub>3</sub> diagram (Fig. 6.14) and both the Okete and Karioi rocks plotted as "within plate basalts". The points were then plotted on a Ti, Zr, Sr/2 diagram (Fig. 6.15) and lie in the low potassium tholeiite (Okete Volcanics) and calc-alkali basalt (Karioi Volcanics) volcanic arc fields. The volcanic rocks of both formations are behind arc basalts so may not be strictly orogenic and are still not strictly "within plate" rocks. It appears then such diagrams using chemical characteristics to classify rock types are not universally applicable especially to atypical rock groups and should therefore be used with discretion.

## 6.4 CRYSTALLISATION TEMPERATURES

A number of different geothermometer (plagioclase, olivine - clinopyroxene, and ortho-clinopyroxene) have been used to estimate the temperature of crystallisation of these various minerals. The iron-titanium oxide geothermometer (Buddington and Lindsley, 1964) could not be used as ilmenite is not present in any lavas.

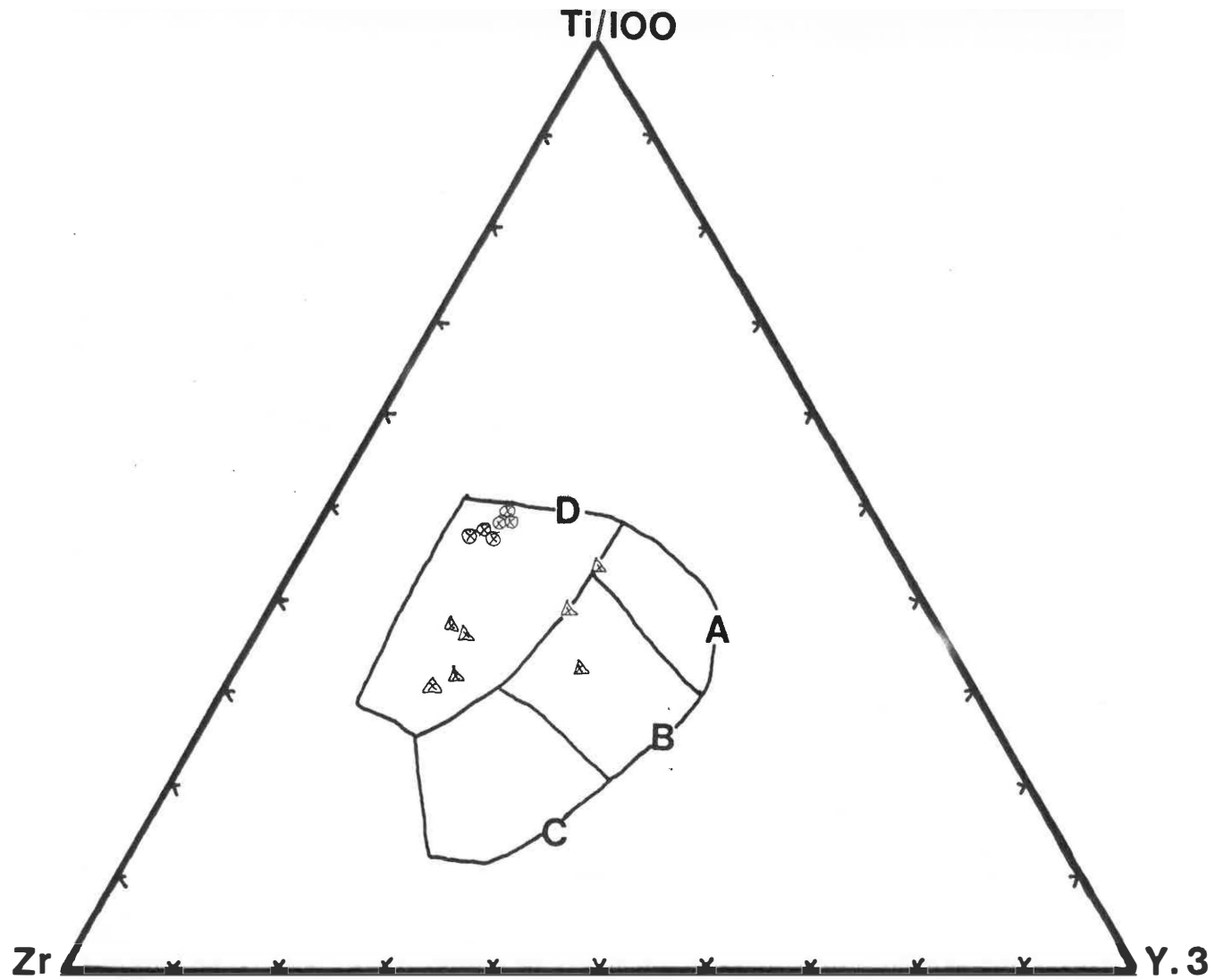


Fig. 6.14 - Discrimination diagram using Ti, Zr and Y. "Within plate" basalts (Ocean island or continental basalts) in field D, ocean floor basalts in field B, low potassium tholeiites in fields A and B, calc-alkali basalts in fields C & B.  $\triangle$  = Karioi Volcanics  $\otimes$  = Okete Volcanics (after Pearce and Cann, 1973).

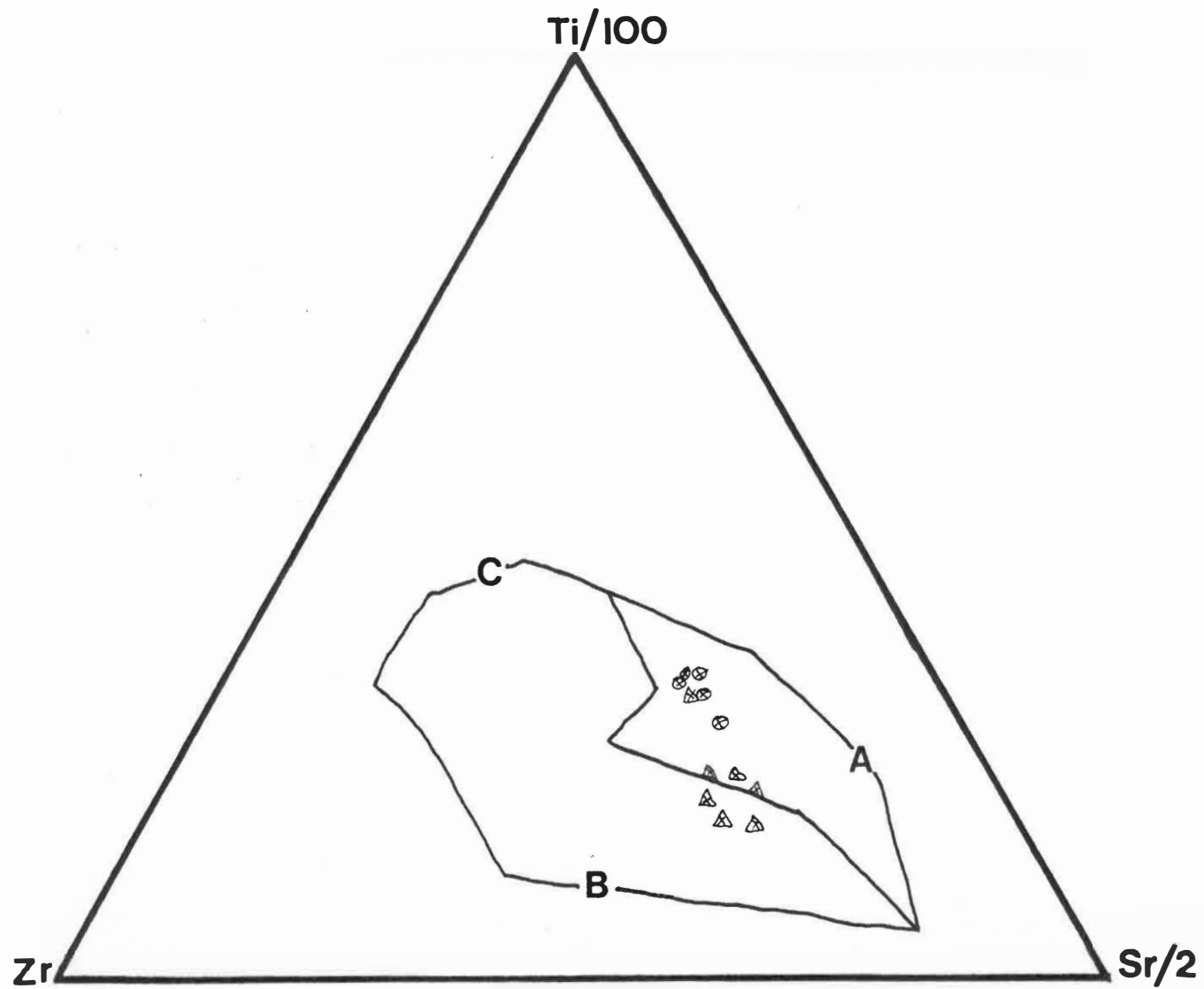


Fig. 6.15 - Ti/Zr/Sr discrimination diagram after Pearce and Cann (1973). A = Low potassium tholeiites, B = Calc-alkali basalts, C = Ocean floor basalts, Karioi Volcanics ( $\triangle$ ), Okete Volcanics ( $\odot$ ).

#### 6.4.1 Plagioclase Thermometer

Plagioclase temperatures were determined by the method of Kudo and Weill (1970) with the activity coefficients of Mathez (1973), and were calculated on the Waikato PDP 11/70 computer. The modification of Mathez (1973) makes use of activity coefficient corrections for the Ab and An components of the plagioclase (Fig. 6.16). This effectively lowers calculated temperatures and gives a more realistic and comparative (to other geothermometers) temperature estimate. The modification requires several assumptions:

- (1) The core composition of the plagioclase was in equilibrium with a liquid whose composition was that of the bulk rock (oxide values are those from XRF bulk rock analysis).
- (2) The rock is not of cumulate origin.

As plagioclase is present as phenocrysts and in most cases makes up a significant part of the rock the first assumption should be valid. Also the plagioclase geothermometer is much less sensitive to bulk rock composition variation than variation in the feldspar composition and hence significant errors are unlikely to be introduced by the assumption regarding bulk compositions (Rutherford, 1978).

Both core and rim values were calculated and the maximum and minimum values of core and rim are presented in Table 6.6. Mathez (1973) states that the most calcic composition of each rock should be used and this equals the core or highest value given.

Magma water pressures are unknown and the computer calculates plagioclase temperatures for water pressures varying from 0.0 kb H<sub>2</sub>O to 5.0 kb H<sub>2</sub>O. It is likely that in the magma which produced the Karioi lavas, water pressures were high as hydrous phases such as amphiboles and phlogopite occur and so the temperatures calculated for 5.0 kb H<sub>2</sub>O are probably the more reliable values.

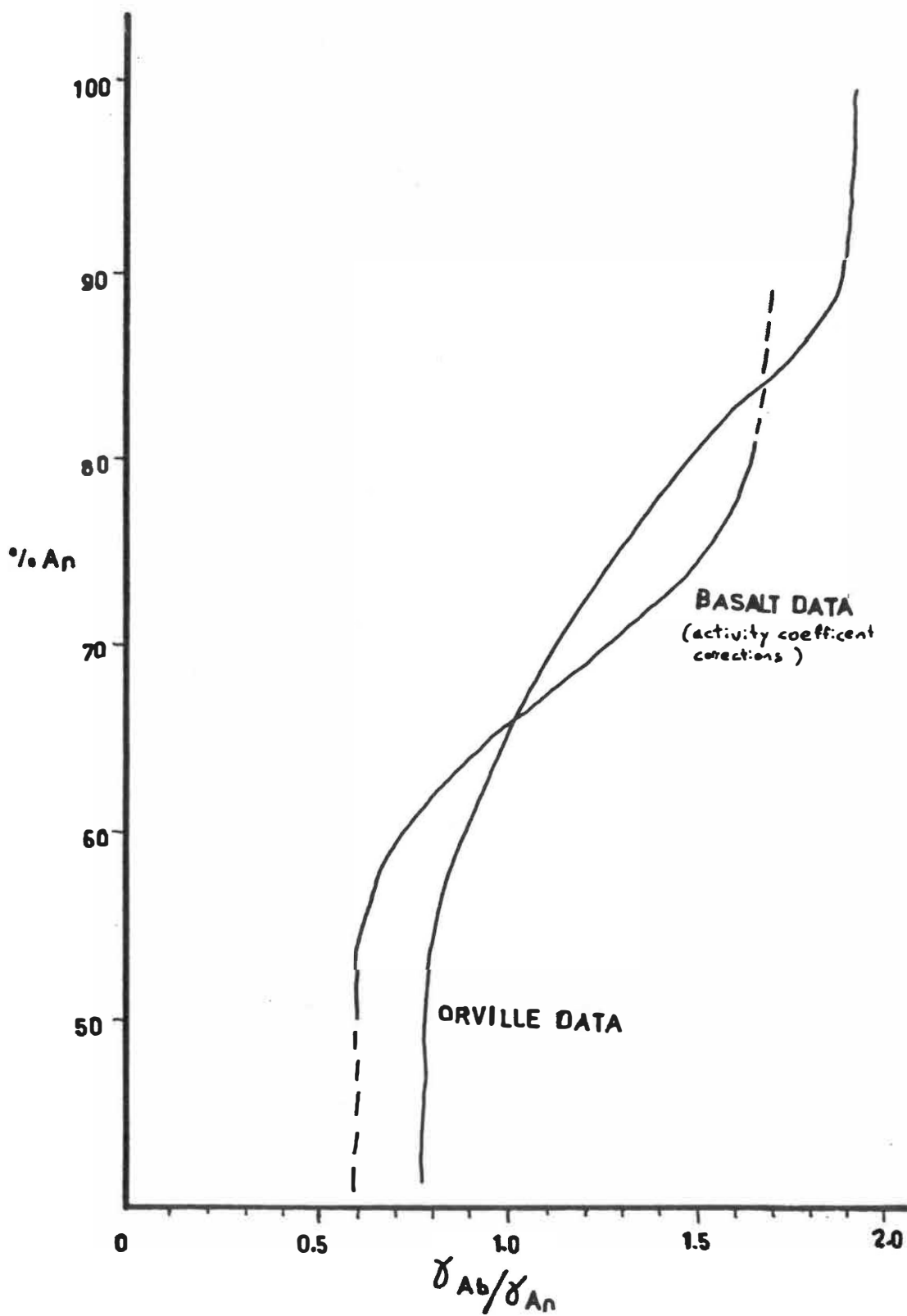


Fig. 6.16 - Derivation of activity coefficient. Correction factors (or Gamma ratio) after Mathez (1973).

TABLE 6.6 - Plagioclase Temperatures ( $^{\circ}\text{C}$ ) from the Kudo and Weill (1970) and Mathez (1973) Geothermometer.

ROCK NAME	0.0 kb $\text{H}_2\text{O}$	0.5 kb $\text{H}_2\text{O}$	1.0 kb $\text{H}_2\text{O}$	5.0 kb $\text{H}_2\text{O}$
KARIOI W17027 core	1228	1281	1227	925
W17027 rim	1223	1275	1221	920
W17040 core	1264	1328	1273	973
W17040 rim	1227	1278	1225	934
W17083 core	1255	1320	1261	941
W17092 core	1291	1364	1306	1002
OKETE W17022 groundmass	1211	1256	1206	919
W17046 core	1226	1280	1224	916
W17046 rim	1216	1266	1211	905

The values within each group are relatively consistent and at the 5 kb  $\text{H}_2\text{O}$  level the Okete lavas are significantly lower on average ( $\approx 910^{\circ}$ ) than the Karioi lavas ( $\approx 950^{\circ}$ ). These results are slightly higher than those of Rafferty (1977) for the South Auckland basalts. His core values are similar ranging from  $1240^{\circ}$  (0.0 kb  $\text{H}_2\text{O}$ ) to  $830^{\circ}$  (5.0 kb  $\text{H}_2\text{O}$ ) but the rim values are significantly lower, ranging from  $1080^{\circ}$  (0.0 kb  $\text{H}_2\text{O}$ ) to  $640^{\circ}$  (5.0 kb  $\text{H}_2\text{O}$ ). The temperatures are however quite comparable with the data used by Kudo and Weill (1970) and Mathez (1973) in the original geothermometer calculations and are similar to those obtained by Rutherford (1978) on Mayor Island basaltic rocks.

#### 6.4.2 Olivine - Clinopyroxene Thermometer

Following the work of Powell and Powell (1974) and assuming that olivine and clinopyroxene are crystallising in equilibrium it is possible to estimate a temperature of crystallisation for these minerals. Estimates from suitable mineral assemblages in the Karioi and Okete rocks are presented in Table 6.7.

TABLE 6.7 - Olivine - clinopyroxene geothermometer temperatures ( $^{\circ}\text{C}$ ).

	KARIOI	OKETE		
Rock	W17040	W17046	W17046	W17039
Temperature	$1040^{\circ} + 28^{\circ}$ per 5 kb	$1007^{\circ} + 27^{\circ}$ per 5 kb	$1018^{\circ} + 27^{\circ}$ per 5 kb	$1029^{\circ} + 27^{\circ}$ per 5 kb

The Fe - Mg exchange reaction between olivine and calcium-rich clinopyroxene on which the geothermometer is based defines a P-T line for the equilibrium conditions of a mineral assemblage (Powell and Powell, 1974). This suggests that the geothermometer is pressure dependent and that the calculated temperature value has little value unless some estimate of total pressure can be obtained. To estimate the total pressure at the time of olivine and clinopyroxene crystallisation is difficult (ie the depth of the magma chamber in which phenocryst phases crystallised and accumulated (Rutherford, 1978)). In comparison to the plagioclase thermometer, the most similar values are at 5 kb  $\text{H}_2\text{O}$  and so it is likely that either the magma chamber is at great depth, or that the rocks had a high water pressure and were at a relatively shallow depth. Considering the presence of hydrous phases within the Karioi lavas the latter is more likely. In the Okete lavas which show lower temperatures ( $1018^{\circ}$  to  $1040^{\circ}$ ) and have no hydrous phases, the magma is more likely to have been at greater depth.

### 6.4.3 Ortho - Clinopyroxene Thermometer

Wood and Banno (1973) showed that temperature was related to co-existing pyroxenes and produced a geothermometer which gave results which reproduced almost all the experimental data on co-existing pyroxenes to within 60<sup>0</sup>C.

Hypersthene-salite pyroxene assemblages occur in the hornblende basaltic andesites on Mt Karioi. Data from these rocks was used to calculate equilibrium temperatures using the Auckland University Geology Department programmable calculator and results are presented in Table 6.8.

TABLE 6.8 - Ortho - Clinopyroxene Equilibrium Temperatures (<sup>0</sup>C)

	KARIOI		
Rock	K191	K191	K209
Temperature	981	966	886

Values of 990<sup>0</sup>C have been obtained for Rabaul andesite lavas (Wood and Banno, 1973) and considering that the above rocks are basaltic andesites the temperatures appear comparable.

## 6.5 PETROGENESIS

### 6.5.1 Introduction

Petrographically it has been concluded that there are two different volcanic groups in the Mt Karioi area and from the variation in major and trace element chemistry within the two groups it appears that they have had a different magmatic evolution.

These differences are best shown in the chemistry where Harker variation diagrams are unique for each group and also from strontium isotope ratios of Stipp (1968) which suggest that simple derivation by fractional crystallisation between the two groups is unlikely (a difference of 0.001

in their ratios). On all trace element diagrams Karioi volcanics show a clear trend of fractionation but the Okete Volcanics appear more primitive, show few trends and generally plot as a cluster of points. Mg values ( $\text{Mg}/\text{Mg} + \text{Fe}^{2+}$ , see Appendix II for valculations) vary from 0.43 - 0.60 for the Karioi Volcanics and 0.65 - 0.74 for the Okete Volcanics. From these atomic ratios which also may be calculated as an oxide ratio and are commonly used as an indicator of differentiation from a primary liquid, it is apparent that the Karioi Volcanics show more differentiation than the Okete Volcanics, which show little differentiation at all.

Field evidence supports the presence of two different volcanic forms. The Okete Volcanics (alkaline lavas) form less voluminous flows, and are usually emitted from a cone associated with scoria and may erupt from numerous small volcanic edifices. The Karioi Volcanics (calc-alkaline suite) form large voluminous flows which are associated with essentially one volcanic edifice which generally lacks scoria and is constructed by lava.

All of these differences suggest that the two groups have undergone different degrees of fractionation and had a different magmatic evolution.

#### 6.5.2 Karioi Volcanics

The Karioi Volcanics represent a suite of chemically related rock types ranging from basalt to andesite. It is the presence of a suite of varying rock types that make these volcanics different from the Okete Volcanics and suggests the genesis of the two varies. The presence of andesite, although small in volume (only 1-2%) compared with the basalts is perhaps of most interest.

There have been a number of hypotheses proposed for the origin of andesites and these have been summarised by several authors (Green and Ringwood, 1968; Boettcher, 1973; Ringwood, 1975). The situation in New Zealand where orogenic andesites occur has also been discussed (Ewart and Stipp, 1968; Carmichael, 1974; Ewart et al., 1977; Cole, 1978(a), 1979) and for the andesites of the Taupo Volcanic Zone, it is generally

accepted that fractional crystallisation of a basalt is incompatible with strontium isotope ratios (Ewart and Stipp, 1968) and the favoured hypothesis is that an andesite magma was formed by assimilation of crustal material (greywackes) by basaltic magma (Cole, 1979). No data on  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the Karioi basalt, has been obtained, although Stipp (1968) produced data on some basaltic andesites and andesites of Mt Karioi and found that they had similar ratios. It is likely then that the Karioi andesites were not produced by the hypothesis suggested for the Taupo Volcanic Zone rocks.

The similarities in  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios between andesites and commonly associated basalts in overseas studies (Dickinson, 1970) makes it reasonable to suggest that andesite may be derived from basaltic parents by fractional crystallisation. This concept (Bowen, 1928) is one of the classic models of igneous petrology and is only possible by a number of limited mechanisms. One of these, amphibole fractionation has been the subject of considerable discussion over recent years but direct supporting evidence has been weak (Ringwood, 1975).

However, recent work on water-bearing systems has revealed a feasible mechanism by which basaltic magma could generate an andesitic melt (Holloway and Burnham, 1972; Eggler, 1972; Eggler and Burnham, 1973; Melz, 1973; and Mysen, 1973). With this new data it has been possible to critically discuss this model and re-examine the hypothesis of amphibole crystallisation (Cawthorn et al., 1973; Cawthorn, 1976; Cawthorn and O'Hara, 1976). It must be borne in mind that the Karioi Volcanics are chemically related basalts, basaltic andesites and andesites which show a trend from nepheline normative to quartz normative. This cannot be explained by any anhydrous fractionation and the direction of this liquid migration is the reverse of that suggested by any high pressure crystallisation mechanism (O'Hara, 1968). It would appear then that amphibole fractionation is not only important to the origin of andesites but also to the genesis of calc-alkaline suites in general.

In the study of a calc-alkaline suite in Granada, West Indies, Cawthorn et al. (1973) have shown that such chemical variation as above (crossing the critical plane of under-saturation) can be explained by amphibole fractionation. The Grenada suite consists of basanitoids, basaltic andesites, and dacites. The amphiboles of these rocks have low silica values (<44%) and high normative nepheline values. Such amphibole exists at or close to temperatures of the water saturated liquidus of the basalts at high pressures. Fractionation of these sub-siliceous amphiboles from a basanite liquid containing higher silica values and lower normative nepheline than amphibole is potentially capable of driving residual liquids across the olivine gabbro thermal divide to give hypersthene and quartz normative products (Cox et al., 1979). This is possible because of the reaction relationship between olivine and clinopyroxene (Cawthorn et al., 1973; and Helz, 1976). The critical point is that once amphibole becomes stable (which is relatively insensitive to pressure changes between 2 kb and 10 kb, Cawthorn and O'Hara, 1976) both olivine and clinopyroxene are in reaction relationship with the liquid. Amphibole crystallises at slightly lower temperatures and once it appears, olivine and clinopyroxene will not precipitate from the liquid. Thus, fractional crystallisation will be dominated by amphibole precipitation and may produce andesitic liquids.

The role of amphibole in the crystallisation of basanite liquids with less than 11% normative nepheline producing a differentiation trend towards  $\text{SiO}_2$  saturation has been demonstrated (Cawthorn et al., 1973), but in more undersaturated liquids the kaersutite is hypersthene normative and liquids trend toward further undersaturation (Cawthorn, 1976). Rafferty (1977) suggested that the strongly alkaline basalts of the South Auckland field (more undersaturated than the Okete Volcanics) were formed in this manner and because of the saturation barrier or thermal maximum of amphibole composition (Cawthorn, 1976), the final composition of any lava will be dependent upon the value of normative nepheline in the parent liquid. Thus a variety of basanitic liquids produced by varying degrees of partial melting

would, when kaersatite crystallises, tend towards silica saturation or undersaturation depending upon the amount of normative nepheline in the liquid. However it appears the Karioi basalts are not as alkaline as the South Auckland lavas and the role of a hypersthene normative kaersutite is not required.

Petrographic evidence from the Karioi lavas is consistent with amphibole fractionation. Hornblende is present in both the basaltic andesites and andesites and rarely in the basalts. Nearly all phenocrysts show considerable resorption effects. Cox *et al.* (1977) found similar petrographic effects in the basanitic lavas of the Shaqua area which may also be the result of amphibole fractionation. The olivines of the Karioi rocks show alteration to opaques on rims and commonly to iddingsite, serpentine and other products which may also be significant.

The hornblendes also meet the chemical requirements of the fractional crystallisation hypothesis. They are of basaltic - hornblende composition, and are less siliceous and more highly nepheline normative compared with the bulk rock composition.

TABLE 6.9 - Compositions and normative data for whole rock Karioi basaltic andesite and amphiboles in W17083.

Oxide	Chemical Composition			Norm Mineral	Norm Values		
	Bulk Rock	Amphibole			Rock	Mineral	
		(1)	(2)			(1)	(2)
SiO <sub>2</sub>	52.13	43.01	43.87	Or	9.01	6.54	6.58
TiO <sub>2</sub>	0.84	2.27	3.35	Ab	44.23	0.55	5.53
Al <sub>2</sub> O <sub>3</sub>	17.77	13.47	12.33	An	20.79	26.97	23.77
Fe <sub>2</sub> O <sub>3</sub>	3.83	-	-	Ne	2.27	7.81	5.08
FeO	4.46	13.07	12.94	Di	12.52	24.96	27.35
MnO	0.15	0.12	0.19	Fo	4.07	20.04	18.34
MgO	3.61	12.61	12.08	Fa	1.35	9.94	8.62
CaO	7.54	11.64	11.54	Mt	4.07	-	-
Na <sub>2</sub> O	5.26	1.50	1.54	Il	1.19	3.18	4.72
K <sub>2</sub> O	1.50	1.10	1.10	Ap	0.51	4.31	-
P <sub>2</sub> O <sub>5</sub>	0.24	-	-				
LOI	1.84	-	-				
TOTAL	99.17	98.80	98.96				

The geothermometer crystallisation temperatures of the Karioi lavas (Tables 6.6, 6.7, 6.8) are generally compatible with available experimental data. For instance plagioclase crystallised at 920 - 973<sup>0</sup> at 5 kb H<sub>2</sub>O according to the Kudo and Weill (1970) plagioclase geothermometer and Cawthorn et al. (1973) from experimental results of a basaltic melt undergoing amphibole fractionation found that plagioclase commenced to crystallise at 925<sup>0</sup>C. From the same 'run' of Cawthorn et al. (1973) olivine and clinopyroxene precipitated at 1125<sup>0</sup>C. From the Powell and Powell (1974) geothermometer a value of 1068<sup>0</sup> at 5 kb is obtained for the Karioi olivine clinopyroxene pairs.

The majority of experimental work on amphibole stability is done at 5 kb water pressure (Cawthorn, 1976) but Yoder and Tilley (1962) examined the phase relationships of natural basalts up to 10 kb water pressure. Their data suggests that the relative stability of olivine, pyroxene and amphibole is comparatively insensitive to pressure change in the range 2 to 10 kb. Holloway and Burnham's (1972) results can be interpreted similarly and Green (1973) analysed amphiboles produced at 10 and 20 kb water pressure, and these were similar to the compositions produced at 5 kb. The wide range over which amphibole stability occurs suggests that a process of amphibole crystallisation either by itself or together with minor olivine and clinopyroxene may produce andesite over a large depth range in the crust and uppermost mantle (Cawthorn, 1976).

The Karioi Volcanic suite then, appears to be the result of amphibole fractional crystallisation of a basaltic magma. It is likely that this magma was sub-alkaline in nature and of an alkali-olivine basalt composition. A melt of this composition may be produced by a relatively small degree of partial melting (5%, Ringwood, 1975) of hydrous pyrolite at 60 km depth with pressures of 12-18 kb.

### 6.5.3 Okete Volcanics

The Okete Volcanics appear to show little, if any, differentiation from chemical diagrams, and this is strongly emphasised by their Mg values which range from 0.65 - 0.74. Green (1971) has shown that basaltic liquids which are in equilibrium with peridotite will have Mg values between 0.68 and 0.72 and that values below this imply that the magma has undergone significant differentiation. These values of the Okete Volcanics confirm that the magma has undergone little if any differentiation and is essentially mantle derived.

The presence of ultrabasic xenoliths in the Okete Volcanics requires rapid ascent rates (Carmichael et al., 1977) and volcanic centres with the highest concentrations of xenoliths should have been the least differentiated and have the highest Mg values (Rafferty and Heming, 1979). The lavas at Kirikiripu Quarry, just east of Raglan, are known to contain abundant large ultramafic nodules (Rodgers et al., 1975) and this centre has the highest Mg value of the whole group (0.74).

Often the fundamental problem in determining the magmatic evolution of a basalt lies in assessing the relative roles of fractional crystallisation and partial melting in producing the lava type seen at the surface. From the Mg values and other chemical parameters it would appear that for the Okete Volcanics, the role of partial melting was more significant and various models of fractional crystallisation of dry and hydrous olivine tholeiite magmas are inconsistent with the CIPW norms and the closely grouped trace element data.

#### Partial Melting Theory

Partial melting from a rising diapir of hydrous pyrolite is capable of producing a series of liquids from olivine nephelinites to alkali olivine basalts as the magma rises and degree of partial melting increases (Green and Ringwood, 1967). Ringwood (1975) has shown that a diapir which rises from the base of the lower velocity zone (ie 150 km depth) will produce a liquid of olivine basanite composition at 90 km depth with 3% partial melting

under hydrous conditions. The importance of water is considerable at this depth where amphibole is no longer stable and water pressure is high and highly undersaturated magmas can be formed by small degrees of partial melting. At lesser depths (65 km) magma segregation will produce an alkali olivine basalt liquid with 5% partial melting and at similar depths and greater degrees of partial melting (30%, Green and Ringwood, 1967) or lesser depths (25 km - 10 km) and moderate partial melting (25 - 18%, Ringwood, 1975) an olivine tholeiite may be produced.

The Okete Volcanics show a range in rock types from olivine tholeiites (6% hypersthene in the norm) to basanitoids (18% nepheline in the norm). With evidence from the chemical data of this thesis and analyses of other Okete Volcanics in the area (R.M. Briggs, unpublished data) the undersaturated basanitoids are clearly the most abundant rock type. Since any fractional crystallisation effects are small, this range in rock types would suggest that several magmas of different type were present in the area.

It is known that the incompatible elements (K, Rb, Sr, Ba, Sr, P, Cl, La, Ce) will be preferentially concentrated (enriched) in the liquid phase during crystallisation and that the compatible elements (Co, Ni, Cr, V) will be retained or extracted (depleted) during crystallisation (Cox *et al.*, 1979). This is in contrast to partial melting whereby incompatible elements are diluted and concentrations fall as the degree of partial melting increases. Trace element data of the Okete Volcanics shows few trends and generally groups as a cluster. The incompatible elements show a slight, generalised decrease from the more nepheline normative rocks (little partial melting) to the hypersthene normative rocks (greater partial melting) but appears to be neither smooth nor of significant size compared to differences described in the literature. Ringwood (1975) for instance suggests that the abundances of incompatible elements are frequently 2-5 times high in alkali basalts than in olivine tholeiites produced by partial melting.

However, a development in partial melting theories to explain such inconsistencies in geochemistry (particularly rare earth and trace element data) has been the suggestion of source heterogeneity while from recent studies it appears that geochemical zoning of the mantle does occur (Sun and Hansen, 1975a, 1975b, 1976; Whitford et al., 1979) the reasons for it are less clear, although Sun and Nisbett (1977) and Whitford et al., 1979 propose several models of mantle evolution to explain such zoning. What is now required is data on rare earth abundances and more trace element data so that models of mantle evolution could be considered with some certainty.

The presence of phlogopite and the nature of the Okete Volcanics in the field (scoria cones etc) suggests that the primitive melts may have been hydrous or volatile rich in nature. This is also confirmed by the crystallisation temperatures which are low and considering that partial melting has occurred could only mean that the melt was hydrous (see Fig. 4.8, Ringwood, 1975).

In summary it is envisaged that several hydrous primitive melts were produced at the base of the lower velocity zone and these rose from this region and underwent varying degrees of partial melting, at various depths and pressures, to produce a range of undersaturated liquids. These liquids underwent little if any differentiation and the lavas at the surface are probably similar in composition to the original melts.

#### 6.5.4 Tectonic Implications

The typical model of genetic relationships between magmas and Benioff zones shown by Kuno (1959) and modified by Green et al., (1967) suggested that the basaltic magma type is related to depth of earthquake foci and hence to the presence of a Benioff zone.

Dickinson and Hatherton (1967) suggested that a relationship occurred between the potassium content of volcanic lavas (K), and depth below the volcano to the Benioff zone (h). K - h curves have been constructed by Hatherton (1969) for the North Island volcanoes and suggests that the high K andesites of Mt Karioi and Pirongia were 'produced' at 200 - 250 km depth.

Ballance (1976) also suggested that the high K calc-alkaline andesites of Mt Karioi occurred above a Benioff zone at similar depths. Cole (1978) stated that the Maungatautari lavas were derived from olivine basalt which fractionated to andesite and this was derived from a greater depth within the subduction zone than the Kiwitahi andesites, presumably  $> 200$  km depth

It is apparent then from these suggestions and from similar studies on island arcs in other areas that the 'initial source region' (Green and Ringwood, 1968) for orogenic parent magmas such as that of Mt Karioi is related to seismic activity and to the position of the Benioff zone under the volcano. According to the models of Kuno (1959) and Green and Ringwood (1968) this source region at great depth (Fig. 6.17(a)), gave rise to a solid diapir which rose and at some depth (0 - 100 km) depending on the magma type began to partially melt and at higher depths magma segregation occurred and an individual magma type is produced. While this situation may occur for calc-alkaline genesis which have a source derived from the subducting lithosphere at  $< 150$  km (Ringwood, 1974), the role of the subducting lithosphere in island arc genesis of other magma types (particularly behind-arc alkaline rocks) would seem to be less clear. Many attempts have been made to explain the relationship between potassium and depth of island arcs for example Ringwood (1974), and Marsh and Carmichael (1974), but explanations involving the progressive breakdown of selected minerals alone, quantitatively fails to explain the observed incompatible element abundances (Whitford *et al.*, 1979). In describing the variations in geochemistry of the Quaternary lavas of the Sunda Arc, Whitford *et al.*, (1979) raise the question of whether the descending slab serves only as a source of water or acts simply as a thermal perturbation which affects melting in the overlying mantle. They go on to suggest that the mantle wedge is the ultimate source for magma material, ie the region where partial melting first occurs, which originates at 0 - 100 km depending on the type of magma, and that mantle below this depth does not generate or produce solid diapir material. Variations in the Sunda Arc lava geochemistry is explained by a heterogeneous geochemically

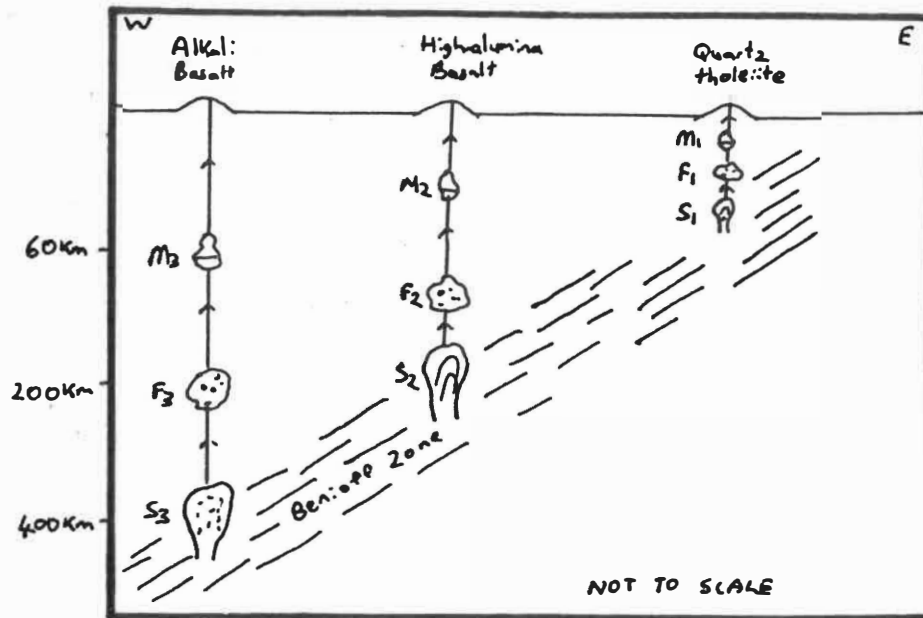


Fig. 6.17 (a) - Diagrammatic description of the origin of magmas in island arcs after Green *et al.*, 1967 and Kuno, 1959. S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub> = loci of initial upward movement of pyrolite mass. F<sub>1</sub>, F<sub>2</sub>, F<sub>3</sub> = beginning of partial melting. M<sub>1</sub>, M<sub>2</sub>, M<sub>3</sub> = depth at which magma segregation occurs.

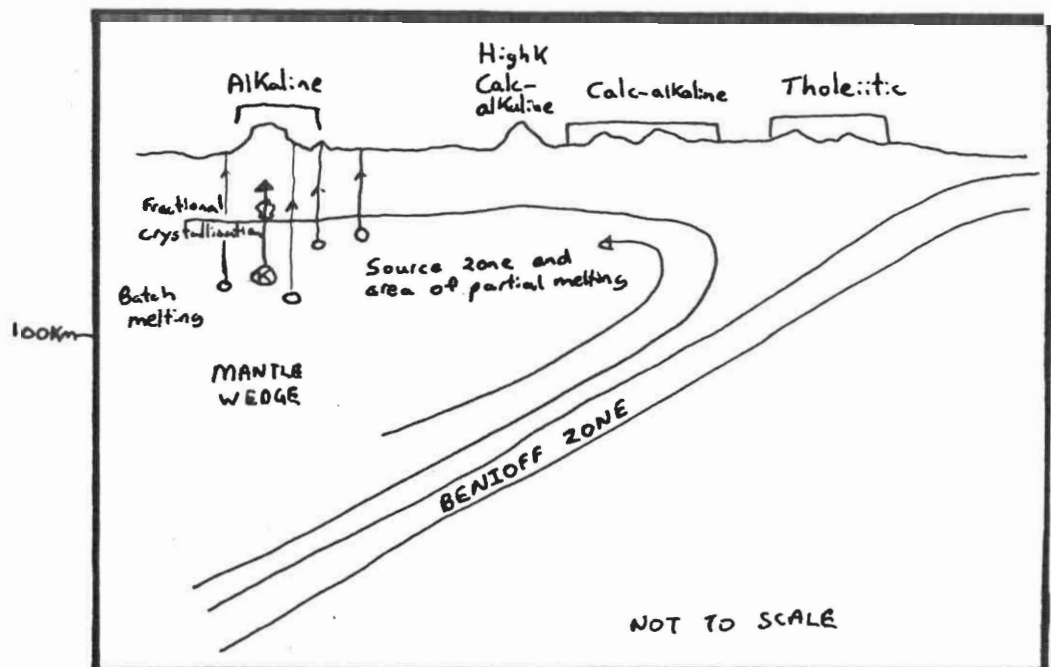


Fig. 6.17 (b) - Modification of (a) for the origin of alkaline rocks in behind arc conditions. Initial source region as the lower velocity zone of the upper mantle where partial melting occurs. Okete Volcanics occur as batch melts of magma while the Karioi Volcanics are the result of fractional crystallisation of one magma (based on Whitford *et al.*, 1979).

zoned mantle source and by varying degrees of partial melting within this region.

If this explanation of the mantle is correct, as it may well be in light of other research (Sun and Nesbitt, 1977 - see Chapter 6.4), then the role the subducting lithospheric slab plays in forming behind arc basalts may be minor or indirect in its effect. Johnson and Arculus (1978) for instance suggested that the petrological features of the orogenic rocks of the Witu Islands, New Guinea, do not require substantial amounts of water or magma generated from a downgoing slab. An analogous situation is that of mid-ocean ridge alkali olivine basalts where subducting plate boundaries do not occur and an explanation involving mantle inhomogeneity and an initial source region in the lower velocity zone of the mantle are most likely.

Sun and Nesbitt (1977) have summarised various models for mantle evolution to explain abundances of incompatible trace elements but less is known about the initiation of partial melting and whether this is related indirectly to convection-like flow in the mantle wedge above the slab (Fig. 6.17(b)).

Thus the presence of behind arc basalts need not be related back to the depth of the Benioff zone at all, and the form of this type of basalt in the North Island of New Zealand, where activity has migrated more or less at random and apparently independently of events at the frontal arc (Ballance, 1976), would tend to support this.

#### Implications to Regional Structure

The field relationships of volcanoes in the Alexandra Volcanics Group are unusual. On one hand the volcanic centres of Mt Karioi, Pirongia, Kapapuku, Te Kawa and Tokanui are aligned in a northwesterly direction ( $300^{\circ}$ ), while the Okete Volcanics show no part of this alignment and appear apparently at random.

The straight nature of the volcanic centre alignment over tens of kilometres suggests a relation to some structural feature (Kear, 1964). Henderson and Grange (1926) noted the alignment of the volcanic centres and stated "Mesozoic rocks are exposed for about ten miles between Pirongia and Karioi. Over half this distance a fault striking north-west has been traced." However such a fault was not displayed on their map and Player (1958), and Kear (1960, 1964) state that no expression of such a fault is seen. It is likely then that any north-westerly structural feature in this area is pre-Mesozoic, and not exposed in the rocks of the region, but is situated in deeper crustal rocks.

The South Auckland and western Waikato areas are dominated by block-faulting related to a tensional tectonic environment. It is likely that because the Okete Volcanics rose to the surface quickly with little apparent differentiation they did not follow the large deep seated fault that the Karioi magma rose to the surface by, but rather came up, with little apparent pattern, along the numerous north and north-easterly striking fractures and faults that occur in the area (see Fig. 1.2). This is clearly seen in the field for instance at Taranaki Pt, south of the mapping area where olivine basalt has localised along a fault and is inferred in numerous other centres within the mapping area.

## CHAPTER SEVEN

### SUMMARY OF THE VOLCANIC HISTORY OF THE MT KARIOI AREA

#### 7.1 INTRODUCTION

The following discussion summarises the volcanic history of the Karioi and Okete Volcanics and has been deduced from the stratigraphy seen in the coastal cliff sections and elsewhere in the mapping area.

A diagrammatic representation of this volcanic history is presented in Fig. 7.1.

#### 7.2 PRE-VOLCANIC HISTORY

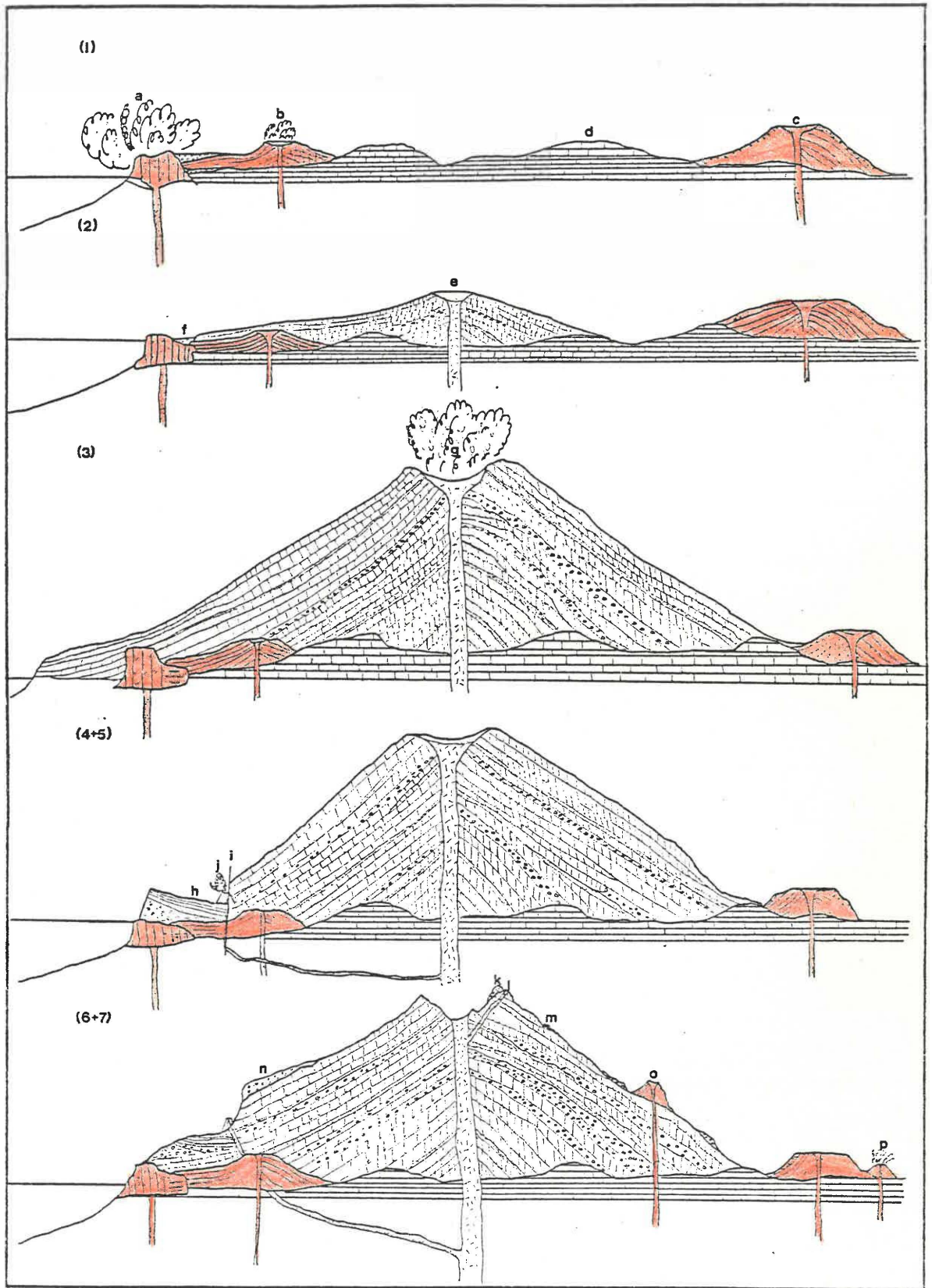
The basement rocks of the immediate Mt Karioi area are the Te Kuiti Group limestones, sandstones and siltstones. Deposition of these rocks ceased in the early Miocene, and was followed in late Miocene times by a major episode of block faulting, leaving a low-lying but irregular surface.

#### 7.3 VOLCANIC HISTORY

- (1) At some time in mid Pliocene times (3.2 to 3.0 m.y. B.P. ?) volcanism began in the Mt Karioi area with a series of olivine basalt eruptions which are part of the Okete Volcanics Formation. Eruptions would have occurred both inland, to the east of Mt Karioi (for example Wharauoa Plateau) and immediately to the east of the present coastline. Eruptions were both explosive and effusive, typically strombolian in nature, and produced airfall deposits of ash and lapilli, scoria cones, and basaltic lava flows.

Fig. 7.1 - Schematic summary (not to scale) of the volcanic history of the Mt Karioi region. Cross-section is approximately west-east. Numbers refer to text.

- (1) Volcanism began in the area with Okete Volcanic (red) phreatomagmatic (a) and strombolian eruptions (b) on the coast and larger strombolian eruptions inland (c), which all erupted through the Te Kuiti Group basement (d).
- (2) Early strombolian eruptions from Mt Karioi built up a small cone (e) which overlies the Okete Volcanics deposits on the coast. Epiclastic sediments (f) were deposited among these volcanic deposits during higher sea level periods.
- (3) The main cone of Mt Karioi (g) was produced between 2.8 and 2.4 m.y. B.P. and consists of deposits of lavas (IIII), ash (-----) and breccias (---) produced by strombolian activity.
- (4 & 5) Erosion and rotational slumping occurred producing semi-circular bays on the coast (h). Faulting occurred in some places (i) and a parasitic cone (j) localised along the Te Toto Fault at Te Toto Gorge.
- (6 & 7) Late stage activity of Mt Karioi included a massive volcanic (k) on the upper slopes and lahars on the lower slopes (n). Eruptions from the Okete Volcanics of a similar age (2.2 m.y. B.P.) also took place, some of which intruded through pre-existing Karioi lavas (o). Younger Okete Volcanics producing mainly scoria and some lava erupted further east of Mt Karioi up to 0.5 m.y. B.P.



A few phreatomagmatic eruptions also took place at this time (Bryant Home Beach and Papanuiti Bay). This type of eruption is common along the coast of many oceanic volcanoes (Williams and McBirney, 1979), and caused violent eruptions when rising magma came into contact with sea water, producing a fragmented deposit with small clasts of vesicular olivine basalt set in a vitric ash. At Papanuiti Pt the initial eruptive blast cleared the vent of limestone and sandstone country rocks which are seen at the base of the deposit.

- (2) These early strombolian and phreatomagmatic eruptions of Okete Volcanics on the coast were subsequently overlain by the initially small eruptive products of Mt Karioi at approximately 3.0 m.y. B.P. Karioi basaltic lavas are clearly seen overlying Okete olivine basalt lavas with no erosional break. Epiclastic sedimentary conglomerates, sandstones and siltstones also occur immediately overlying the Okete lavas, towards the bottom of most of the coastal cliff sections. The sediments contain little Karioi material and are dominantly composed of Okete olivine basalt clasts. It is envisaged then, that when these sediments were formed either only a few Karioi flows had been erupted, or else they were restricted to the inland areas where erosion was limited. This would leave the Okete lavas on the coast as the immediate and dominant source of material for marine and fluvial processes to erode and rework.
- (3) After significant amounts of these sediments had been deposited the main period of the Karioi eruptions then took place from about 2.8 to 2.4 m.y. B.P. Eruptions were typically strombolian in type and built a considerable composite type volcano of interbedded lavas and ash. Effusive eruptions of aa lava dominated activity and these flowed from a central vent down all sides of the volcano in a radial fashion. Some volcanic events were preceded by weak explosive eruptions which ejected small volumes of ash, lapilli

and bombs. Explosive clouds of this type seldom rise more than 500 m into the air and this would explain the limited distribution of Karioi ash which is restricted to the mountain cone itself.

- (4) Towards the end of this period of activity, faulting (for example Te Toto Fault, Homestead Fault) and erosion occurred. Fluvial action down the flanks of Mt Karioi produced gullies and ravines, and deposited alluvial conglomerates (see Section H). Marine erosion and deposition along the coast would also have been operative. Also at this time numerous rotational landslides on the coast took place forming the several bay-like rotational slump features at Te Toto Gorge, Spray Bay and particularly at Hills Flat. This effect is common on composite cones and MacDonald (1972) described similar troughs and grabens caused by bulk landslides and faulting on the slopes of Api volcano in Indonesia. The rotational slides result from the instability of the poorly cemented pyroclastic material on the steep flanks of the cone, and was enhanced by loading of the upper slopes by debris from later eruptions and often by saturation with water in heavy rainfalls.

Sea level was probably relatively high at this time and marine action subsequently eroded much of the slumped and faulted material, and redeposited it as epiclastic sediments. The large amounts of sediment at the Homestead section probably resulted from deposition of such eroded material into a faulted (and slumped ?) depression.

- (5) A parasitic flank vent then erupted at Te Toto Gorge, probably localised along the Te Toto Fault, which may have initiated the original landslide. This vent occurs approximately 2.5 km from the presumed central crater site and is composed of steeply dipping lavas, brecciated lavas and volcanic breccias. These deposits formed a small cone, although similar deposits of volcanic breccia were observed 600 m west of the vent which could indicate these

eruptions were relatively violent in nature. The growth of parasitic cones on the flanks of large composite volcanoes is usually a sign of old age (Williams and McBirney, 1979) and the development of a cone at Te Toto is consistent with this suggestion. It is possible that other cones were present also at similar times but were either subsequently buried or eroded.

- (6) Several other features also occurred during the late stages of Karioi activity. For example the large deposits of massive, crystal and ash-rich volcanic breccia at Tamahine O Karewa Peak and on Te Toto Ridge are thought to represent a particularly violent explosive airfall deposit of strombolian type late in Mt Karioi's active period. It is also possible that these deposits were a phreatomagmatic deposit of basaltic material of a phreatic andesitic eruption which fragmented existing basaltic rocks. However, considerable water is needed for these types of eruptions and it is unknown whether sufficient groundwater would have been available for this purpose.

The andesite lavas and andesite dyke would have also been emplaced at this time high on the mountain's upper ridges and the dyke strikes northwest along the main ridge to the mountain summit intersecting pre-existing basaltic andesite lavas.

Another volcanic phenomena often said to relate to the declining stages of volcanic activity are hot springs (Williams and McBirney, 1979). While there is no direct evidence for such activity to have occurred on Mt Karioi, the presence of numerous siliceous boulders and rounded chert pebbles in the regolith of the upper slopes, around the banks of streams, and near a modern fresh water spring, all on the eastern side of the mountain, suggest that one or more hot water springs on the upper slopes may have been present during this late stage of eruption. Such a spring could reinforce ideas of previous phreatomagmatic activity as it could imply groundwater

was readily available.

During these late stages of activity while the mountain was still barren with little or no vegetation, the potential for lahars to occur is high. It is likely that the lahars on Mt Karioi were deposited at this time when heavy rains initiated large mudflows which swept down the mountain incorporating large volumes of ash and blocky lava material.

- (7) More eruptions of the Okete Volcanics were also taking place during these latter stages of eruption from Mt Karioi. Several volcanic centres over a wide area all have a similar age (about 2.3 m.y. B.P.) and produced relatively larger proportions of lava than ash and scoria and appear to have erupted similarly to the effusive volcanoes of the Auckland field (Searle, 1965).

While sea levels were relatively high (60 m above present) at the time of Kaawa deposition (pre-Karioi), they were relatively low during the main period of basaltic volcanic activity from Mt Karioi (2.8 to 2.4 m.y. B.P.). Thus the underlying Karioi basalt lava flow at the Papanui Pt Okete Volcanic centre (2.41 m.y. B.P., Stipp, 1968) is thought to have erupted over a dry surface but it is envisaged (Chappell, 1970) that a sedimentary conglomerate of 20 m height between the Karioi and overlying Okete lavas (2.28 m.y. B.P.) represents an oscillation in sea level at some time between 2.41 and 2.28 m.y. B.P.

Okete Volcanic centres have probably also erupted in more recent times, and many relatively younger scoria cones are seen in the Te Mata area (for example Houchens Hill) with only weakly weathered, bedded scoria, and may be about 0.5 m.y. old or even younger.

#### 7.4 POST VOLCANIC HISTORY

Mt Karioi is now considerably eroded and entering the residual mountain stage of erosion (Kear, 1957) with deeply dissected gullies and ravines, "razorback" ridges, and dykes exposed on the upper ridges. The sea has considerably eroded the volcanic deposits along the coast and formed steep vertical cliffs. Erosion is still presently active, particularly on the coast and on the steep upper ridges.

## CHAPTER EIGHT

## CONCLUSIONS

The following conclusions have been drawn from this study of the volcanic geology of the Mt Karioi region.

- (1) Two distinct volcanic formations in the mapping area have been recognised: the Karioi Volcanics and the Okete Volcanics (new formation), and these together with Pirongia, Kakepuku, Te Kawa and Tokonui Volcanic Formations make up the Alexandra Volcanic Group. The two volcanic formations can be separated by their volcanic form, their petrology and petrochemistry.
- (2) The Karioi Volcanics consist of basalt, basaltic andesite, and andesite lavas, volcanic breccias and tuffs, and lahar deposits. The bulk of the stratovolcano has been produced by strombolian type eruptions from a central crater high on Mt Karioi and from a small parasitic flank vent.
- (3) The Okete Volcanics consist of numerous small volcanic centres spread over a wide area which produced olivine basalt lava flows, scoria cones and ash by strombolian and phreatomagmatic eruptions.
- (4) The deposits of both volcanic formations are closely spatially related in the field and intercalate in many areas. They also intercalate with epiclastic sediments which were produced as a result of the deposition of marine and fluvial processes of large amounts of volcanic detritus of ash, lapilli, block and bomb material eroded from these volcanics.

- (5) Petrographically the Karioi lavas are generally coarse grained porphyritic rocks with large phenocrysts of plagioclase, clinopyroxene and olivine set in a coarse grained groundmass. The Okete Volcanics are dominated by olivine phenocrysts which are typically set in a fine grained pilotaxitic groundmass.
- (6) The Karioi Volcanics represent a calc-alkaline rock series ranging from nepheline normative basalts, through basaltic andesites to quartz normative andesites. This series was produced largely by amphibole fractionation of a nepheline normative hydrous basaltic melt which produced a series of liquids which crossed the critical plane of undersaturation, and crystallised amphibole, + olivine + clinopyroxene + plagioclase + titanomagnetite + phlogopite.
- (7) The Okete Volcanics underwent little or no differentiation and are essentially mantle derived from a source near the base of the lower velocity zone. Diapirs produced in this region underwent varying degrees of partial melting at various depths and produced a variety of liquids from strongly nepheline normative basanitoids to hypersthene normative olivine tholeites.
- (8) The limited volumes of andesites of Mt Karioi result from the fractional crystallisation of a basalt and hence are not themselves derived from the Benioff zone. The basalts of the Karioi Volcanics (and the Okete Volcanics) represent behind-arc orogenic basalts and were produced from a source in the lower velocity zone of the upper mantle ( 100 km depth) which is probably only indirectly related to the sinking subducting lithosphere which passed 220 km beneath the west coast of the North Island 2 - 3 million years ago (Ballance, 1976).
- (9) The Karioi Volcanics are one of several similar formations (for example Pirongia) which are part of the Alexandra Volcanics and form a volcanic centre alignment which is probably due to a deep seated pre-Mesozoic fault. The Okete Volcanics were probably erupted along

smaller tensional block faults, but show no apparent alignment patterns with the larger composite cones of the other formations in the Alexandra Volcanic Group, or amongst themselves.

- (10) The author envisages that future research should concentrate on more detailed geochemical studies of both the Karioi and Okete Volcanics to confirm the fractional crystallisation and partial melting hypotheses proposed here.

Further field mapping and general geological studies of all centres of the Okete Volcanics is required, together with more K - Ar dating particularly of the apparently younger centres.

Further research is necessary on the sedimentary rocks, particularly the epiclastic sediments which are volumetrically significant on the west coast of the mapping area. Such a study may elucidate Plio-Pleistocene climatic events and sea level changes.

## APPENDIX I

MODAL ANALYSIS

Modal analyses of selected thin sections were carried out using an Olympus Pom 201000 microscope with a magnification of X100 and a Swift Automatic Point Counter (Model E).

500 or 750 points were counted depending on grain size which gives errors between + 2-4% at the 95% confidence level depending on the percentage of each mineral present (Carver, 1971).

Average modal analyses are presented in Chapter 4 for the major rock types and some of the Okete Volcanics (Table 4.1 and 4.2). These average figures were derived from the following data presented in Table I.1, I.2, I.3, I.4, I.5.

TABLE I.1 - MODAL ANALYSES - Karioi Basalts  
(a) coarse grained lavas  
Location of samples shown in Table IV.3.

	W17004	W17009	W17014	W17017	W17023	W17025	W17040	W17050	W17052	W17088	W17092
Groundmass	-	-	-	-	-	-	36.2	-	-	-	-
Plagioclase	55.2	56.0	56.7	51.9	59.2	76.0	32.9	39.9	42.8	61.7	58.9
Clinopyroxene	23.0	23.2	34.3	25.5	22.4	12.4	24.9	23.0	19.8	16.0	22.9
Orthopyroxene	-	-	0.9	-	5.2	-	-	-	-	-	0.4
Olivine	5.7	11.6	1.7	10.0	5.8	4.0	4.0	11.2	5.4	9.0	8.7
Phlogopite	0.3	-	-	-	trace	-	trace	-	-	0.4	0.5
Opaques	4.9	9.6	4.4	12.6	6.0	7.6	2.0	5.0	8.4	4.9	3.7
Apatite	1.4	trace	trace	-	trace	trace	-	1.6	0.4	2.0	0.4
Alteration Products											
- Phenocryst	1.6	-	-	-	-	-	-	6.3	8.4	2.4	1.2
- Groundmass	6.9	-	-	-	2.4	trace	-	13.0	14.8	3.6	3.2

TABLE I.2 - MODAL ANALYSES - Karioi Basalts  
 (b) porphyritic lavas  
 Location of samples shown in Table IV.3.

	W17013	W17015	W17026	W17027	W17044	W17080	W17081	W17086	W17109	W17110
Groundmass	30.7	65.3	48.3	32.5	23.3	42.2	53.4	36.9	42.0	54.2
Plagioclase	53.0	21.5	33.6	60.0	58.9	33.8	26.0	45.9	35.4	17.0
Clinopyroxene	7.4	7.8	6.5	2.7	7.8	17.0	19.4	8.9	17.6	16.2
Orthopyroxene	-	-	trace	0.2	-	-	-	-	-	-
Olivine	7.0	3.0	9.1	2.5	6.4	5.6	0.8	7.1	2.6	12.2
Phlogopite	-	-	-	-	-	-	-	-	-	-
Opagues	1.9	2.4	1.9	2.1	3.6	1.4	0.4	1.2	1.6	0.4
Apatite	trace	-	-	-	-	-	-	-	-	-
Alteration Products										
- Phenocryst	-	-	-	-	-	-	-	-	0.80	-
- Groundmass	-	-	-	-	-	-	-	-	-	-
Calcite	-	-	0.6	-	-	-	-	-	-	-

TABLE I.3 - MODAL ANALYSES - Karioi Basaltic Andesites  
(a) olivine basaltic andesites  
Location of samples shown in Table IV.3.

	W17053	W17056	W17067	W17068	W17069	W17072	W17084	W17087	W17095	W17098	W17117
Groundmass	46.6	44.3	42.5	49.5	31.9	44.5	61.4	26.4	43.3	42.4	37.6
Plagioclase	24.7	26.5	33.6	19.8	43.2	27.1	17.0	52.6	24.6	41.6	37.5
Clinopyroxene	20.7	18.9	13.7	17.1	17.2	18.8	11.6	12.3	16.7	10.4	11.9
Orthopyroxene	-	-	-	-	-	-	1.6	0.6	-	-	-
Olivine	3.6	7.5	1.6	5.4	4.7	7.6	7.0	2.3	10.5	2.6	4.4
Hornblende	trace	trace	1.4	5.1	-	0.4	-	-	-	-	6.0
Phlogopite	trace	-	trace	trace	-	trace	-	-	0.6	-	-
Opagues	4.4	2.8	2.9	2.8	3.0	1.6	1.4	2.7	2.9	3.0	2.6
Alteration Products	trace	-	4.3	4.3	-	-	-	3.1	1.4	-	-

TABLE I.4 - MODAL ANALYSES - Karioi Basaltic Andesites and Karioi Andesites  
 (b) hornblende basaltic andesites Location of samples shown in Table IV.3.

	KARIOI BASALTIC ANDESITES					KARIOI ANDESITES				
	W17078	W17083	W17091	W17096	W17116	W17016	W17057	W17070	W17071	W17082
Groundmass	34.4	46.4	47.2	52.2	46.2	43.8	37.6	60.0	55.6	51.6
Plagioclase	44.0	44.2	30.7	32.4	26.2	38.0	36.0	26.3	34.1	34.9
Clinopyroxene	11.2	3.4	9.2	6.0	3.8	7.8	4.6	5.5	5.0	6.7
Orthopyroxene	3.6	0.4	2.8	-	-	5.8	-	-	-	4.3
Olivine	-	-	-	-	-	-	-	-	2.3	-
Hornblende	3.5	1.4	7.7	6.9	20.2	-	18.6	5.3	2.7	-
Opaques	2.8	4.2	2.4	2.5	3.6	3.8	3.2	2.9	0.3	2.5
Alteration Products	0.5	-	-	-	-	-	-	-	-	-

TABLE I.5 - MODAL ANALYSES - Okete Olivine Basalts  
Location of samples shown in Table IV.3.

	W17001	W17007	W17012	W17018	W17019	W17020	W17021	W17022	W17029	W17035	W17039	W17042	W17043	
Groundmass	-	75.4	78.8	67.6	69.3	70.1	58.8	58.0	74.5	-	61.1	82.0	-	
Plagioclase	49.2	-	-	23.4	24.8	12.6	17.9	11.4	-	41.9	9.5	-	35.1	
Clinopyroxene	25.2	7.0	2.4	3.4	2.2	14.3	13.8	14.4	7.2	23.3	12.9	2.8	24.6	
Olivine	21.8	13.4	18.6	3.1	1.0	3.0	9.5	16.2	17.5	18.2	16.5	14.7	15.2	
Opagues	3.8	4.2	0.2	2.5	2.7	-	-	-	0.8	8.0	-	0.5	2.3	
Apatite	-	-	-	-	-	-	-	-	-	-	-	-	-	
Alteration Products	-	-	-	-	-	-	-	-	-	8.6	-	-	22.8	
	W17046	W17047	W17049	W17054	W17066	W17093	W17101	W17105	W17106	W17112	W17114	W17120	W17127	W17131
Groundmass	52.6	76.2	-	82.4	-	72.7	69.4	-	73.8	61.1	62.4	65.4	79.2	66.0
Plagioclase	11.5	-	41.8	-	50.8	4.9	-	52.6	-	6.9	6.4	-	-	13.6
Clinopyroxene	20.9	9.2	27.6	3.6	26.0	3.0	13.0	23.4	3.8	15.1	11.6	1.0	4.2	6.0
Olivine	13.3	11.6	22.6	14.0	15.6	19.0	17.4	18.8	12.0	16.9	15.2	27.4	14.0	14.4
Opagues	0.1	2.0	6.7	-	5.8	0.4	0.2	4.6	8.2	-	1.0	6.2	2.6	-
Apatite	-	-	1.3	-	1.8	-	-	0.6	-	-	-	-	-	-
Alteration Products	1.6	-	-	-	-	-	-	-	3.2	-	3.4	-	-	-

## APPENDIX II

### WHOLE ROCK ANALYSES

13 new analyses are presented on the Alexandra Volcanics. These were analysed at the Victoria University of Wellington by Ken Palmer.

Loss on ignition values which represent  $H_2O^+$  and volatiles such as fluorine were completed at University of Waikato after heating the samples to  $1000^{\circ}C$ . Rock powders were fused with Sigma x-ray lithium tetraborate flux (Norrish formula) and made into a glass disc to produce a homogeneous sample. Both these procedures were completed by the author following the Victoria University Department of Geology Technical Information Tome number three, which is based on the method of Norrish and Hutton (1968).

FeO was determined by the conventional titrimetric method using standard dichromate solution, with diphenylamine indicator (Sarver, 1927; Shapiro and Brannock, 1956). Values were corrected according to the Ngatutura basalt standard.

$Fe_2O_3$  values were calculated by subtracting the  $Fe_2O_3$  equivalent of FeO (FeO value x 1.11) from the total iron value given by XRF. The percentage loss between the sum of the FeO (calculated by titration) and  $Fe_2O_3$  (as calculated above) and the total iron value by XRF was added to the LOI value so that the rock total remains constant.

CIPW norm values were calculated using the HNORM Fortran program on the University of Waikato PDP 11/70 computer. This programme also calculates the differentiation index, various end member data and other useful statistics.

Mg values were calculated according to Whitford et al., 1979 as expressed in the equation below. Total iron as FeO was calculated according to Irvine and Baragar (1971). Values for the Okete and Karioi Volcanics are presented in the table below.

$$\text{Mg value} = \text{Mg} / (\text{Mg} + \text{Fe}^{2+})$$

where

$$\frac{\text{MgO wt\%}}{\text{molecular weight MgO (=40.32)}}$$

and

$$\text{Fe}^{2+} = \frac{0.85 \sum \text{Fe (total iron expressed as Fe}^{2+}\text{)}}{\text{molecular weight of FeO (=71.85)}}$$

where

$$\sum \text{Fe} = \text{FeO (wt\%)} + 0.8998 \text{ Fe}_2\text{O}_3 \text{ (wt\%)}$$

KARIOI		OKETE	
Sample Number	Mg value	Sample Number	Mg value
W17016	0.50	W18007	0.69
W17027	0.45	W17035	0.68
W17040	0.59	W17039	0.67
W17083	0.49	W17046	0.68
W17084	0.60	W17029	0.70
W17086	0.55	W17145	0.65
W17092	0.58	H+G13	0.66
H+G5	0.43	H+G14	0.65
H+G6	0.51	H+G17	0.67
H+G7	0.51	K	0.74
H+G10	0.53	V	0.65
H+G11	0.52		
H+G9	0.44		

## APPENDIX III

MINERAL ANALYSES

Polished thin sections were made of some selected slides at the University of Waikato. These were carbon coated and analysed by microprobe at the University of Auckland Geology Department using a Jeol JKA59 instrument.

Beam current was 20 KV and specimens were counted over 10 seconds and an average of 5 counts was taken.

The oxide count values were calculated into percentage values at Waikato University using the Fortran BENCEEALBEE programme on the PDP 11/70 computer. This programme uses the correction factors of Bence and Albee (1968). Bence and Albee standards were used.

End member data was subsequently calculated using a programmable calculator at the University of Auckland Geology Department.

Tables II.1 - II.4 list all the mineral analyses with totals between 98 - 101% (for anhydrous minerals). Other analyses were made but their totals ranged between 94 - 108%. The error is probably due to drift on the microprobe, although the current correction programme was used during the operation of the probe. The error is most likely in the silica content as the silica peak is not sharp, but end member values are still considered valid.

TABLE III.1 - MINERAL ANALYSES: PLAGIOCLASE (Analyst - S.G. Matheson)

c = core

r = rim

g/m = groundmass

Location of samples and descriptions of rock types are given in Table IV.1

	KARIOI VOLCANICS														OKETE VOLCANICS					
	W17027				W17040				W17083			W17092			W17035		W17046			
	c	r	c	r	c	r	c	r	c	c	c	c	r	g/m	g/m	c	r	c	r	
SiO <sub>2</sub>	51.09	50.34	50.93	51.68	45.83	53.15	46.85	48.34	47.06	49.42	47.74	54.10	56.48	54.81	50.87	49.55	51.85	51.79	51.62	
TiO <sub>2</sub>	0.06	0.06	0.10	0.07	0.04	0.05	0.00	0.02	0.05	0.05	0.01	0.08	0.10	0.17	0.09	0.12	0.10	0.11	0.22	
Al <sub>2</sub> O <sub>3</sub>	30.52	30.91	29.68	30.19	33.50	28.78	33.58	33.57	32.80	32.28	34.24	29.44	27.30	29.48	30.58	31.96	31.83	31.06	30.33	
FeO	0.54	0.58	0.61	0.64	0.73	0.73	0.72	0.77	0.53	0.45	0.63	0.71	0.62	0.79	0.82	0.59	0.73	0.62	0.51	
MnO	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	
MgO	0.10	0.12	0.11	0.12	0.06	0.10	0.10	0.08	1.54	1.45	0.01	0.07	0.06	0.06	0.12	0.12	0.16	0.14	0.13	
CaO	13.81	14.00	13.02	12.86	17.55	11.31	17.33	16.63	16.58	14.06	17.48	12.40	9.44	11.80	14.73	14.89	13.74	13.70	13.20	
Na <sub>2</sub> O	3.73	3.40	3.89	3.95	1.60	4.12	1.61	1.76	2.28	3.35	1.41	3.99	5.83	4.28	3.02	2.59	3.03	3.25	3.62	
K <sub>2</sub> O	0.25	0.21	0.31	0.28	0.21	1.06	0.19	0.18	0.10	0.21	0.10	0.60	0.66	0.26	0.19	0.15	0.18	0.21	0.30	
TOTAL	100.11	99.62	98.64	99.78	99.53	99.30	100.38	101.36	100.95	101.30	101.61	101.38	100.49	101.68	100.41	99.99	101.63	100.87	99.93	
End Members																				
Or	1.43	1.23	1.81	1.64	1.21	6.30	1.11	1.07	0.57	1.23	0.59	5.18	3.78	1.56	1.11	0.90	1.10	1.26	1.78	
Ab	32.36	30.16	34.46	35.14	13.99	37.23	14.23	15.90	19.81	29.76	12.66	34.90	50.78	39.01	26.76	23.73	28.21	29.66	22.58	
An	66.21	68.62	63.73	63.22	84.80	56.47	84.66	83.03	79.61	69.01	86.75	59.92	45.43	59.43	72.13	75.37	70.69	69.08	65.64	

TABLE III.2 - MINERAL ANALYSES: CLINOPYROXENE (Analyst - S.G. Matheson)

c = core  
r = rim

Location of samples and descriptions of rock types are given in Table IV.1.

	KARIOI VOLCANICS									OKETE VOLCANICS					
	W17016		W17040		W17083		W17091	W17092		W17039		W17046			
	c	r	c	r	c	r	c	c	c	c	r	c	r	c	r
SiO <sub>2</sub>	53.78	53.71	52.98	52.49	55.04	56.54	53.39	48.94	48.35	46.67	49.62	48.37	48.64	51.50	51.08
TiO <sub>2</sub>	0.59	0.74	0.71	0.98	0.42	0.31	0.65	0.80	0.51	2.30	1.27	1.71	0.00	1.31	1.53
Al <sub>2</sub> O <sub>3</sub>	2.30	3.11	2.37	4.80	2.00	1.76	3.09	4.91	5.47	8.08	5.49	6.23	6.71	5.44	6.25
FeO	8.83	9.53	7.31	9.26	9.80	10.24	9.30	7.82	4.85	8.16	6.18	6.41	7.94	5.76	6.49
MnO	0.28	0.26	0.16	0.23	0.49	0.52	0.33	0.21	0.08	0.11	0.11	0.09	0.11	0.07	0.10
MgO	11.90	12.91	13.56	11.87	11.13	12.38	11.35	14.13	14.96	11.38	13.26	12.69	11.74	13.16	12.81
CaO	20.76	21.22	22.74	22.03	20.28	18.77	20.87	22.79	23.84	22.83	24.11	23.37	23.57	23.23	23.07
Na <sub>2</sub> O	0.35	0.24	0.21	0.32	0.32	0.24	0.32	0.27	0.16	0.38	0.35	0.34	0.00	0.35	0.41
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	98.79	101.72	100.04	101.98	99.50	100.77	99.31	98.87	98.21	100.40	100.50	99.21	98.71	100.82	101.74
End Members															
Fs	15.59	15.95	12.06	15.97	17.61	18.17	16.52			14.14	10.18	10.87	13.44	9.76	11.02
En	37.45	38.53	39.87	36.08	35.67	39.16	35.95			35.16	38.93	38.87	35.43	39.77	38.78
Wo	46.97	45.52	48.07	48.14	46.72	42.68	47.52			50.70	50.89	50.78	51.13	50.47	50.20

TABLE III.3 - MINERAL ANALYSES: OLIVINE (Analyst: S.G. Matheson)

c = core

r = rim

Location of samples and descriptions of rock types are given in Table IV.1.

	KARIOI	OKETE VOLCANICS							
	W17040 c	W17035		W17039		W17046			
		r	c	r	c	r	c	c	c
SiO <sub>2</sub>	38.14	42.65	30.84	41.31	39.82	39.64	41.56	38.35	39.98
TiO <sub>2</sub>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Al <sub>2</sub> O <sub>3</sub>	0.00	0.00	0.02	0.02	0.04	0.02	0.04	0.04	0.06
FeO	14.12	19.28	17.06	21.00	12.95	13.38	13.62	17.06	21.70
MnO	0.23	0.23	0.14	0.29	0.21	0.14	0.17	0.22	0.30
MgO	45.40	36.34	51.29	35.23	46.75	45.18	44.68	43.19	38.58
CaO	0.29	0.23	0.16	0.29	0.31	0.30	0.24	0.35	0.38
Na <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	98.18	98.23	99.51	98.13	100.08	98.66	100.50	99.21	101.00
La	0.39	0.35	0.19	0.44	0.41	0.41	0.33	0.47	0.54
Fa	14.80	22.86	15.70	24.95	13.40	14.19	14.74	18.06	23.86
Fo	84.81	76.79	84.11	74.61	86.19	85.40	84.93	81.47	75.60

TABLE III. 4 - MINERAL ANALYSIS (Analyst - S.G. Matheson)

c = core

r = rim

Location of samples and descriptions of rock types are given in Table IV.1.

	ORTHOPYROXENE					AMPHIBOLE		PHLOGOPITE	MUSCOVITE
	KARIOI					KARIOI		KARIOI	KARIOI
	W17016 c	W17083	W17091	W17083	W17092	W17092	W17092	W17092	
SiO <sub>2</sub>	55.11	56.35	57.62	57.94	57.62	44.03	43.01	41.59	66.30
TiO <sub>2</sub>	0.26	0.26	0.15	0.26	0.16	3.34	2.27	5.69	0.13
Al <sub>2</sub> O <sub>3</sub>	1.21	1.67	0.85	1.14	1.06	12.40	13.47	11.39	19.77
FeO	18.84	18.39	18.29	18.77	16.94	12.94	13.07	9.22	0.38
MnO	0.68	0.71	0.72	0.56	0.59	0.19	0.12	0.06	0.00
MgO	20.14	19.40	20.18	20.33	21.51	12.19	12.61	17.78	0.01
CaO	2.00	1.64	1.44	1.55	1.40	11.52	11.64	0.00	0.58
Na <sub>2</sub> O	0.00	0.00	0.02	0.02	0.00	2.71	1.50	0.63	4.10
K <sub>2</sub> O	0.00	0.00	0.00	0.00	0.00	0.63	1.10	8.96	8.09
TOTAL	98.42	98.41	99.27	100.57	99.28	99.95	98.80	95.32	99.37
End Members									
Fs	32.87	33.39	32.59	32.93	29.68				
En	62.65	62.80	64.12	63.59	67.18				
Wo	4.47	3.82	3.29	3.49	3.14				

## APPENDIX IV

SAMPLE LOCATION

The location of the 13 rocks that have been analysed and the location of the 10 rocks that have been previously analysed is shown in Fig. IV.1. Grid references and rock types are shown in Table IV.1 and IV.2.

Any sample mentioned in the text is listed in Table IV.3 which is essentially a quick reference to sample location and rock type. Column 1 lists the University of Waikato Earth Science Department reference number (the number in the text), Column 2 the personal field number, Column 3 the grid reference on NZMS 1 Sheet N64, 1971, Column 4 the site location and Column 5 the rock type.

All these samples (hand specimens, rock powders and thin sections) are stored in the University of Waikato Earth Science Department Rock Store.

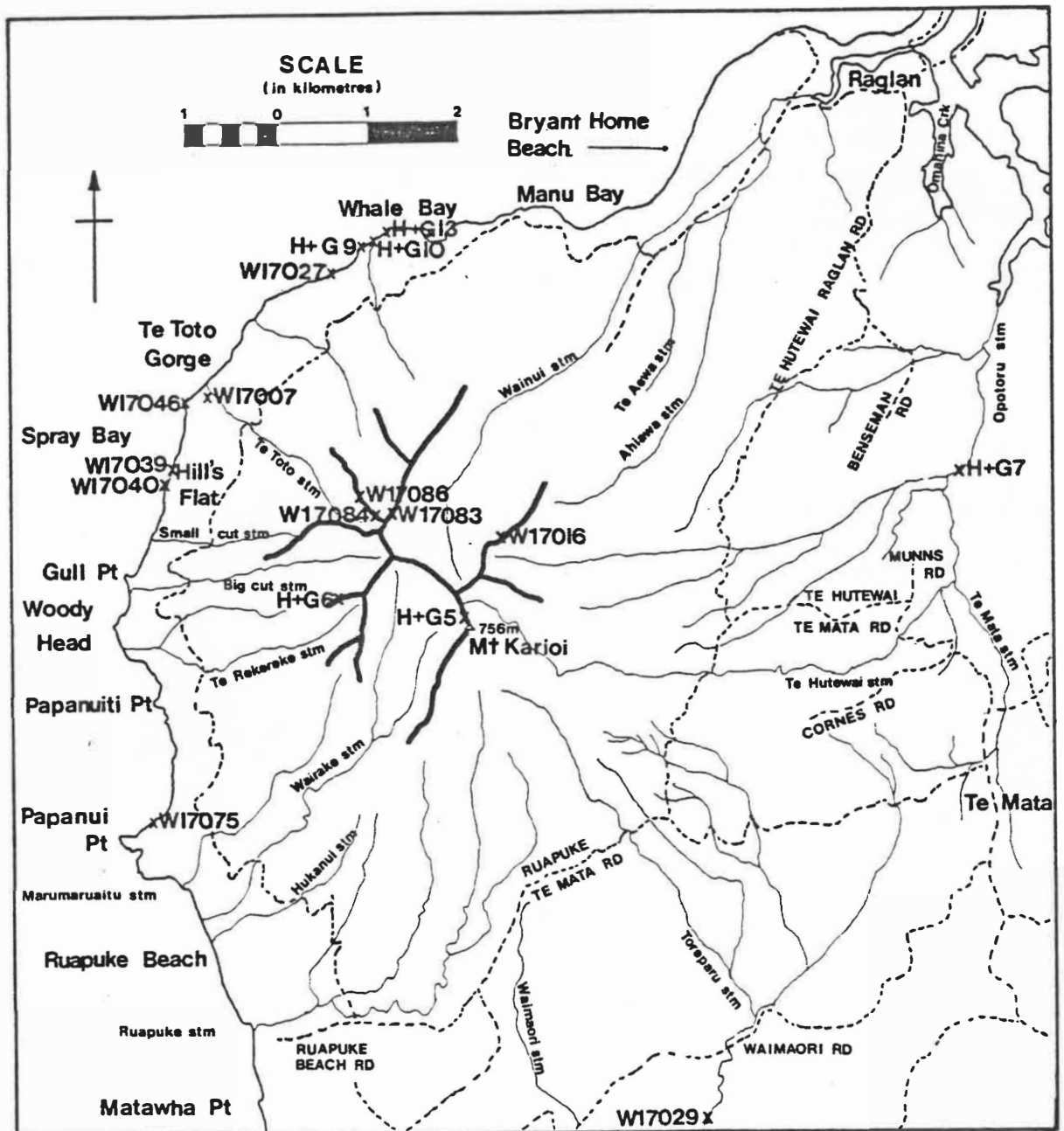


Fig. IV.1 - Location of analysed samples in the mapping area.  
 (W17007 = this thesis, H + G 5 = Henderson and Grange (1926)).

TABLE IV.1 - Location and rock type of analysed rocks (this thesis).

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17007	K11	298403	clast from sediments Te Toto remnant structure	Okete olivine basalt boulder (identical to W17043)
W17016	K24	330381	Millward ridge Mt Karioi	Karioi hypersthene andesite lava
W17027	K52	308417	Tait Section (south of Whale Bay)	Karioi porphyritic basalt lava
W17035	K85	289350	Papanui Pt (Northern Cliffs)	Okete olivine basalt lava
W17039	K96	291391	Coastal Cliffs below Hills Flat	Okete olivine basalt lava
W17040	K98	291389	Coastal Cliffs below Hills Flat	Karioi porphyritic basalt lava
W17046	K121	294402	Te Toto Southern Point	Okete olivine basalt dyke
W17083	K191	319389	Whale Bay ridge Mt Karioi	Karioi hornblende basaltic andesite lava
W17084	K192	317388	Te Toto ridge Mt Karioi	Karioi olivine basaltic andesitic
W17086	K195	315389	Te Toto ridge Mt Karioi	Karioi porphyritic basalt lava
W17092	K212	349379	Main branch of Opororu River	Karioi coarse grained basalt lava
W17029	K60	355310	Toreparu Stream	Okete olivine basalt lava
W17145	104B	438439	Okete Quarry	Okete olivine basalt lava

TABLE IV.2 - Location and rock type of published analytical data of Karioi and Okete Volcanics. H + G = Henderson and Grange (1926)  
K, V = Rodgers *et al.* (1975).

	Grid Reference (N64)	Location	Rock Type	Possible corelative with this thesis
H + G 5	329375	Karioi Trig	Karioi hornblende andesite dyke	W17070
H + G 6	313374	Jacksons Rock (Mt Karioi)	Karioi olivine basaltic andesite lava	-
H + G 7	388388	Opotoru Stream	Karioi olivine basaltic andesite lava	W17087
H + G 9	316423	South of Whale Bay	Karioi porphyritic basalt lava	-
H + G 10	316423	South of Whale Bay	Karioi coarse grained basalt lava	W17017
H + G 11	355305	Toreparu Stream	Karioi coarse grained basalt?	-
H + G 13	317423	South of Whale Bay	Okete olivine basalt lava	W17018
H + G 14	495335?	Wharauroa Plateau	Okete olivine basalt lava	-
H + G 17	380495	Pangonui Inlet (Northern side of Raglan Harbour)	Okete olivine basalt lava	-
K	411439	Kirikiripu Quarry	Okete olivine basalt lava	-
V	419321	Bridal Veil Falls	Okete olivine basalt lava	-

TABLE IV.3 - Summary of sample locations and rock types referred to in this thesis.

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17001	3	285349	Northern side of Papanui Pt	Okete olivine basalt lava
W17002	4	285349	"	Xenolith
W17003	6	348426	Bryant Home Pt	Okete olivine basalt lava
W17004	9	315415	Karioi coast road	Karioi coarse grained basalt lava
W17005	10	298403	Te Toto Gorge	Well bedded epiclastic sediment
W17006	10a	298403	"	"
W17007	11	298403	"	Epiclastic sediment
W17008	11a	298403	"	Okete olivine basalt clast
W17009	13	298403	"	Karioi coarse grained basalt lava
W17010	14	301419	Te Toto Northern Cliffs	Karioi tuff
W17011	15	301419	"	"
W17012	18	301419	"	Okete olivine basalt lava
W17013	19	303398	Te Toto Gorge road cutting	Karioi porphyritic basalt
W17014	20	339426	Coast, Manu Bay	Okete olivine basalt lava
W17015	23	333425	Coast, south of Manu Bay	"
W17016	24	330381	Millward ridge Mt Karioi	Hypersthene andesite lava
W17017	25	319423	Coast, south of Whale Bay	Karioi coarse grained basalt
W17018	26	319423	"	Karioi porphyritic basalt lava
W17019	26a	319423	"	"

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17020	28	314421	Coast south of Whale Bay (Tait Section)	Okete olivine basalt
W17021	29	314421	"	"
W17022	30a	314421	"	"
W17023	35	311417	Above Tait Section	Karioi coarse grained lava
W17024	39	303410	Pauaeke Stream	Karioi porphyritic basalt lava
W17025	42	303399	Road cutting Te Toto Gorge	Karioi coarse grained basalt lava
W17026	45	302402	"	Karioi porphyritic basalt lava
W17027	52	308417	Tait Section	Karioi porphyritic basalt lava
W17028	58	304419	"	Karioi coarse grained basaltic lava
W17029	60	355310	Toreparu Stream	Okete olivine basalt
W17030	72	291363	Papanuiti Pt	Okete volcanic breccia
W17031	73	291364	"	"
W17032	80	293356	Top of Homestead Cliffs	White siltstone
W17033	81	293356	"	"
W17034	83	289350	Northern cliffs at Papanui Pt	Okete lapilli tuff
W17035	85	289350	"	Okete olivine basalt lava
W17036	89	292360	Homestead Fault	Karioi porphyritic basalt dyke
W17037	94	292395	Coast, south of Spray Bay	Charcoal
W17038	95	292395	"	Epiclastic siltstone
W17039	96	291391	Coast, below Hills Flat	Okete olivine basalt lava
W17040	98	291389	"	Karioi porphyritic basalt lava

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17041	101	302402	Te Toto Vent	Karioi porphyritic basalt lava
W17042	110	294402	Te Toto Southern Pt	Okete olivine basalt lava
W17043	112	294401	"	"
W17044	114	302402	Te Toto Vent	Karioi porphyritic basalt lava
W17045	120	294401	Te Toto Southern Pt	Okete olivine basalt dyke
W17046	121	294401	"	"
W17047	124	291389	Coast, below Hills Flat	Okete olivine basalt lava
W17048	126a	383396	A. Benseman's farm, Opoturu River	Karioi coarse grained basalt lava
W17049	127	383393	"	Okete olivine basalt boulder
W17050	128	388393	"	Karioi coarse grained basalt lava
W17051	133	389390	J. Roberts' farm Opoturu River	Karioi porphyritic basalt
W17052	134	389390	"	Karioi coarse grained basalt lava
W17053	136	289350	Northern Cliffs Papanui Pt	Karioi olivine basaltic andesite lava
W17054	138	300314	Matawha Pt	Okete olivine basalt lava
W17055	143	290365	Papanuiti Pt	Okete volcanic breccia
W17056	146	292378	Big Cut road road cutting (lahar)	Karioi porphyritic basalt boulder
W17057	149	313374	Jacksons Rock	Karioi hornblende andesite lava
W17058	149a	313374	"	Xenolith
W17059	150	313374	"	Karioi hornblende andesite lava
W17060	150a	313374	"	xenolith

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17061	151	315376	Swann Ridge Mt Karioi	Karioi porphyritic basalt boulder
W17062	152	299373	North of Jacksons Cut	Okete tuff breccia
W17063	153	36448	D.J. Bishop farm	Okete olivine basalt boulder
W17064	154	365425	"	"
W17065	155	362422	"	"
W17066	156	362423	"	Karioi coarse grained basalt lava
W17067	158	324368	Trig Ridge Mt Karioi	Karioi olivine basaltic andesite lava
W17068	159	325369	"	"
W17069	161	329373	"	"
W17070	162	329275	Karioi Trig	Karioi hornblende andesite dyke
W17071	163	329376	"	"
W17072	164	329379	Millward Ridge Mt Karioi	Karioi olivine basaltic andesite
W17073	165	330382	Millward Ridge Mt Karioi	Karioi porphyritic basalt lava
W17074	167	331384	"	Karioi volcanic breccia
W17075	168	336388	"	Karioi olivine basaltic andesite boulder
W17076	170	389413	C.R. Field's farm	Okete olivine basalt lava
W17077	171	389410	"	Okete olivine basalt boulder
W17078	177	358402	J.D. McNaughton's farm	Karioi hornblende basaltic andesite boulder
W17079	181	309388	Big Cut Ridge Mt Karioi	Karioi porphyritic basalt boulder
W17080	185	310387	"	Karioi porphyritic basalt lava

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17081	189	315385	Big Cut Ridge Mt Karioi	Karioi porphyritic basalt lava
W17082	190	316386	"	Karioi hypersthene andesite lava
W17083	191	319389	Whale Bay Ridge Mt Karioi	Karioi hornblende andesite lava
W17084	192	317388	Te Toto Rdige Mt Karioi	Karioi olivine basaltic andesite lava
W17085	194	316389	"	Karioi volcanic breccia
W17086	195	315389	"	Karioi porphyritic basalt lava
W17087	197	366398	Derne farm	Karioi olivine basaltic andesite lava
W17088	198	372395	"	Karioi coarse grained basaltic lava
W17089	203	372408	Te Hutewai- Raglan road	Okete olivine basalt boulder
W17090	207	359385	L. Cornes farm	Karioi hypersthene andesite boulder
W17091	209	348385	"	Karioi hornblende basaltic andesite lava
W17092	212	346386	"	Karioi coarse grained basaltic lava
W17093	220	355381	Cornes Ridge Mt Karioi	Karioi porphyritic basalt boulder
W17094	228	327379	Central Ridge Mt Karioi	Karioi volcanic breccia
W17095	230	327379	"	Karioi olivine basaltic andesite lava
W17096	232	324380	"	Karioi hornblende basaltic andesite lava
W17097	232A	324380	"	xenolith from above lava
W17098	233	323380	"	Karioi volcanic breccia
W17099	238A	318384	Whale Bay Rdige Mt Karioi	Xenolith from hornblende rich lava
W17100	262	349359	M. Sweetman's farm	Karioi olivine basaltic andesite lava

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17101	272	354340	D.J. Walmsley farm	Okete olivine basalt lava
W17102	276A	383370	Te Hutewai - Te Mata Rd	Xenolith from basaltic andesite
W17103	284	381356	T. Sweetman farm	Chert boulder
W17104	291	364356	Cornes Hill	Okete olivine basalt boulder
W17105	305	390407	C. Field's farm	Okete olivine basalt boulder
W17106	312	390369	Te Huteway - Te Mata Rd	Okete olivine basalt lava
W17107	320	378361	C. Cornes farm	Scoria and ash from Okete Volcanics
W17108	321	360440	T. Tait's farm	Pumiceous silts
W17109	333	299336	G. Goulter-Ward farm	Karioi porphyritic basalt lava
W17110	337	293342	Maramaruaitu Stream	"
W17111	338	293342	"	"
W17112	347	310418	Tait Section	Okete olivine basalt lava
W17113	348	302402	Te Toto Vent	Karioi tuff
W17114	350	294401	Te Toto Southern Pt	Okete olivine basalt dyke
W17115	358	364324	Waimaori Rd	Okete Volcanics tuff and scoria
W17116	361	322383	Central Ridge Mt Karioi	Karioi hornblende andesite lava
W17117	366	314370	Swann Ridge Mt Karioi	Karioi olivine basaltic andesite boulder
W17118	367	388436	Opoturu Estuary	Okete olivine basalt lava
W17119	369	386437	"	"
W17120	370	396432	"	"

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17121	370A	396432	"	Te Kuiti Group limestone
W17122	372	398424	"	"
W17123	373	401442	"	Te Kuiti Group siltstone
W17124	374	398439	"	Te Kuiti Group limestone
W17125	375	397439	"	"
W17126	378	291364	Papanuiti Bay	Epiclastic sediments
W17127	396	293395	Coast, south of Spray Bay	Okete olivine basalt lava
W17128	401	351428	Bryant Home Beach	Okete volcanic breccia
W17129	402	349427	Bryant Home Pt	Epiclastic sediments
W17130	403	348426	"	Okete olivine basalt lava
W17131	405	346425	"	"
W17132	406	345425	"	"
W17133	407	314421	Tait Section	Okete olivine basalt lava
W17134	408	299373	North of Jacksons Cut	Okete tuff breccia
W17135	108	301419	Te Toto Northern Cliffs	Okete olivine basalt lava
W17136	54	304419	Tait Section	"
W17137	400	289350	Papanuit Pt	Karioi porphyritic basalt
W17138	113	294401	Te Toto Southern Pt	Karioi coarse grained basalt lava
W17139	111	294401	"	Okete tuff
W17140	240	228379	Big Cut Stream	Karioi porphyritic basalt lava
W17141	144	227370	Southern side of Woody Head	"
W17142	145	229368	Section I	White siltstone
W17143	115	302402	Te Toto Vent	Karioi lapilli tuff

Waikato Number	Field Sample Number	Grid Reference (N64)	Location	Rock Type
W17144	104	301419	Te Toto Northern Cliffs	Okete olivine basalt lava
W17145	104B	438439	Okete Quarry	"
W17146	345	378344	Adams/Carter Boundary	Karioi coarse grained basalt
W17147	99	338390	Millward track	Karioi basalt boulder
W17148	344	308328	Ruapuke Beach Rd Remnant Stack	Okete olivine basalt lava
W17149	148	294380	Big Cut road cutting	Karioi olivine basaltic andesite lava
W17150	74	290365	Papanuiti Bay	Epiclastic sediments
W17151	118	295405	Te Toto Gorge coast	Epiclastic sediments
W17152	147	294380	Big Cut road cutting	Karioi basaltic andesite lava
W17153	404	346425	Bryant Home Beach	Okete olivine basalt lava
W17154	408A	299373	North of Jacksons Cut	Okete olivine basalt volcanic breccia
W17155	76	290365	Papanuiti Bay	Epiclastic sandstone
W17156	77	290365	"	"
W17157	65	292354	Homestead Cliffs	"
W17158	139	373438	Oxidation Ponds	Te Kuiti limestone
W17159	141	373438	"	Te Kuiti calcerous sandstone
W17160	244	306323	Ruapuke Beach Rd	Okete olivine basalt lava
W17161	245	307327	"	"
W17162	252	365355	Cornes Hill	Okete olivine basalt lava
W17163	270	354340	Walmsley Hill	"

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