

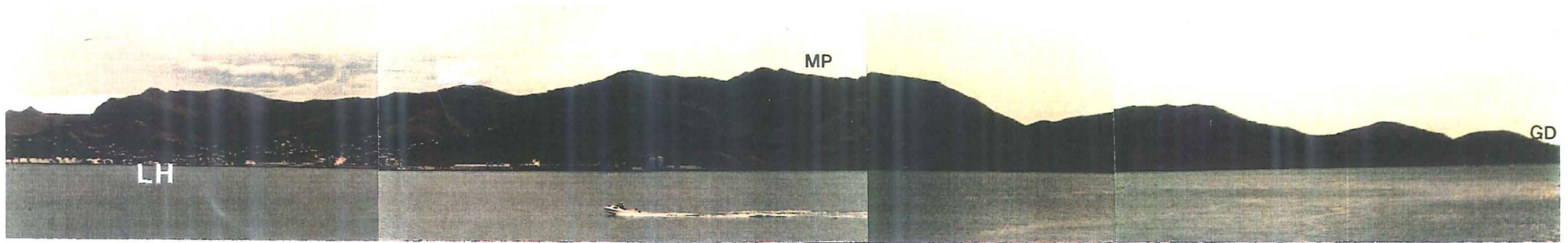
THE GEOLOGY AND GEOCHEMISTRY  
OF  
THE NORTH - EASTERN SECTOR OF  
LYTTELTON VOLCANO,  
BANKS PENINSULA, NEW ZEALAND

A Thesis  
submitted in partial fulfilment  
of the requirements for the degree  
of  
Master of Science in Geology  
in the  
University of Canterbury  
by

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1989



*Distant view of the study area, looking north from Diamond Harbour. (LH= Lyttelton Harbour, MC= Mt Cavendish , MP= Mt Pleasant and GD= Godley Head).*



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## ABSTRACT

Miocene volcanic activity constructed the Lyttelton composite cone 11-10 Ma ago. The Lyttelton volcano which forms the north western half of Banks Peninsula represents a significant volume of mafic volcanic rocks together with some of felsic and minor intermediate composition. In addition to these, the volcano is characterized by pyroclastic deposits (lahars and lithic-crystal tuffs). Lyttelton lavas are intruded by numerous radial dikes and also by a variety of lava domes, sills and plugs. The volcanism was mainly Hawaiian in style, with some Vulcanian and occasional Strombolian styles of activity.

Within this composite volcano, two major phase of volcanic activity are recognized. These are the main phase (the older) and late phase (younger) Lyttelton volcanics defined on the basis of field relationships, petrography and geochemistry. The late phase volcanics are designated formally as the Mt Pleasant Formation. The main and late phase Lyttelton volcanics range from mafic to felsic rocks compositions. The dikes range from basalt to trachyte and intruded the volcano during the main and late phase of volcanic activity. Sills and intrusions have felsic compositions. The major valleys and the lahar deposits represent periods of degradation of the active cone.

Both the main and late phase (Mt Pleasant Formation) Lyttelton volcanics are alkaline tending transitional in geochemical affinity. The alkaline, sodic series Lyttelton rocks are members of the alkali olivine basalt association and this designation is consistent with mineralogy. Some intermediate and felsic Lyttelton rocks are subalkaline and potassic in composition, but they are classified as alkaline olivine basalt associations on the basis of their mineralogy.

There are geochemical distinctions in major oxides, trace-elements and normative mineralogy between the main and late (Mt Pleasant Formation) Lyttelton rocks. The petrogenesis of the main and late Lyttelton volcanics mafic lavas is best explained by low pressure crystal fractionation of the observed phenocryst phases. The intermediate and felsic rocks are derived by similar processes with minor crustal contamination. Tectonically, Lyttelton volcanics represent "within plate" alkaline mafic volcanism.

## CHAPTER 1

### INTRODUCTION

Banks Peninsula consists mainly of the eroded remnants of two large stratovolcanoes, Lyttelton and Akaroa. In recent years, the geology of Banks Peninsula has been increasingly studied and discussed. However, studies on the Lyttelton volcanics, have been very limited. For this reason, the present study has been selected with the primary intention of producing detailed geological, volcanological and petrological interpretations and secondly to add to the present understanding of the evolution of Banks Peninsula.

#### 1.1 Location of study area

The north-eastern sector of Lyttelton volcano is located about Long.172 44' and Lat.43 36' in the northern quadrant of Banks Peninsula, on the east coast of the South Island, New Zealand (Fig. 1.1).

The boundary of the area towards the east is the Tors and towards the north Ferrymead, including the Redcliffs and Sumner areas. The southern boundary is Cass Bay and Lyttelton Harbour (Fig. 1.1).

#### 1.2 Physiography

Lyttelton volcano has undergone extensive erosion to produce the present highly dissected terrain. Points of highest elevation are mostly confined to the central parts of the mapped area (Fig. 1.1). Most of these peaks are made up of successions of lava flows. The highest peaks in the area are Mt. Pleasant (499 metres a.s.l), the Tors (460 metres a.s.l.) and Mt. Cavendish (455 metres a.s.l.). These peaks have an ill-defined east-west alignment, probably related to the Lyttelton crater-rim margin (see later discussion).

In general, the physiography of the area records a juvenile drainage pattern. Numerous valleys radiate from the Summit road in different directions and are incised into rock bodies comprising lava flows and minor intrusives (Fig. 1.2).

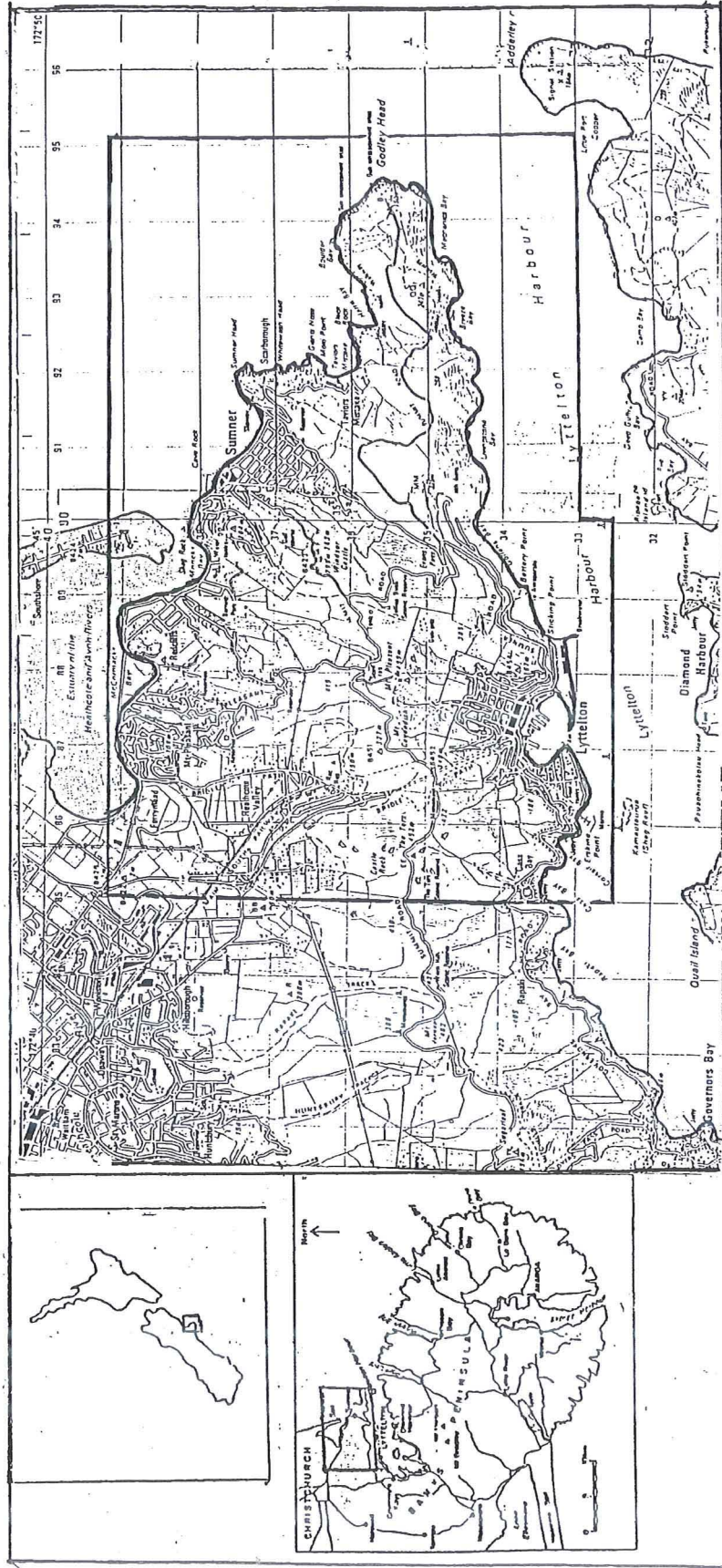


Fig. 1.1 Location map of study area.



Vegetation is dominantly a mixture of grazing land, both grass and tussock, with some native bush in the inaccessible valleys and creeks. Patches of bush occur in some places, such as the Jollies Bush Scenic Reserve (Fig. 1.1).

Access to the mapped area is generally good and gained via the Summit Road (Fig. 1.1) which goes though the central part of area. Numerous tracks and walkways cross the study area.

### 1.3 Purpose and scope of study

The aim of this study is to describe the stratigraphy, petrology, geochemistry and volcanic geology of the north-eastern sector of Lyttelton volcano (Fig. 1.1).

*The primary objectives of the study are three fold:*

[1] Detailed geological mapping and stratigraphy of the area:-

- (a) The identification of lava flows and their correlation between different outcrops on the basis of field characteristics.
- (b) The description of vertical variation in lithologies (stratigraphy).
- (d) To present a detailed geological map

[2] Petrological and geochemical studies :

- (a) To present geochemical data, and describe the variation of major and trace element concentrations.
- (b) To compare the petrology of the volcanic rocks of the study area with other parts of Banks Peninsula.
- (c) Discuss the petrogenesis of the magmas and magmatic processes involved.
- (d) To assess the regional tectonic setting based on geochemical data.

[3] To comment upon the geological history of the area, based on the results obtained from the stratigraphy and geochemistry.

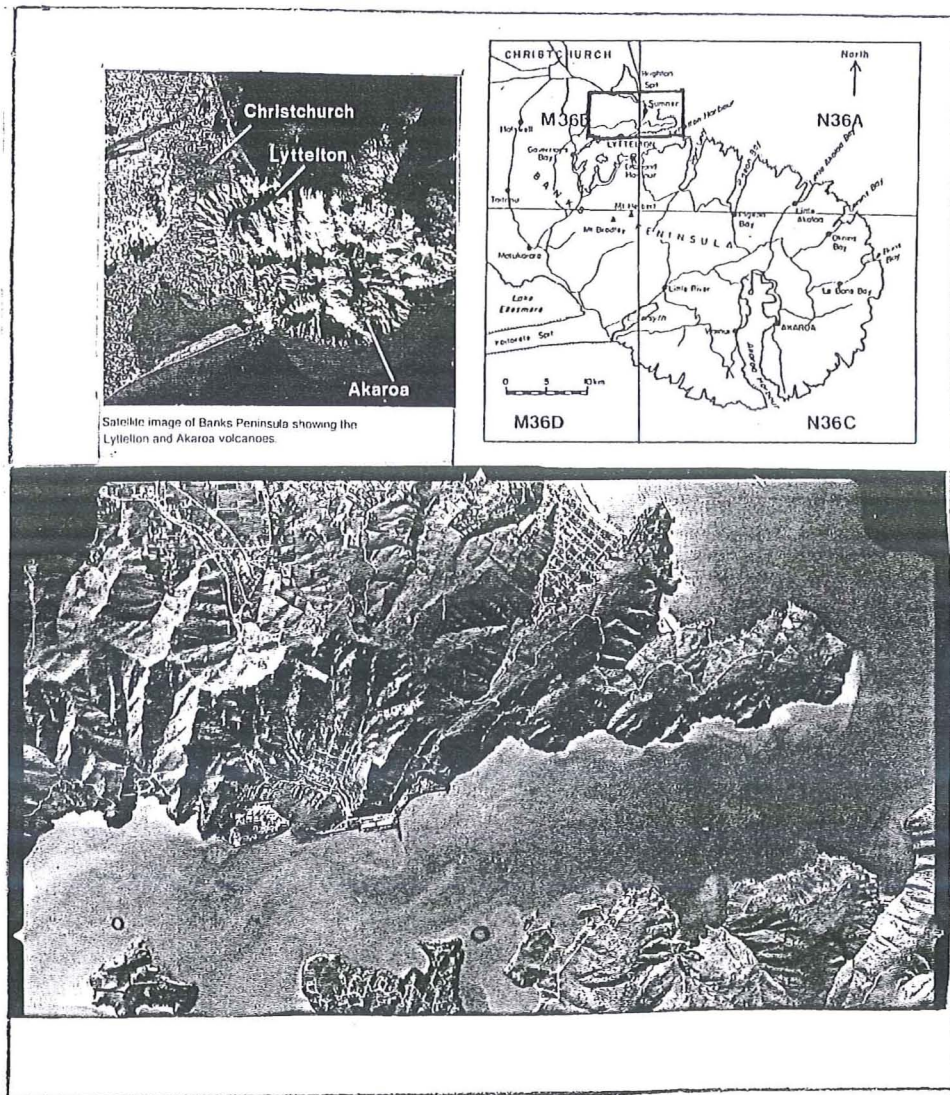


Fig. 1.2 Satellite image of Banks Peninsula and aerial photograph to illustrate the geomorphology of the mapped area.

#### 1.4 Field work

Field work was undertaken over a period of five months between June and December 1987. Mapping was conducted using aerial photographs and topographic maps. Maps and aerial photographs used during field work are presented in appendix I and sample description and grid references are listed in appendix II.

Rock exposures are mainly confined to valley sections, clifflines and road cuts. Most of the lavas are mantled by loess deposits. 265 samples were collected from different localities for petrographical and geochemical analysis.

#### 1.5 Previous work

Julius Von Haast was the first to work on the geology of Banks Peninsula. In 1859 Haast undertook geological studies on Mt Pleasant. Haast (1864) described two centres of volcanism on Banks Peninsula (Akaroa and Lyttelton volcanic centres), but later (Haast, 1879) modified his ideas and suggested four centres of volcanism (Akaroa, Lyttelton, Little River and Mt Sinclair).

Speight (1908, 1917 and 1924) extended the earlier work of Haast, and in his 1935 publication identified three eruption centres (Akaroa, late Lyttelton and early Lyttelton phases).

Ligget and Gregg (1965) produced the first detail geological map of Banks Peninsula and distinguished the Diamond Harbour volcanics from Lyttelton and Akaroa volcanoes. Stipp and McDougall (1968) established the age of Banks Peninsula volcanics (ranging from 12.0 to 5.8 Ma) using K/Ar dating.

Much of the information on the Banks Peninsula region is drawn from Canterbury University unpublished theses (Dorsey, 1981, Falloon, 1981, Thiele, 1983 and Sewell, 1985). Recent published accounts are those of Weaver (1980) on Lyttelton volcano, Shelley (1985, and 1988) on Lyttelton volcano radial dikes and Sewell (1988) on the geology of the central region of Banks Peninsula. Summaries on the general geology of



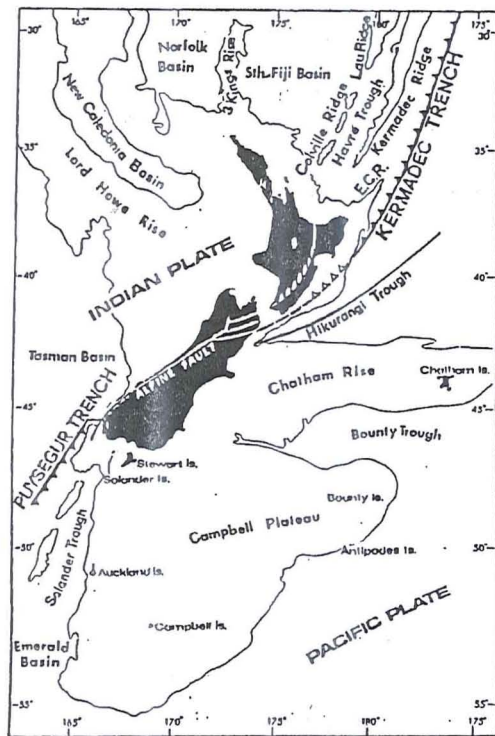


Fig. 1.3 Sketch map showing the major tectonic features of New Zealand region, bathymetric contour is 2000m ( Cole, 1986 ).

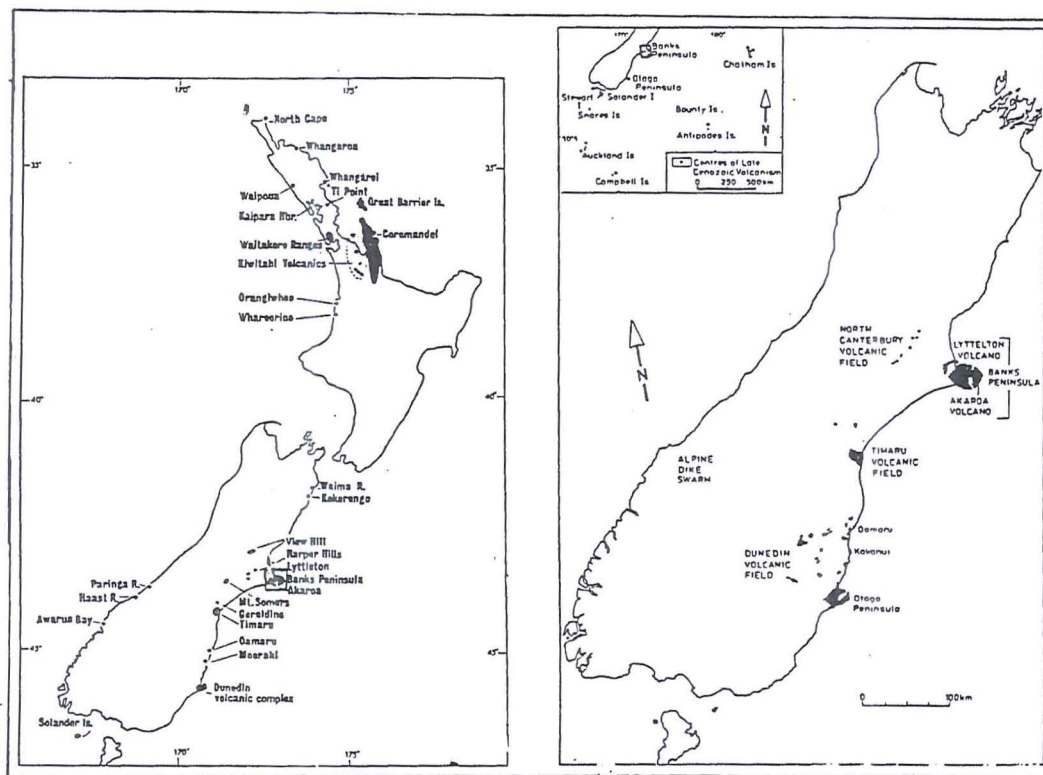


Fig. 1.4. Sketch map of New Zealand showing the distribution of late Cenozoic Volcanism ( Cole. 1986 ).



Banks Peninsula have been published by Weaver et al (1985) and Weaver and Sewell (1986). Lyttelton geological map 1:50,000 Sewell et al. (1989).

### 1.6 Tectonic setting of Banks Peninsula

Most of the different volcanic provinces in New Zealand are related to Cenozoic tectonic processes (Figs. 1.3, 1.5) involving the convergence of the Pacific and Indo-Australian lithospheric plates (Smith, 1986). Cole (1986) has noted that the tectonic setting of most late Cenozoic volcanism in New Zealand can be related to the change in position of the Indian-Pacific plate boundary (Fig. 1.3). The major active tectonic features in New Zealand are a subduction zone dipping westwards (Kermadec trench) under the North Island, a subduction zone dipping eastward (Puysegur trench) under the South Island and the dextral Alpine Fault system between them (Fig. 1.3). At the beginning of Miocene, *Intra-plate* volcanism occurred along the East Coast of South Island (Fig. 1.5).

Late Cenozoic volcanism in New Zealand has occurred in eleven provinces since the beginning of the Miocene (Cole, 1986). The distribution of the volcanics is shown on Figure 1.5. The age, chemical type and tectonic setting of the late Cenozoic volcanism are given in Table 1.1.

### 1.7. Geology of Banks Peninsula

This section draws heavily from data and results that have been provided by other earth scientists writing about the stratigraphy and geologic history of the Banks Peninsula region. This section provides a summary of previous work which forms a basis for this more detailed study.

#### 1.7.1 Geological setting and volcanic history of Banks Peninsula

Banks Peninsula is on the east coast of the South Island, New Zealand and comprises two dissected strato-volcanoes, Lyttelton in the north-west adjacent to the city of Christchurch, and Akaroa in the south-east (Fig 1.1).

Table 1.1 - Data on the volcanic provinces of New Zealand region ( Cole, 1986 ).

1	2	3	4	5	6	7	8	9
Volcanic Province	No. on Fig. 2	Age	Age of Subduction	Distance to edge of Subduction (km <sup>2</sup> )	No. of volcanic features	Spreading (km)	Chemical type	Designation
Colville Ridge	1	Ol-M	Ol-M?	2?	?	—	AmK?	A
Havre Trough	2	P-Q	P-Q	2-3	—	>80	Bt?	O
Kermadec Ridge	3	P-Q	P-Q	2	5(V)	—	Bt-AIK	A
Bay of Plenty	4	Q	Q	2.5-3	12(V)	?	Bt-AmK	O-C
TVZ { arc	5a	Q	Q	2.5	19(V)	—	AmK	A
{ marginal basin	5b	Q	Q	2.5-3	>50(V)	>4.2	Bha/R	C
Mayor Island	6	Q	Q	4	1(V)	—	Rp	?
{ Waiakare	7a	M	Ol-M?	2?	3(M)	—	Bt-AmK	A
{ E. Northland- Coromandel- Kiwitahi	7b	M-P	Ol-M?	2?	>50(V)	<5	AmK-R	A-C
Taranaki	8	Q	Ol-M?	>3.5?	4(M)	—	AmK	A?
Northland-Auckland-Waikato	9	M-Q	—	>4?	>50(V)	<5?	Ba-Bt-Rp	I
Banks Peninsula-Dunedin	10a	M-Q	—	?	6(M)	—	Ba-Bt	I
Chatham Rise-Campbell Plateau	10b	E-Q	—	?	6(M)	—	Ba-Bt	I
Solander Island	11	Q	Q	1.7	1(V)	—	AmK	A

Column 1 gives the name of the province, most names being in general use. Column 2 gives the number of the province as shown in Fig 1.5. Column 3 and 4 gives the geological age which may be inferred directly from radiometric dating or indirectly from stratigraphy. Column 5 gives the horizontal (map) distance to the relevant subduction zone. Column 6 shows the number of volcanic features within the province. Column 7 gives the amount of spreading inferred for the province and Column 8 the chemistry of the bulk of the province according to the symbols given below. Column 9 gives the designation of the tectonic environment. Symbols are as follows: Age (Columns 3 and 4): Q = Quaternary; P = Pliocene; M = Miocene; Ol = Oligocene; E = Eocene. Volcanic features (Column 6): (V) = Volcano; (M) = volcanic massif. Chemistry (Column 8): Bt = tholeiitic basalt; Ba = alkali basalt (+ differentiates); Bha = high-alumina basalt; AmK = medium-K andesite/dacite; AIK = low-K basaltic andesite/andesite; R = rhyolite; Rp = peralkaline rhyolite. Designation (Column 9): A = arc; O = oceanic marginal basin; C = continental (ensialic) marginal basin; I = "intra-plate".

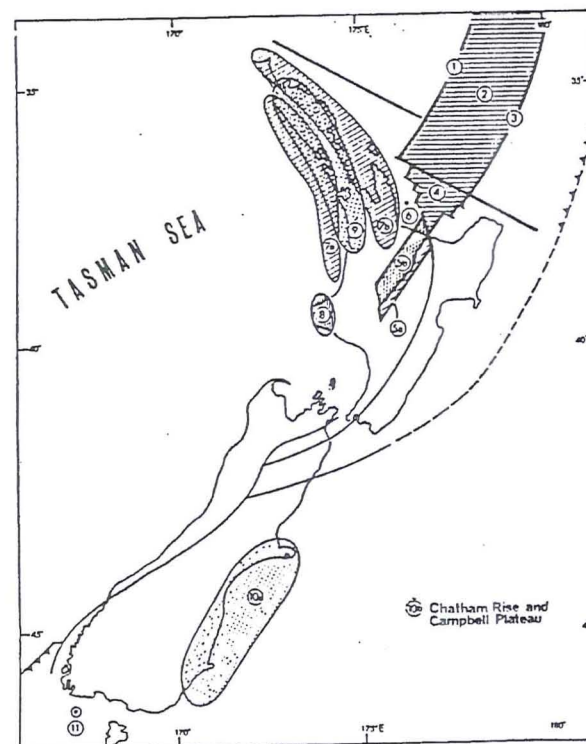


Fig .1.5 Sketch map of New Zealand showing the position of the volcanic provinces (Cole, 1986). The symbol used for each province indicates the inferred tectonic designation (see table 1.1). Vertical or diagonal lines = arc; horizontal lines = oceanic marginal basin; cross hatching = continental (ensialic) marginal basin; dots = "intra-plate".

The oldest rocks on Banks Peninsula are those which crop out in the Gebbies Pass area, towards the head of Lyttelton Harbour, which are Triassic in age. They belong to the Torlesse Terrane, such as the Southern Alps, the Marlborough Ranges and the main range of the North Island. They are sedimentary rocks originally deposited as sand, silts and muds.

According to Weaver et al (1985) the oldest volcanic rocks occur in McQueens Valley and south along Gebbies Pass and were erupted about 90 Ma ago. They belong to the McQueens Volcanics (pyroxene andesite and peraluminous high silica rhyolites) and are a part of an extensive calc-alkaline volcanic field now largely removed by erosion. Volcanic rocks of similar age and type occur at Mt Somers, the Malvern Hills and Rakaia Gorge (Figs.1.4, 1.6).

Banks Peninsula was submerged beneath the sea 65 Ma ago. During this time, sediments were deposited, compacted and consolidated to form Charteris Bay Sandstone. About 15 Ma ago the land had become uplifted, probably as part of the Kaikoura Orogeny. Volcanic activity began at the same time, with the eruption of Governor's Bay volcanics (15.0-12.0 Ma), followed by Lyttelton volcanism about 12 Ma years ago (Table 1.2). Lyttelton lavas are mostly erupted as aa lavas and the activity is dominantly Hawaiian in style with some more explosive strombolian interludes represented by parasitic scoria cones within the main crater and on the outer slopes (Fig.1.8).

To summarize, Lyttelton volcano is constructed on basement rock consisting of Triassic sandstones, mudstones, cherts (Torlesse group), Cretaceous volcanics, (McQueens andesite and rhyolite) early to middle Tertiary sandstones (Charteris Bay sandstone) and middle Miocene Governors Bay Volcanics. During the construction of the Lyttelton cone basaltic to trachytic radial dikes were emplaced. Mount Herbert and Akaroa volcanoes become active and were followed by Church volcanic activity. Then the final phase of activity produced Stoddart volcanics (Fig.1.7 and Table 1.2). Miocene volcanic eruption in Banks Peninsula started about 12 Ma years ago and continued for 6 million years recording a change from transitional tholeiitic to moderately alkaline chemistry. Lyttelton and Akaroa volcanics constitute a mildly alkaline



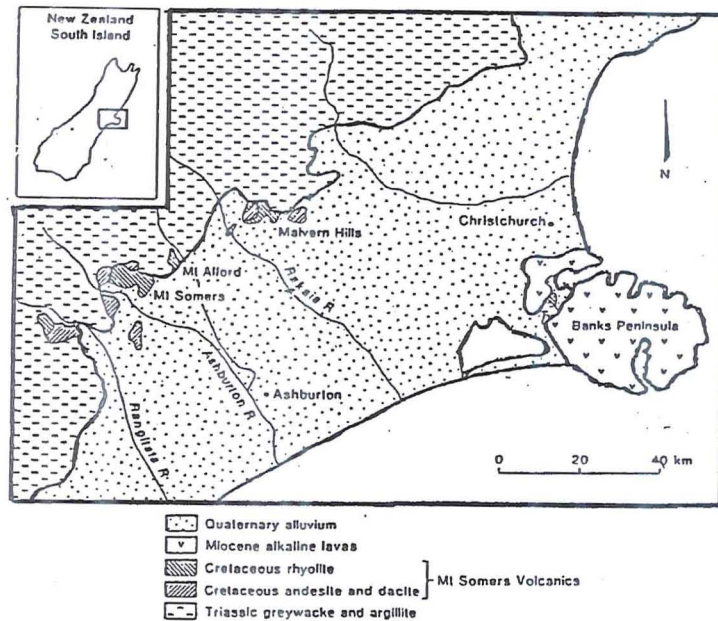


Fig. 1.6 Regional setting of Banks Peninsula, Mt Somers and Canterbury Volcanic field. The Cretaceous andesites and rhyolites on Banks Peninsula are the same age as the Mt Somers Volcanics (Barley, 1986).

Table 1.2 Stratigraphy of Miocene Volcanics of Banks Peninsula (Weaver and Sewell, 1986)

GROUP	FORMATION	K/Ar AGE RANGE (Ma)	LITHOLOGY
STODDART VOLCANICS	STODDART POINT OLIVINE-BASALTS	7.0 - 5.8	Fresh, columnar-jointed, olivine ± clinopyroxene -phyric basalts, olivine-basalts and olivine-hawaiites - rare olivine-basalt dikes
	KAIORURU OLIVINE HAWAIIITES	6.9 - 6.8	Commonly weathered, vesicular, pale pink, olivine ± clinopyroxene -phyric and aphyric olivine-hawaiites
CHURCH VOLCANICS	CHURCH BAY OLIVINE-BASALTS	7.8 - 7.3	Fresh, columnar-jointed, olivine ± clinopyroxene ± plagioclase -phyric olivine-basalts
	DARRA BASANITOIDS	8.1 - 7.7	Fresh, columnar-jointed olivine ± clinopyroxene -phyric basanitoids - rare basanitoid dikes
AKAROA VOLCANICS		9.0 - 8.0	Fresh, medium to fine-grained, olivine-clinopyroxene - plagioclase -phyric and grey, aphyric hawaiites - rare trachyte domes and dikes
MT HERBERT VOLCANICS	MT HERBERT HAWAIIITES	8.5 - 8.0	Grey, columnar-jointed, aphyric and rarely olivine-phyric olivine-hawaiites
	CHATEAU INTRUSIVES	8.0	Grey, columnar to knobby-jointed aphyric hawaiites
	PORT LEVY FORMATION	8.9 - 8.5	Grey-black, columnar-jointed, aphyric hawaiites - rare porphyritic basalts and mugearites
	ORTON-BRADLEY FORMATION	9.5 - 8.6	Black, fresh aphyric, olivine-hawaiites & olivine ± clinopyroxene ± plagioclase-phyric olivine-basalts
	KAITUNA OLIVINE-HAWAIIITES	9.7 - 9.5	Columnar-jointed, dark grey-black, fresh, olivine ± clinopyroxene-phyric olivine-hawaiites
LYTTELTON VOLCANICS		11 - 10	Moderately weathered, plagioclase ± olivine ± clinopyroxene -phyric hawaiites - trachyte lava flows and domes - numerous trachytic and basaltic dikes
GOVERNORS BAY VOLCANICS		? 12 - 11	Atered plagioclase ± clinopyroxene ± olivine ± orthopyroxene -phyric andesite flows and quartz-alkali feldspar-phyric rhyolite domes

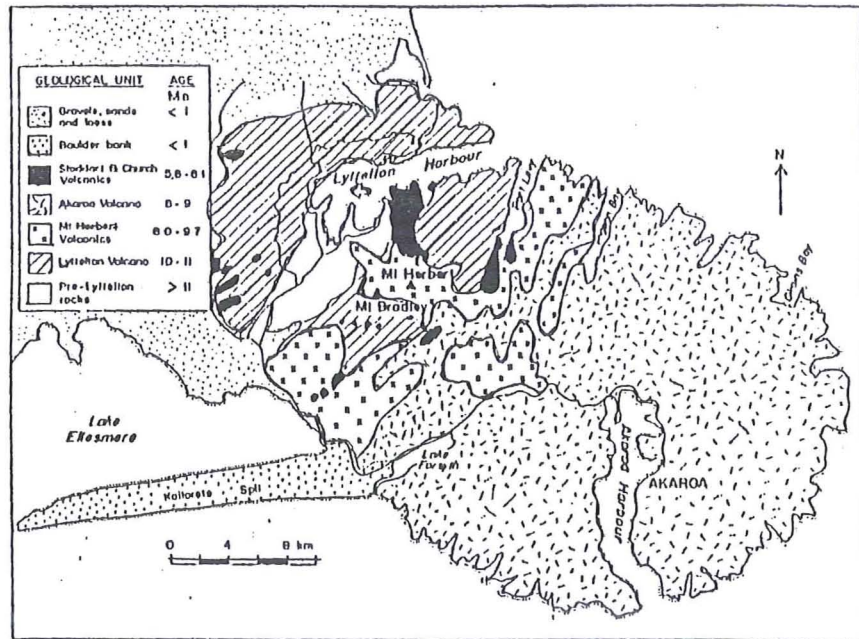


Fig. 1.7 Simplified geological map of Banks Peninsula (Weaver and Sewell, 1986).

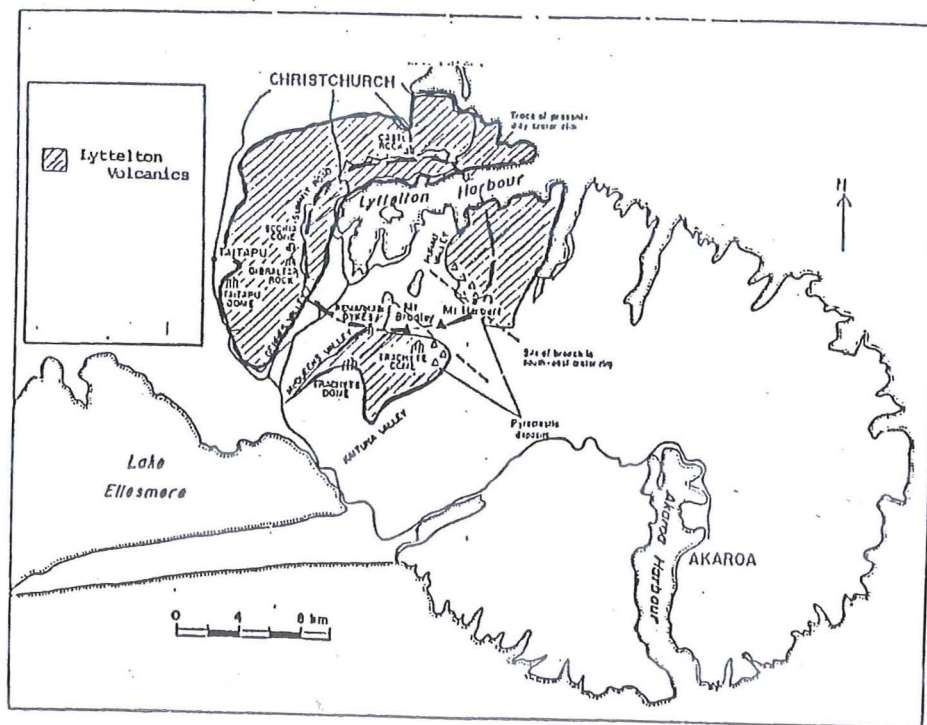


Fig. 1.8 Sketch map showing geological features of Lyttelton volcano (Sewell, 1985).

olivine basalt-trachyte suite. The older Governors Bay volcanics include sub-alkaline anorogenic andesites and rhyolite. The younger Church and Stoddart volcanics (Fig 1.7 and Table 1.2) are composed of basaltoid rock ranging from basanites to hawaiites (Weaver and Sewell 1986).

Banks Peninsula remained above sea level throughout the period of Miocene volcanic activity. This is supported by the absence of fossils, pillow lavas and hyaloclastites. Walcott (1984) noted that the region has not been disturbed tectonically during the Miocene. The elevated area of Banks Peninsula is about 1200 square kilometres. 8 Ma years ago the highest peaks of Banks Peninsula were about 1500 metres above the present sea level. Since then, through erosion, the present height of Lyttelton peaks has been reduced to approximately 500 metres. The Lyttelton and Akaroa volcanic peaks have been deeply dissected by erosion and the sea has invaded major drainage channels to form Lyttelton and Akaroa Harbours (Figs 1.7, 1.8). Figure 1.9 summarizes the geological evolution of the Miocene volcanics of Banks Peninsula.

### 1.7.2 Post volcanic history

Many of the Banks Peninsula valleys are of ancient origin and are related to a drainage system established on the active Lyttelton cone (Weaver et al 1985). Old radial drainage channels developed into Lyttelton and Akaroa Harbours were lengthened and deepened in post volcanic periods (Figs.1.8 and 1.9).

During glacial periods, thick blankets of loess were deposited on Banks Peninsula. The loess originated from the accumulation of wind-blown fine quartz sand and silt, probably coming from the Torlesse rocks of the Southern Alps and picked up from Canterbury plain by north-west winds during glacial periods. About 6000 years ago sea level was a few metres higher than it is now. This is confirmed by the presence of old sea cliffs, caves and stacks at different localities, around the Peninsula such as Redcliffs and Sumner, (Fig 1.1). Recent deposits are represented by alluvium resulting from the weathering and disintegration of volcanic rock and mixture with loess.



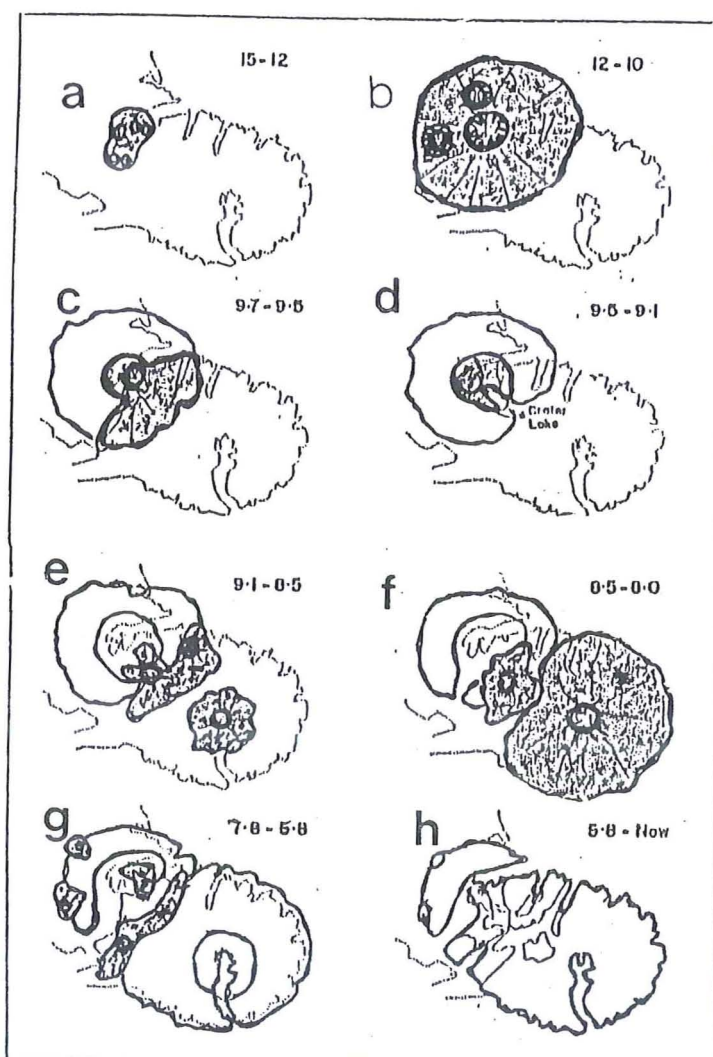


Fig. 1.9 Geological evolution of Banks Peninsula Volcanoes (Weaver et al, 1985).

Numbers refers age in million years.

- a- Eruption of the Governor's Bay Volcanics from numerous centres at the head of Lyttelton Harbour.
- b- Construction of the main cone of Lyttelton Volcanoe.
- c- Initial eruptions of Mt Herbert Volcanics on to the South eastern flanks of the eroded Lyttelton cone, through a breach in the crater wall.
- d- Deep excavation of Lyttelton crater by erosion. Formation of lake on the crater floor and eruption of basalt lavas into the lake water.
- e- Further eruptions of Mt Herbert Volcanics from vents close to the crater wall breach and from near Port Levy. Akaroa volcano became active.
- f- Construction of the cone of Akaroa, Mt Herbert volcanism ceases and a new breach in the Lyttelton crater opens along Gebbies Pass.
- g- Eruption of Diamond Harbour volcanics from numerous vents on the flanks of the eroded Lyttelton crater. Excavation of Akaroa crater and the main channel along which Lyttelton and Akaroa Harbours developed.
- h- Development by erosion of the present topography of Banks Peninsula. Gravels of the Canterbury Plains joined the Island to Mainland.



## CHAPTER 2

## STRATIGRAPHY AND VOLCANOLOGY

Field and petrographic work has led to the sub-division of the *Lyttelton Volcanic Group* into *main Lyttelton* and *late Lyttelton* phases. The *late phase volcanics* are formally designated the "Mt Pleasant Formation" (new name).

## 2.1 INTRODUCTION

In this chapter, the stratigraphy and volcanology of the north-eastern sector of Lyttelton volcano are described and discussed. Description is based on field relationships, petrography and geochemical data. Field descriptions and the locations of 310 samples are given in appendix II, 184 thin sections examined are listed in appendix III and 64 chemical analyses of selected samples are presented in appendix V and VI.

Exposure over most of the north-eastern sector of Lyttelton volcano is poor due to a thick mantle of Quaternary loess and vegetation cover. However, good exposures occur around the crater walls of the volcano, major valleys and shore platforms. The mapped area consists of approximately 62% lava flows, 12% pyroclastics and lahars and 1% intrusives, with 25% loess cover.

The stratigraphic geology is discussed under separate sub-chapters in terms of *main and late phase Lyttelton volcanics*. Intrusive rocks are described separately. Most of the discussion is in terms of three areas identified on the basis of geological and geomorphological relationships. These are the Tors-Mt Cavendish area, the Mt Pleasant area and Taylors Mistake and area east of Evans pass. The stratigraphy of each area is presented and composite stratigraphic columns for the whole area have been constructed (Fig 1.51). This is followed by a summary discussion of the entire mapped area.



Fig. 2.1 Distant view of the main phase Lyttelton lava flows sequence exposed between Evans Pass (EV) and Livingstone Bay (LB). 1- Plagioclase-phyric benmoreite lava flow, 2= Plagioclase-phyric hawaiiite and mugearite lava sequence.

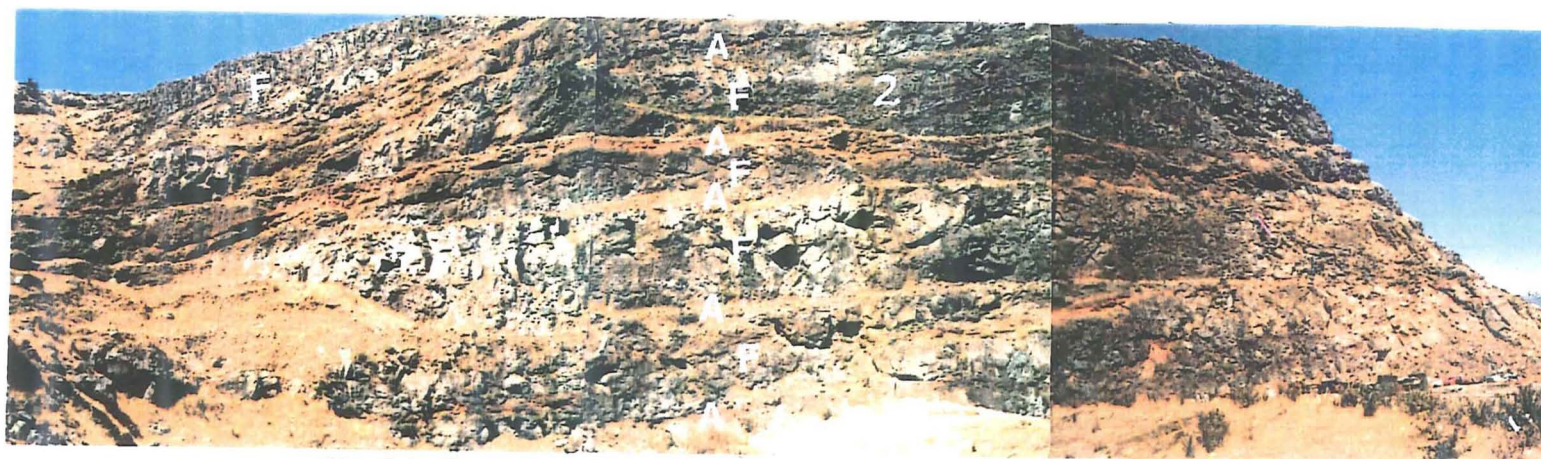


Fig. 2.2 Close-up view of the Evans pass lava flows sequence (2), exposed east of Evans Pass. The red material is ash/lapilli tuff or the pyroclastic layers (A) which occur between most lava flows (F).



## 2.2 STRATIGRAPHY

### 2.2.1 Main phase Lyttelton Volcanics

These comprise plagioclase-phyric hawaiiite, mugearite and benmoreite lava flows. The hawaiiite and benmoreite flows cover mostly the outer and inner slopes of the volcano and are distributed throughout the study area.

#### *Plagioclase-phyric hawaiiite lava flows :-*

*General characteristics:-* These are dark-grey, moderately weathered and medium grained. The dominant phenocrysts are olivine, clinopyroxene and plagioclase. Flows are massive and/or have weak columnar jointing in lavas > 8 metres thick. Flows often show rubbly texture and have basal flow breccia and alternate with thin (< 0.5 metres) pyroclastic horizons (red ash and lapilli material). Individual lava flows vary in thickness between 2 and 5 metres. The total thickness of the sequence is about 80 metres.

The hawaiiite lava flows are exposed throughout the mapped area (Fig. 2.7, 2.13 and 2.22). They have a typical rubbly appearance (Figs. 2.18, 2.21) and have basal flow breccias (Fig. 2.15) around Mc Cormacks Bay (GR, M36/883390). Around Moncks Bay they are separated by thin (<0.50 metre) pyroclastic layers and show columnar jointing (Fig. 2.19). The total thickness of the flows is more than 50 metres at Moncks Bay (Fig. 2.21 and GR, N36/904374). Cave Rock, Sumner (Fig. 2.5) is a good example of the rubbly nature of the flows. This cave was formed by the removal of rubbly aa lava by marine erosion. South of Sumner, (GR, M36/895352), flows show regular to knobbly jointing (Fig. 2.46). Around Sumner (GR, M36/915373) flows are medium to coarse grained and porphyritic (Fig. 2.20).

#### *Plagioclase-phyric mugearite:-*

*General characteristics:-* This unit is dark-grey in colour and fine-medium grained. The thickness of the unit is variable (5-15 metres). The dominant phenocrysts are plagioclase, olivine and clinopyroxene. This flow is weakly jointed and is separated from the overlying and underlying flows by thin (<0.50 metre) pyroclastic (ash and lapilli) layers. Flow breccia is absent or very poorly developed. This unit is exposed around the Evans Pass area

Table 2.1 Stratigraphy of the north-eastern sector of Lyttelton volcano.

GROUP	PHASE	FORMATION	EXTRUSIVE ROCKS	INTRUSIVE ROCKS	
LYTTELTON VOLCANICS	LATE	MT PLEASANT	<ul style="list-style-type: none"> <li>-Dark-grey moderately tabular to columnar jointed, medium grained, olivine-pyroxene-plagioclase-phyric hawaiite of the Tors, Mt Cavendish and Mt Pleasant area.</li> <li>-Medium to fine grained mugearite lava flows of the Tors area and benmoreite lava flow of the Mt Cavendish area.</li> <li>-Columnar, tabular to irregular jointed, weathered, medium-coarse grained, grey yellow pink, plagioclase phyric trachyte flow of the Mt Pleasant area.</li> <li>-Lithic-crystal tuff of the Mt. Pleasant and Mt. Cavendish area and lahar deposits.</li> </ul>	LYTTELTON VOLCANIC GROUP	<ul style="list-style-type: none"> <li>-Basaltic dikes</li> <li>-Castle rock trachyte intrusion</li> <li>-Basalt to trachyte composition dikes</li> <li>-Trachyte lava plug of the Tors area</li> <li>-Trachyte sills of the Tors and Mt Pleasant area</li> </ul>
	MAIN		<ul style="list-style-type: none"> <li>-Columnar, tabular, knobably jointed, weathered dark grey yellow-brown plagioclase phyric benmoreite lava flows.</li> <li>-Dark grey moderately columnar jointed, plagioclase-phyric mugearite lava.</li> <li>-Grey dominantly porphyritic plagioclase-phyric hawaiite lava flows.</li> </ul>		





Fig. 2.3 View looking north-west towards Mt Pleasant from Summer road. Note: (i) a thick deposit of loess (LS), the vertical fluting on the surface of the loess is the result of erosion by surface run-off; (ii) the red crystal tuff (CT) and the underlying lava flow (F).

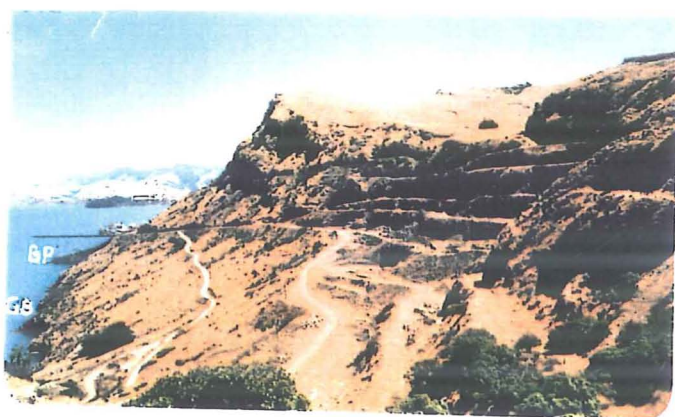


Fig. 2.4 Thick succession of lava flows exposed on the north-eastern side of Lyttelton Harbour. (BP=Battery Point, GB=Golliar Bay)

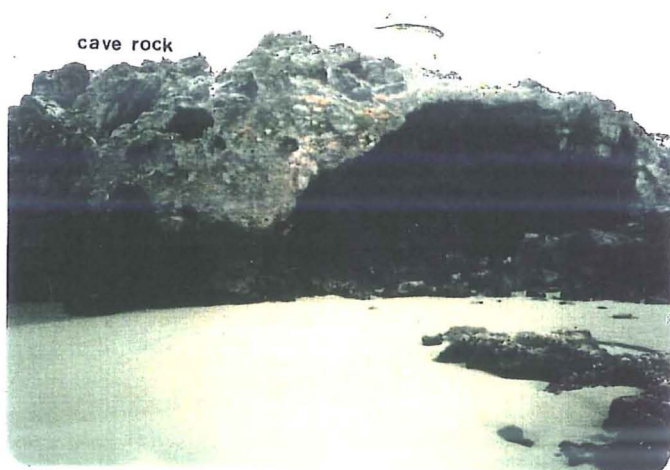


Fig. 2.5 Rubbly aa lava flow (GR, N36/906379). Note: coherent lava at top and rubbly at the base of the flow.



Fig. 2.6 Distant view of lava flow forming prominent cliff at Scarborough (TM=Taylors Mistake, BR=Black Rock, GN=Giant's Nose).

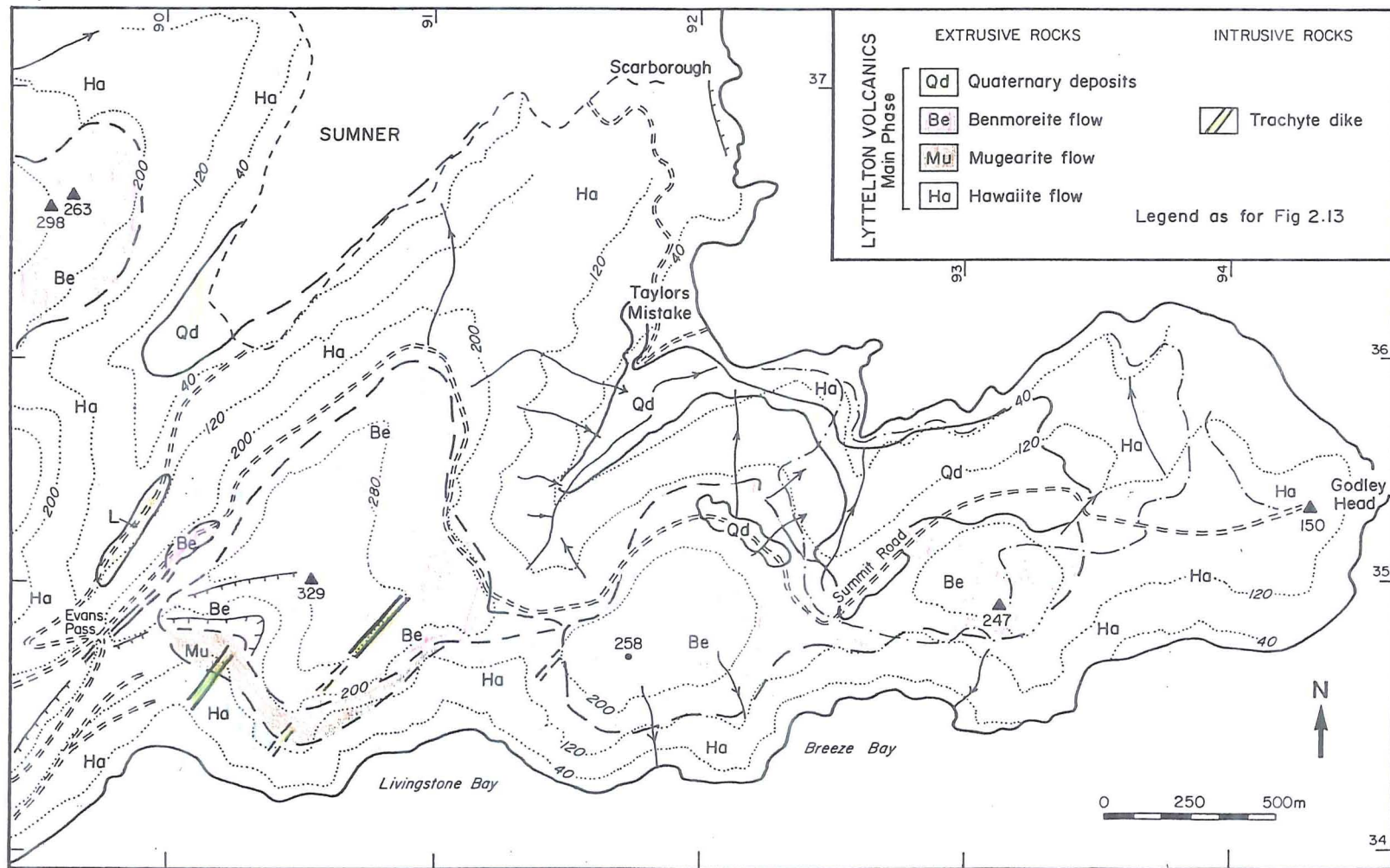


Figure 2.7: Simplified geological map and stratigraphy of east of Evans Pass and Taylor's Mistake area



(GR, M36/903348). The unit overlies the plagioclase-phyric hawaiiite flow and underlies a plagioclase-phyric benmoreite flow (Figs. 2.1, 2.2).

*Plagioclase-phyric benmoreite:-*

*General characteristics:-* A single flow can be distinguished from other units by its well developed columnar and horizontal jointing, tabular jointing and grey-yellow brown colour in the field. The other distinguishing characteristic is the absence of basal flow breccia and unconformable relationship on the plagioclase-phyric hawaiiite and mugearite lava flows. The flow is generally weathered, medium-grained and the dominant phenocrysts are plagioclase and clinopyroxene. The thickness of the unit is variable (2-50 metres). The best exposure of this unit is at Windsor Castle (GR, M36/895363 and Figs. 2.13, 2.10). Here the flow strikes NNE and overlies plagioclase-phyric hawaiiite (Fig. 2.13). Benmoreites are exposed around the Tors-Mt Cavendish areas, Mt Pleasant and Evans Pass areas (Fig. 2.7, 2.12 and 2.22).

*Taylor's Mistake and east of Evans Pass area.*

*General:-* This section summarizes the general geology and stratigraphy of the Taylor's Mistake east of Evans Pass area (Fig. 2.7). 52 samples were collected and described (appendix IIA), 32 thin sectioned (appendix IIIA) and 13 chemically analysed (appendix V and VI). The exposures in these areas are represented by the main phase Lyttelton Volcanics. North-east of Lyttelton Harbour (GR, M36/903348), good stratigraphic sections of main phase Lyttelton lavas are exposed along the cliffs (Figs. 2.13, 2.14). The cliffs are made up of three major lava flows (plagioclase-phyric hawaiiite, mugearite and benmoreite) separated by thin (< 0.50 metre) pyroclastic layers (Figs. 2.1, 2.2). The coherent lava flows and the thin pyroclastic layers are collectively called the Evans Pass lava sequence (Fig. 2.7). Plagioclase-phyric hawaiiite flows cover areas around Sumner, Scarborough and Taylor's Mistake (Fig. 2.7). Most of the area east of Evans Pass are covered by benmoreite lava flows (Gr, M36/903346). Similar outcrops of benmoreites are exposed north of Breeze Bay (GR, N36/924348). Lahar deposits exposed in this part of the area have similar characteristics to the Mt Pleasant area lahars (later discussion).



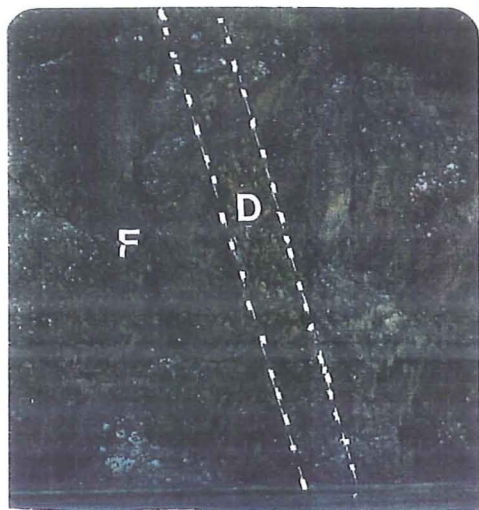


Fig. 2.8 Dike cutting lava flow, west of Corsair Bay, (GR, M36/855332)

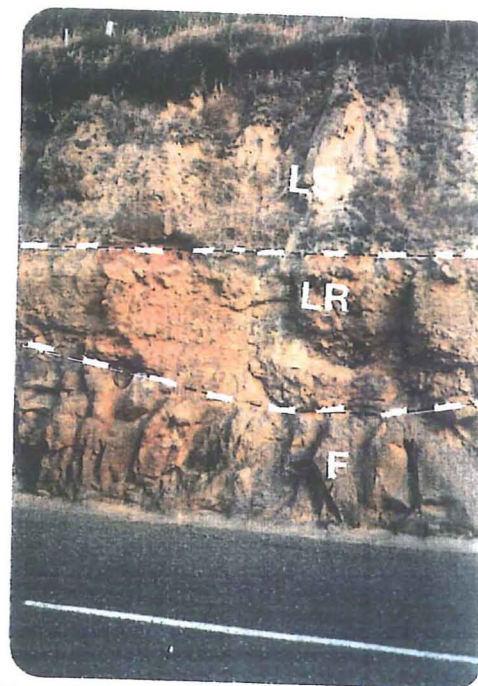


Fig. 2.9 Section around Evans Pass showing loess deposit (LS). LR=red lahar and lava flow (F). (GR, M36/90034)



Fig. 2.10 Distant view of Windsor Castle benmoreite flow (GR, M36/895363).



Fig. 2.12 Irregular to knobby jointed lava flow (GR, M36/895352). Note, spheroidal weathering of the lava.

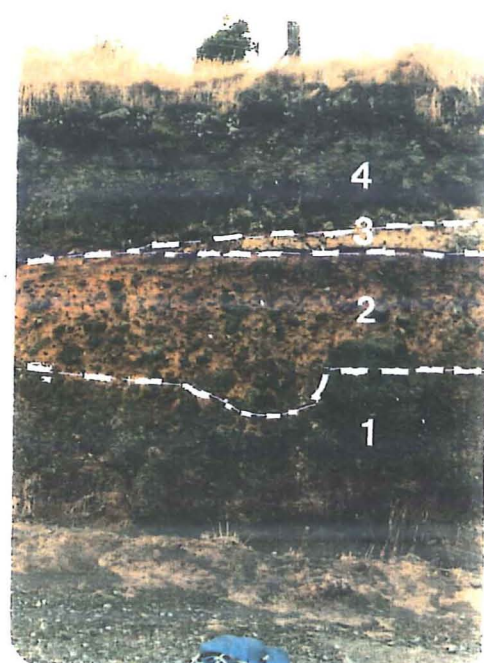


Fig. 2.11 Field relations of lava flows and lahar at Evans Pass (GR, M36/897345). Note: vertical contact of, lava flow (1), red lahar (2), yellowish lapilli ash (3) and lava flow (4).

## 2.2.2 Late phase Lyttelton Volcanics :-

### Mt Pleasant Formation (new name):-

The *late phase Lyttelton volcanics* are designated as Mt "*Pleasant Formation*":- This comprises hawaiite, mugearite, benmoreite and trachyte lava flows of the Mt Pleasant, the Tors and Mt Cavendish sequences. The other members are lithic-crystal tuffs and lahar deposits (Table 2.1). Around Mt Pleasant (M36B876354) the main phase and late phase volcanics are separated by an angular unconformity. The lower (main phase) lava flow dip more steeply than the late phase. The main phase lava sequence dips away from the main Lyttelton centre with varying dip directions. The late phase flows dip towards the north-east.

### *The Mt Pleasant area.*

*General:-* The sub-areas discussed under this section includes those north-east of Lyttelton Harbour, south of Sumner and west of Evans Pass. The geology of the Mt Pleasant area is shown in figure 2.13. From this area 96 samples were collected (appendix IIA) 66 thin sections (appendix IIIA) were made and 18 samples chemically analysed (appendix IVA and IVB). The major outcrops are lava flows, intrusives (dikes and sill) and pyroclastics (lahar and lithic-crystal tuff). The Mt Pleasant area lava flows include both the main and late phase Lyttelton Volcanics. The main phase Lyttelton Volcanics around Mt Pleasant include plagioclase-phyric hawaiite lavas and benmoreite lava flows.

### 2.2.2.1 The Mt Pleasant sequence

This includes two distinctive flow units:-plagioclase-phyric trachyte and hawaiite. The other members are lithic-crystal tuffs and lahars.

(i)*Plagioclase-phyric trachyte:-*This flow is distinguished from the other flows by its well developed columnar and horizontal jointing, non-vesicular appearance, abundance of plagioclase phenocrysts, grey to yellow appearance and the absence of flow breccia (Figs. 2.24, 2.25). The flow always forms cliff-like features and rests unconformably upon the main phase plagioclase-phyric hawaiite lavas. Pyroclastic material is absent beneath the



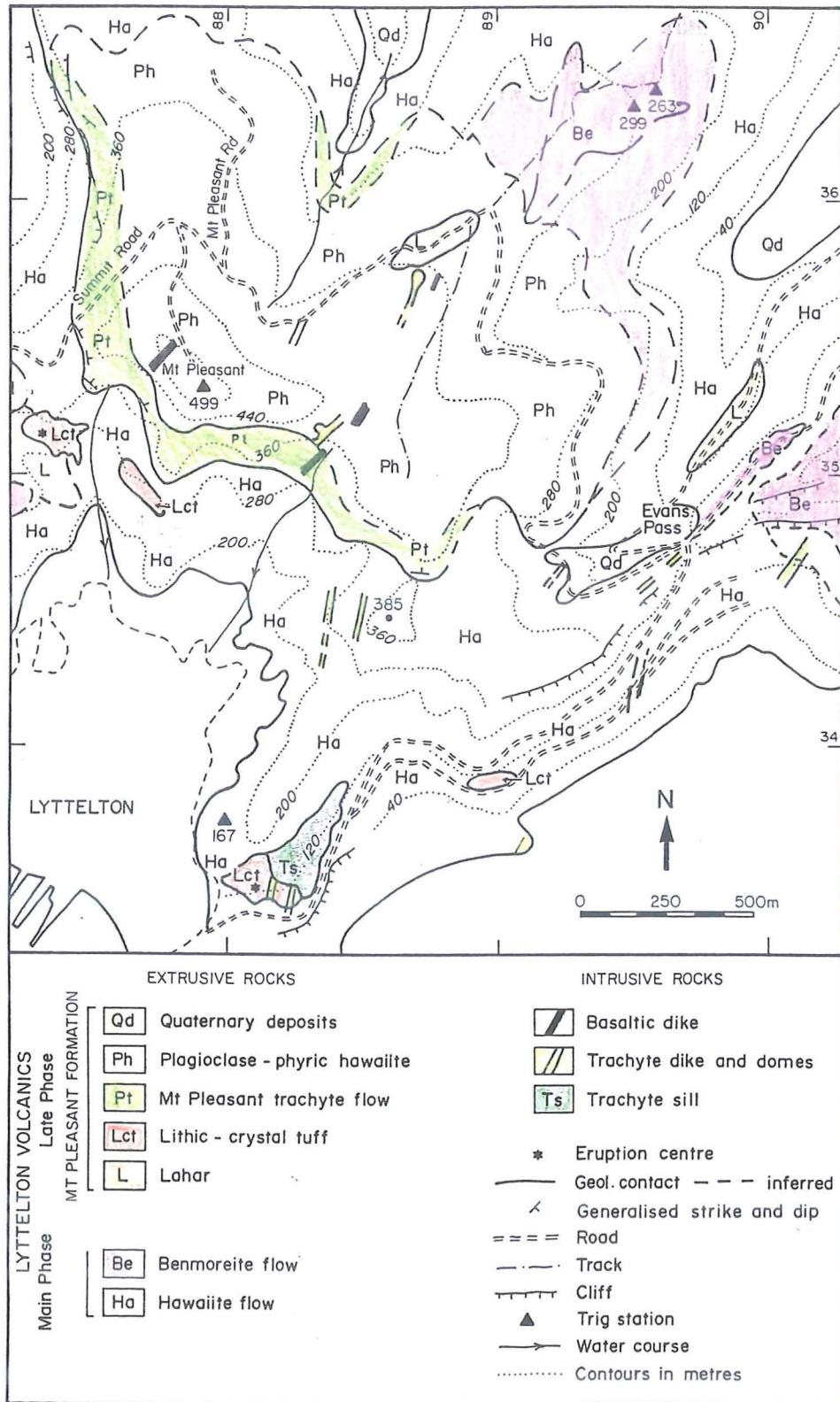


Figure 2.13: Simplified geological map and stratigraphy of the Mt Pleasant area



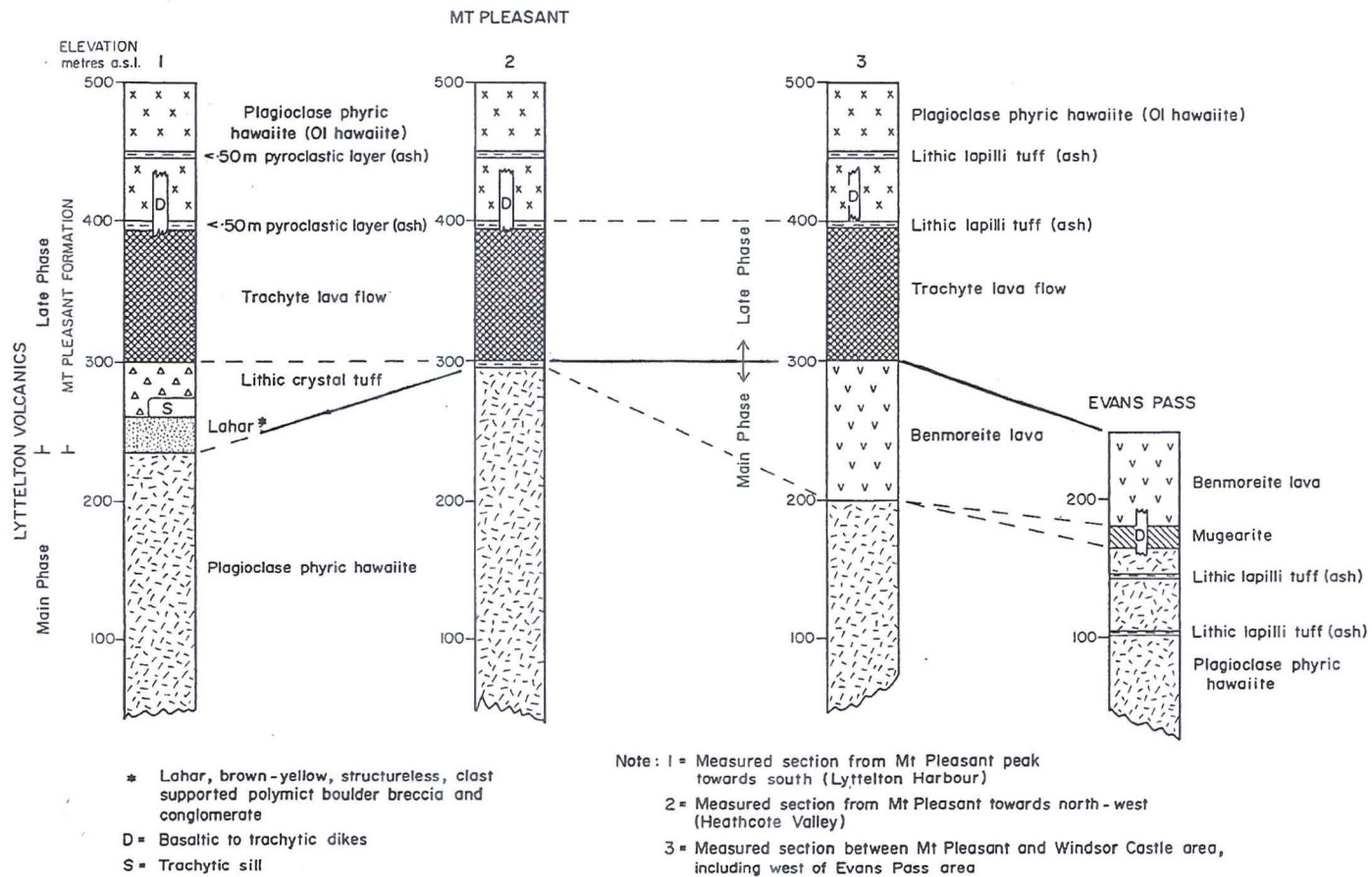


Fig. 2.14: Composite stratigraphic columns and correlation of Mt Pleasant and Evans Pass areas

flow. The flow is exposed around the Summit Road (GR, M36/876354) lying unconformably on the main phase Lyttelton plagioclase-phyric hawaiite lavas (Figs. 2.13, 2.26). The dip of the trachyte varies but suggests that the source area is somewhere south of Mt Pleasant peak area. The flow reaches a maximum thickness of 30 metres at Mt Pleasant where it is best exposed (Figs. 2.13, 2.14). The thickness of the trachyte also supports the likely locality of the source suggested above.

(ii) *Plagioclase-phyric hawaiite*:—This unit is best exposed at Mt Pleasant (GR, M36/879354). The unit is made up three lava flows alternating with thin (0.50 metre) pyroclastic (lapilli-ash) layers. Flow breccias are absent and lava flows are dark-grey in colour, non-vesicular and are moderately fresh. These flows are medium-grained, olivine-clinopyroxene-plagioclase-phyric hawaiite. The total thickness of the three hawaiite flows are about 10 to 30 metres. These flows have poorly developed horizontal and columnar jointing or may be massive. This sequence overlies the Mt Pleasant plagioclase-phyric trachyte (Fig. 2.26) and collectively named the Mt Pleasant plagioclase-phyric hawaiite lava sequence (Fig. 2.13).

#### *The Tors-Mt Cavendish area*

*General*:—This area includes the Major Hornbrook track, Castle Rock, Cass Bay, Corsair Bay and Heathcote (Fig. 2.22). From these localities 155 samples were collected and described (appendix II-A), 85 thin sectioned (appendix III-A) and 34 X-Ray fluorescence analyses obtained (appendix V and VI). A simplified geological map and stratigraphic column for the area is presented in figure 2.22 and 2.23. Both main and late phase volcanics occur in the Tors-Mt Cavendish area. The major outcrops include lava flows, intrusive rocks (basaltic to trachytic dikes, trachyte sills and lava plug) and pyroclastics (lithic crystal tuffs and lahar deposits). The area around Mt Cavendish is characterized by parasitic cones representing strombolian interludes. The Tors area is dominated by intrusive rocks.

#### 2.2.2.2 The Tors sequence

The Tors sequence is best exposed at the Tors (GR, M36/885351). It consists of dark grey, moderately fresh, fine-medium grained olivine-clinopyroxene -plagioclase-phyric hawaiite and aphyric mugearite lava



Fig. 2.15

Typical features of the Lyttelton aa lava flows (B). The succeeding lava flow is seen at the top of the picture. The rubble grades up into coherent lava at the top. The red ash (A) is within the clinker. (GR, M36/915373). Note: the red tuff (ash) is typical of minor pyroclastic layers which occur between most lava flows.

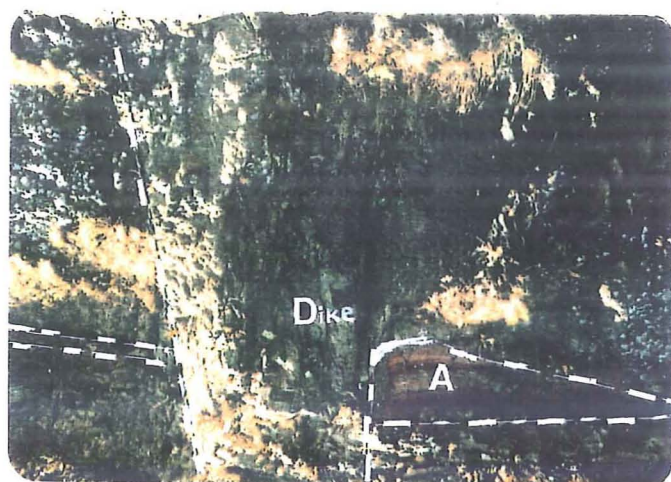


Fig. 2.16

Dike-like structure (?) or lava neck feeding the overlain lava. Note: the red ash (A) between the flow. (GR, M36/891341)

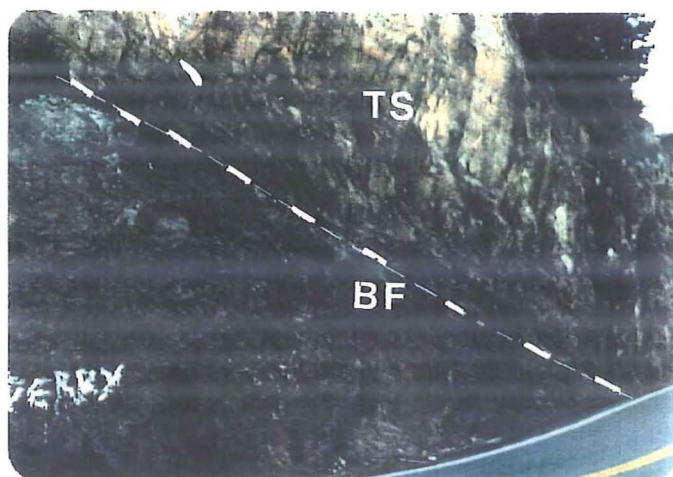


Fig. 2.17

A trachyte sill (TS) near the view point on the road between Evans Pass and Lyttelton Harbour. The sill is intruded the basaltic flow (BF). The intruded lava has been baked to a darker colour at the contact. The field of view is approximately 20 metres across (GR, M36/884334). The sill extends towards the south-west and intrudes the pyroclastic material. The broken line shows the glossy contact of sill chilled against the contact.



flows. The flows are massive or have weak columnar jointing. Flow breccia is absent or poorly developed.

*Plagioclase-phyric hawaiiite and mugearite:-* This lava sequence overlies the main phase Lyttelton plagioclase hawaiiite flows (Figs 2.22 and 2.34). The sequence is 5-8 metres thick and is composed of three flows separated by thin (<0.50 metres) pyroclastic material (ash and lapilli). Of the sequence of three flows, the top and bottom lavas are plagioclase-phyric hawaiiites and the middle flow is an aphyric mugearite. Individual flows are 1-3 metres thick and are weakly columnar, horizontally jointed and dark grey colour. Mugearite lavas exposed between the Tors and Mt Cavendish area (M36/862349) are flows with clinkery top surfaces, coherent interiors and nearly horizontal sheeted jointing at the base (Figs. 2.46, 2.22). These flows are dark-grey, 1-2 metres thick, and overlie main phase Lyttelton plagioclase-phyric hawaiiite (Fig. 2.22).

#### 2.2.2.3 Mt Cavendish sequence

The Mt Cavendish hawaiiite and benmoreite is best exposed at Mt Cavendish (GR, M36/871351). This unit consists of a thick succession of lava flows which unconformably overlie the lahar deposits. These in turn rest upon main phase Lyttelton hawaiiite lava flows. A thick unit of lithic-crystal tuffs and lahar deposits is included under the Mt Cavendish member.

*Plagioclase-phyric hawaiiite:-* This unit which forms the bulk of Mt Cavendish (Figs. 2.22, 2.23) is a succession of three major plagioclase-phyric hawaiiite flows (Figs. 2.38, 2.42) that display weakly developed columnar and horizontal jointing. The thickness of the unit is 30-70 metres. Individual lavas are separated by thin (< 0.50 metres) pyroclastic layers (Fig. 2.42) and flow thickness range from 2-15 metres thick. The hawaiiite flows are dark grey, non-vesicular and have plagioclase and olivine phenocrysts.

*Benmoreite:-* This lava flow overlies the plagioclase-phyric hawaiiite flows of Mt Cavendish (Fig.2.22). This flow is grey, yellow-brown in colour and has plagioclase and clinopyroxene phenocrysts. It is about 2 metres thick. The flow displays weakly horizontal jointing and is separated from the underlying flow by a thin (<0.50 metre) pyroclastic unit.

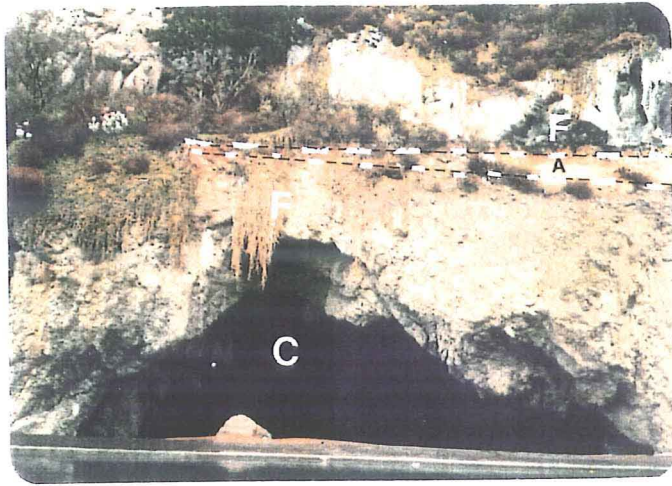


Fig. 2.18 Rubbly aa lava flow on the eastern side of McCormacks Bay (GR, M36/883390). Note: the cave (C) was formed by removal of rubbly aa lava flow by marine erosion. C=Moa Bone Point Cave.



Fig. 2.19

Close-up view of moderately jointed plagioclase-phyric hawaiite lava (S) resting upon an oxidized layer of ash (A) exposed east of Moncks Bay. S=Shag Rock (stack). Note: the red material (A) is a lapilli tuff or ash, typical of the minor pyroclastic layers which occur between most lava flows.



Fig. 2.20 Close up view of plagioclase phyric hawaiite. The flow contains plagioclase crystals (PL) up to 10 mm in diameter. (GR, M36/919354)

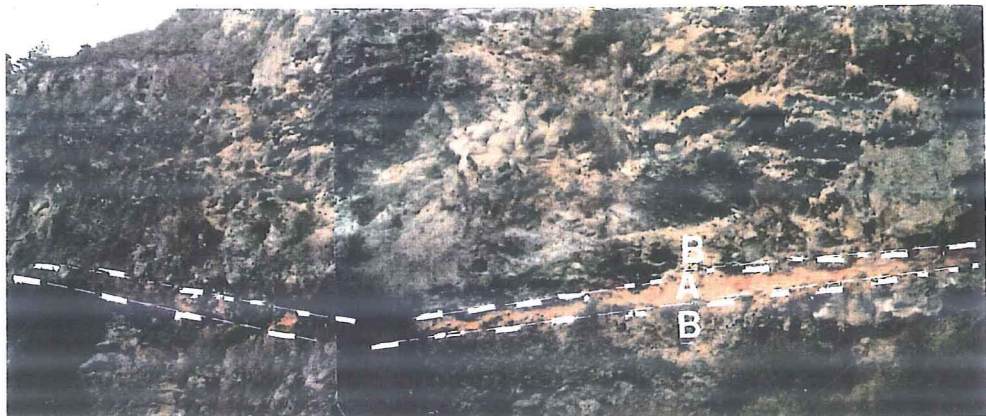


Fig. 2.21 Thick, rubbly aa lava flow (B). The succeeding red material is ash (A) or lapilli tuff. (GR, N36/904374). The field of view is approximately 50 metres across.



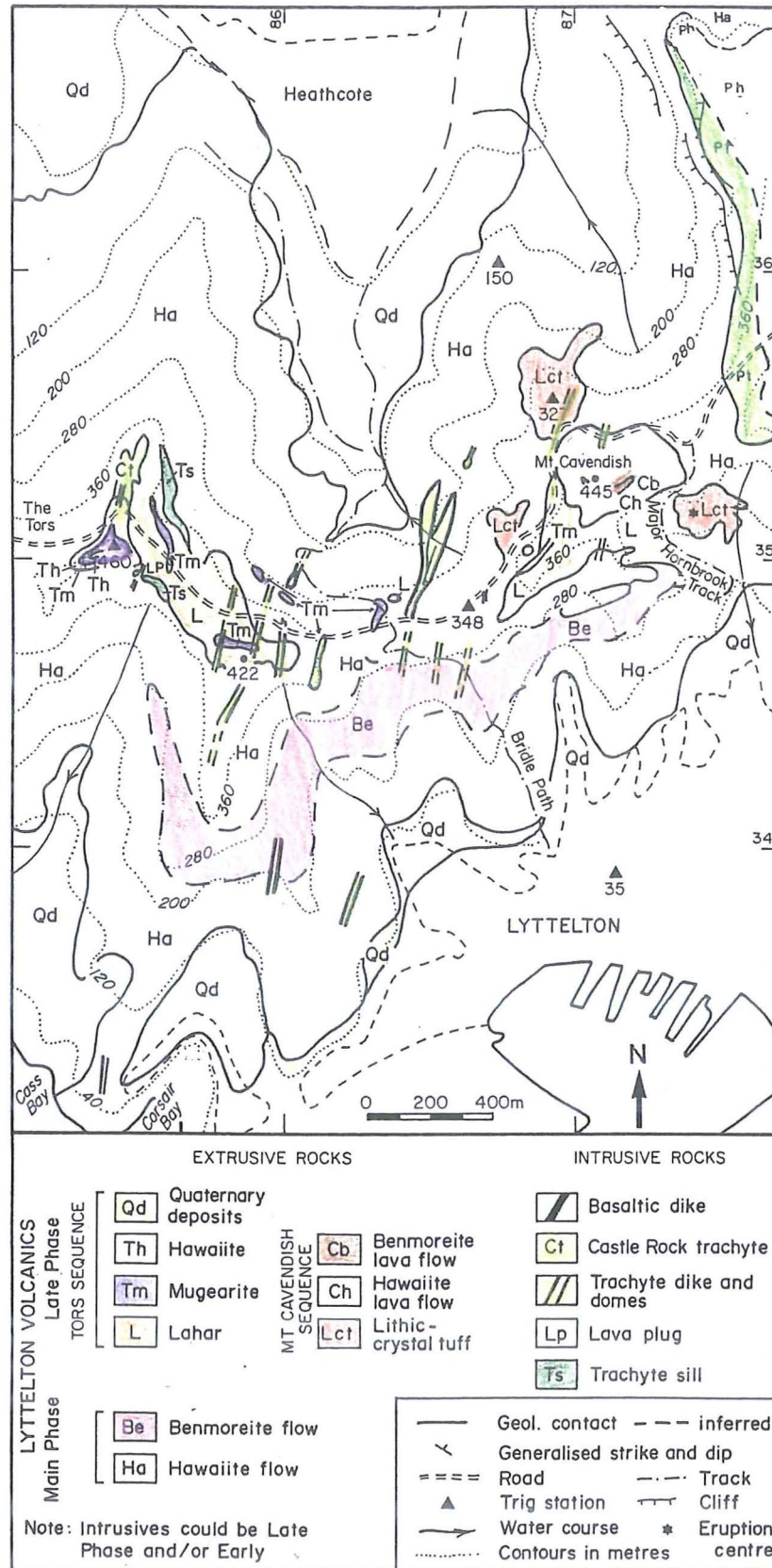


Figure 2-22 Simplified geological map and stratigraphy of the Tors - Mt Cavendish area.



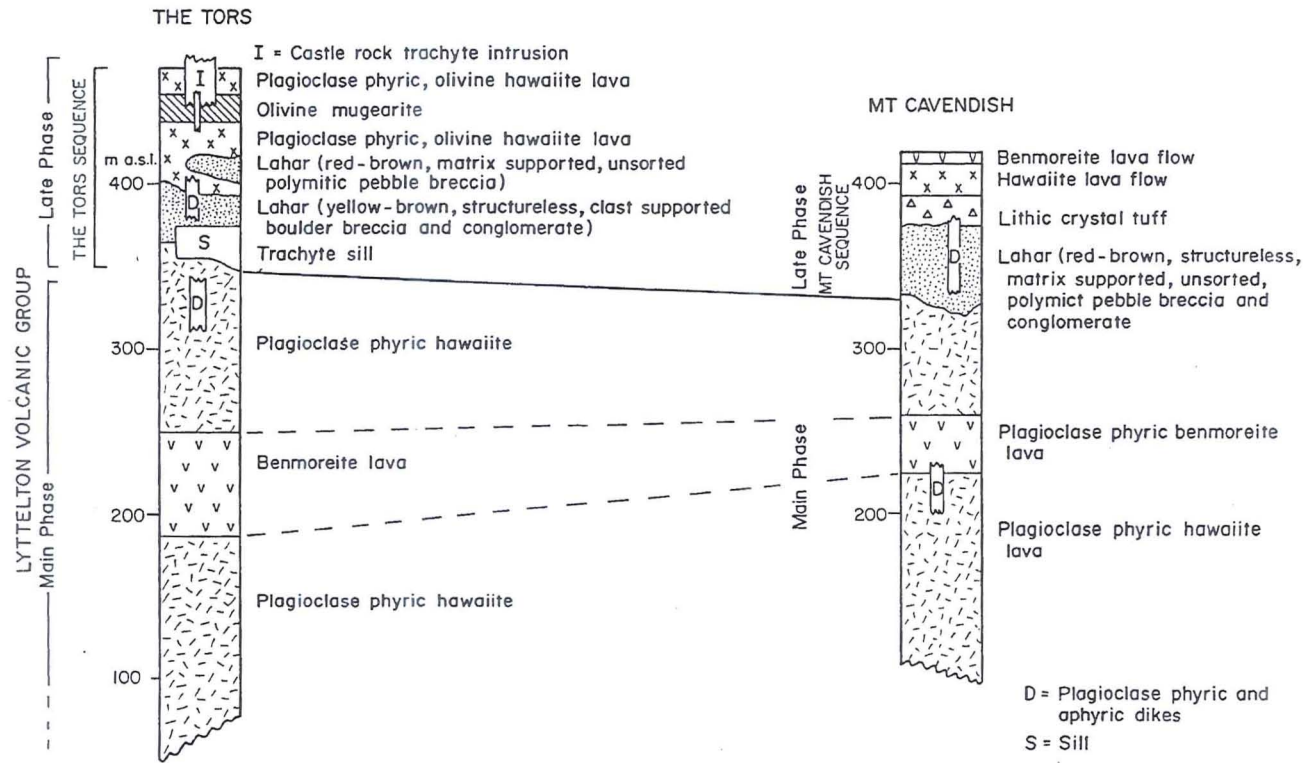


Figure 2.23: Composite stratigraphic columns and correlation of the Tors and Mt Cavendish areas

#### 2.2.2.4 Pyroclastic deposits

The pyroclastics are classified into minor and major units on the basis of thickness and field characteristics. (i) Minor units occur between lava flows, are less than 0.50 metres thick and are composed of fine lapilli and ash. (ii) Major units are the lithic-crystal tuffs, greater than 0.50 metres in thickness which represent individual pyroclastic centres around Mt Cavendish and Mt Pleasant area. There is no consistent stratigraphic relationship between the minor and major pyroclastics (lithic-crystal tuffs) which are related to strombolian activity from parasitic vents. The minor pyroclastics (< 0.50 metres) exposed between lava flows are related to the changes in the eruptive style of the magma and probably originated from the central main vent of the volcano.

##### *[A] Lithic-crystal tuffs of the Mt Pleasant area:-*

Around the Mt Pleasant area, four small centres from which lithic-crystal tuffs were erupted are exposed (Fig. 2.13). These pyroclastic deposits are collectively termed lithic-crystal tuffs of the Mt Pleasant area and overlie the main phase Lyttelton plagioclase-phyric hawaiite. Two centres are around the south western slopes of Mt Pleasant (GR, M36/876352) and the other two centres lie between the Lyttelton Harbour Road and Evans Pass (GR, M36/882334).

The lithic-crystal tuffs are red in colour and composed of plagioclase and clinopyroxene crystals with scoriaceous lithics distributed in a crystal-tuff matrix (mostly ash size particles). The lithic crystal tuff exposed around the south western slope of Mt Pleasant (GR, M36/876352) has a thickness of about 5-15 metres. This deposit is slightly welded, poorly sorted and jointed (Fig. 2.35). The lithic-crystal tuff exposed on the road between Evans Pass and Lyttelton Harbour is about 25 metres thick (GR, M36/882334). This pyroclastic deposit is cut by a dike and a sill towards the north and eastern sides respectively. Another exposure of similar material is found north-east of Battery Point (Fig. 2.13). This is interpreted as a pyroclastic fall deposit because it is characterized by spherical and irregular bombs.

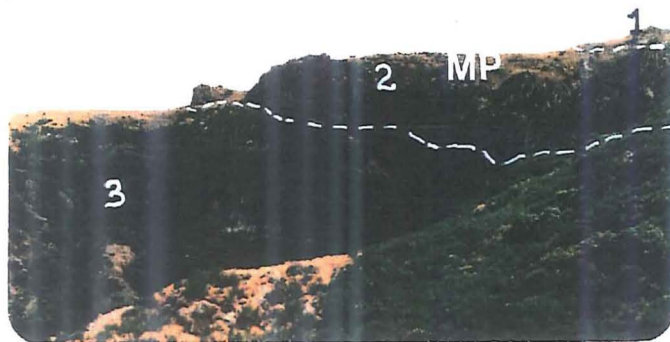


Fig. 2.24 Moderately columnar jointed pattern on the south-western face of Mt Pleasant (MP) 1= Mt. Pleasant Peak lava flows, 2= Mt. Pleasant plagioclase phyric trachyte lava flow, 3= Pyroclastics and main phase Lyttelton lava flows.



Fig. 2.25 Weakly columnar to irregular (tabular) sheeting, horizontally jointing in the Mt Pleasant plagioclase phyric lava flow (2) exposed west of Mt Pleasant (GR, M36/876354).



Fig. 2.26 View of the central region of Mt Pleasant, showing the thick succession of lava flows. 1= The Mt Pleasant peak hawaiiite lava flows, 2= Plagioclase phyric trachyte lava, 3= Pyroclastics



*[B] Lithic crystal tuffs of the Mt Cavendish area:-*

The three pyroclastic deposits around Mt Cavendish are grouped as lithic-crystal tuffs of the Mt Cavendish area (Fig. 2.22). Crystal-tuff (GR, M36/870356), about 5 metres thick, is exposed on the northern slope of Mt Cavendish. The crystal-rich tuff is made up of plagioclase and clinopyroxene crystals and scoriaceous lithic and tuffaceous material. The second lithic-crystal tuff deposit is exposed south-west of Mt Cavendish (GR, M36/868351) and is lithologically very similar to the above. Both crystal-tuff dips towards the north suggesting their source vent some where south of the Mt Cavendish area.

South-east of Mt Cavendish peak and a few metres east of Major the Hornbrook track (Gr, M36/873335) there is an eroded scoria tuff cone (Fig. 2.22, 2.38). The deposit which forms the cone suggests strombolian eruptive activity evidenced by large blocks and bombs within the tuff matrix. The bombs were ejected in a semi-molten state and shapes were modified aerodynamically. The cone is made up of tuffaceous rubbly material, scoriaceous, ashy materials, basaltic bombs and broken crystals of plagioclase and clinopyroxene. The scoria cone was built by successive explosive eruptions, which deposited material of varying grain size in regular layers which dip away from the vent. The lithic-crystal tuff has varying dips, suggesting a source vent close to the Major Hornbrook track (Fig. 2.22). An estimate for the original height of the cone from its dip is about 50 metres. Field relationships show that the Mt Cavendish tuffs are at a lower stratigraphic position and therefore older than the Mt Cavendish peak lava sequence (Figs. 2.38, 2.39) and overlie the main Lyttelton phase plagioclase-phyric hawaiite.

#### **2.2.2.5 Lahar deposits**

*(a) Lahar deposits of Mt Pleasant area :-*

Lahar deposits are exposed in different places around the Mt Pleasant area, for example in road side cutting between Sumner and Evans Pass (GR, M36/899352). At this location the lahar is 10 metres thick, clast supported, structureless, poorly sorted and contains boulder size lithics. Around the south and western slope of Mt Pleasant (GR, M36/877352) a 4 metre



Fig. 2.27 View of the Tors (TT), MT Cavendish (MC) and Mt Pleasant (MP) area.

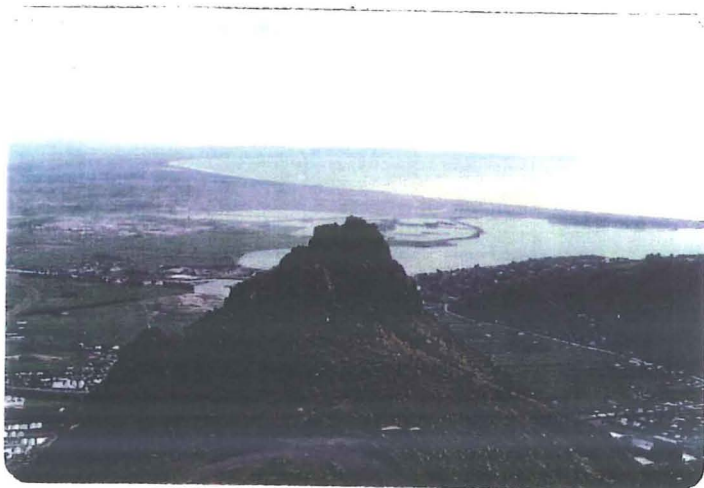


Fig. 2.28 View of southern face of Castle Rock intrusion (GR, M36/856354).



Fig. 2.29

Thick (5m) red crystal tuff flow (CT) exposed on the south-western slopes of Mt Pleasant. GR, M36/876352



Fig. 2.30a

Columnar jointing pattern on the western face of Castle Rock (GR, M36/856354). Note: the change in orientation of the columnar joints fanning outwards towards the top of the intrusion.



yellow-grey heterolithic lahar is exposed (Fig. 2.13). This unit is similar to the one exposed around the Bridle Path track (Fig. 2.50).

*(b) Lahar deposits of the Tors-Mt Cavendish area:-*

There are two kinds of lahar deposit in the Tors-Mt Cavendish area:-(i) A weakly bedded and moderately compacted lahar :- This deposit is exposed about 10 metres east of the Bridle Path track and about 30 metres south of the Summit Road (GR, M36/865349). The unit is 1-2 metres thick, yellow to grey in colour, structureless and moderately compacted. Petrographically the unit is a heterolithic tuff breccia (Fig. 2.50). A similar lahar is also exposed south west of Mt Cavendish (Fig. 2.47).

(ii) Blocky lahar :- This deposit covers areas around the south of Mt Cavendish and west of the scoria tuff cone. The unit is structureless, heterolithic (Fig. 2.38, 2.40) and dominated by large boulders ( 0.50 metres in diameter). It is therefore, termed blocky lahar. The large clast size suggests deposition close to the source.

Thick lahar deposits exposed east of the Tors particularly along and to the south north of the Summit road. The deposit is thick (about 60 metres) and flat lying (Figs. 2.30, 2.32) and covers a considerable area (GR, M36/862347). The deposit is grey or grey-yellow, structureless, matrix-supported, boulder-breccia and conglomerate with coarse sand and pebble-sized lithics. The clasts consist mainly sub-angular and heterolithic plagioclase phyric and aphyric lavas.

### **2.2.3 Intrusive Rocks**

#### **2.2.3.1 Dikes**

Numerous dikes of the radial swarm are exposed in the Tors-Mt Cavendish area (Figs. 2.22, 2.32). The dikes intrude main phase Lyttelton volcanics and the Tors and Mt Cavendish sequences. Most of the dikes are from 0.50 to 1.50 metres in width and a few rarely exceed more than 5 metres. The dikes range from trachyte to basalt in composition. Basaltic dikes are younger than trachytic dikes in some places. For example the younger Castle rock intrusion and the late phase hawaiites (GR, M36/885352 and GR,





Fig. 2.30b Lahar (LR) deposit, thick, structureless (unbedded) matrix supported boulder breccia (b) and conglomerate with coarse sand and pebble size lithics, exposed on the south east side of the Tors (GR, M36/862347).



Fig. 2.31 Trachytic lava neck exposed as topographic knob south of the Tors ( GR, M36/857350). Note: the cross-sectional geometry, brecciation (4) and weakly columnar jointed sheets (5).

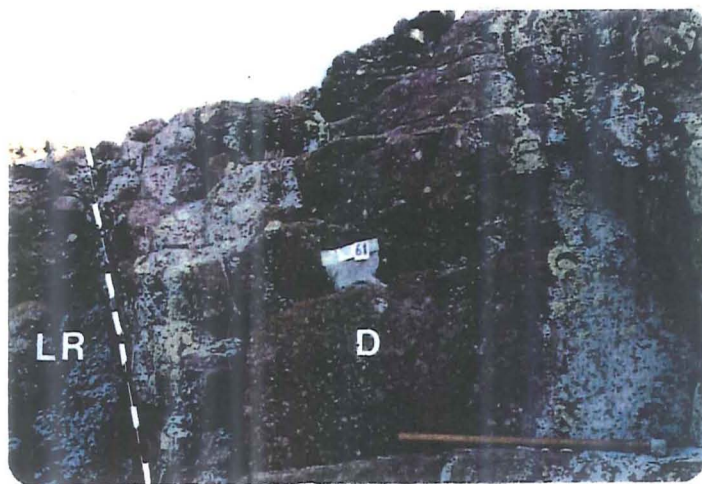


Fig. 2.32 Trachyte dike (D) intruding lahar (LR). (GR M36/863347).

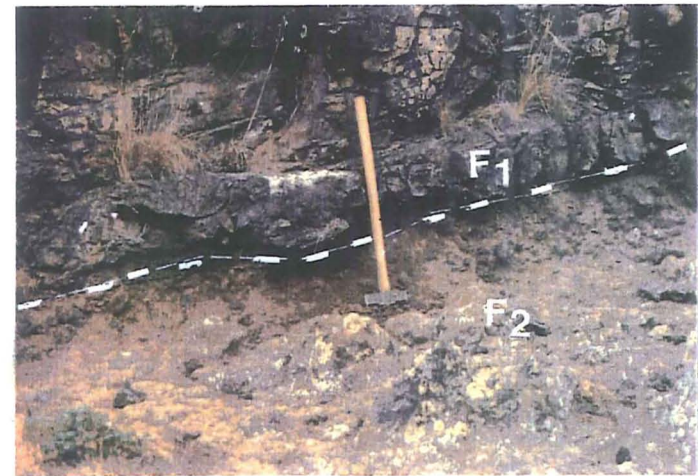


Fig. 2.33 An example of vertical contact between moderately tabular flow (F1) and plagioclase phyric hawaiite (F2).

M36/878355) are intersected by a basaltic dike.

Exposed dikes extend laterally for a few hundred metres and change their thickness markedly. Most dikes run straight along strike for about 200 metres and sometimes bend or are off-set (Fig. 2.13). Shelley (1988) noted that the likely morphology of a radial dike is a *blade* shape with long axis horizontal and intermediate axis vertical. Around the intersection of the Summit Road and the Bridle Path track a trachyte dike feeds a trachyte flow at the quarry (GR, M36/867352 and Figs. 2.45, 2.43). North of Mt Cavendish (on the Summit road), a near vertical dike has intruded pyroclastic material and fed a plagioclase phyric mugearite lava flow (Figs. 2.39, 2.41). This flow is 1 metre thick and overlain by thick Mt Cavendish plagioclase-phyric hawaiiite (GR, M36/870357). The flow fed by the dike is stratigraphically older than Mt Cavendish plagioclase-phyric hawaiiite lava sequence and extends laterally for a short distance (<50 metres in length) towards the east and west.

Some dikes branch vertically (Fig. 2.49) whereas others branch laterally to feed flows around Mt Cavendish and east of the Bridle path track (Figs 2.22, 2.43 and 2.45). Most dikes feed flows or domes around the Mt Cavendish and Mt Pleasant areas (Figs. 2.41, 2.16) and thicken progressively as they pass into flows or domes. North west of Mt Pleasant (GR, M36/887358), there is thick (about 3 metres) trachyte flow, elongated in a NNE direction. The flow is thicker towards the northern end and forms a dome-like feature (Fig. 2.13). This flow is fed by an ill-defined trachyte dike. There are several examples of trachyte dome-like features (GR, M36/885353) fed by trachyte dikes around Mt Pleasant area. Most feeder dikes when traced along strike, are rarely continuous. Commonly dikes are discontinuous and show off-sets. A basaltic dike (GR, M36/891341) feeds a flow on the road between Evans Pass and Lyttelton Harbour (Fig. 2.16). Here the lava flow fed by the dike is separated from the underlying lava by ash material.

Around Evans Pass, Battery Point and Breeze Bay the only intrusives are prominent dikes (Fig. 2.7). The strike of these dikes is NE-SW. This suggests that they are radial dikes fed from the Lyttelton main centre. The plagioclase-pyroxene-phyric benmoreite flow exposure in Evans Pass (GR, N36/901351) is probably fed by a dike judging by flow geometry (Fig. 2.7).



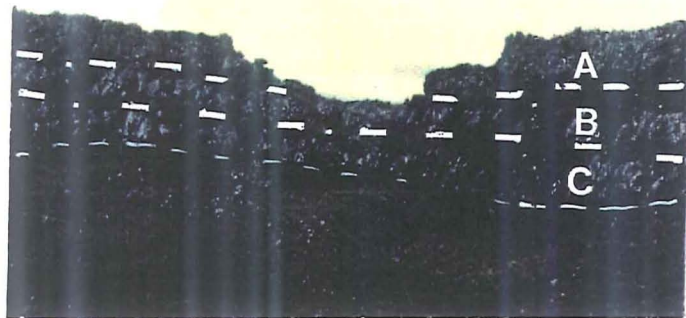


Fig. 2.34 View of the Tors lava sequence exposed on the southern side of the Tors. A, B and C are lava flows



Fig. 2.35 10 m thick, columnar jointed red crystal tuff (pyroclastic flow) exposed on south-western slopes of Mt Pleasant (GR, M36/876352). Note: the columnar jointing of the crystal tuff (CT).



Fig. 2.36 Distant view of the south-eastern slopes of Mt Pleasant (MP).

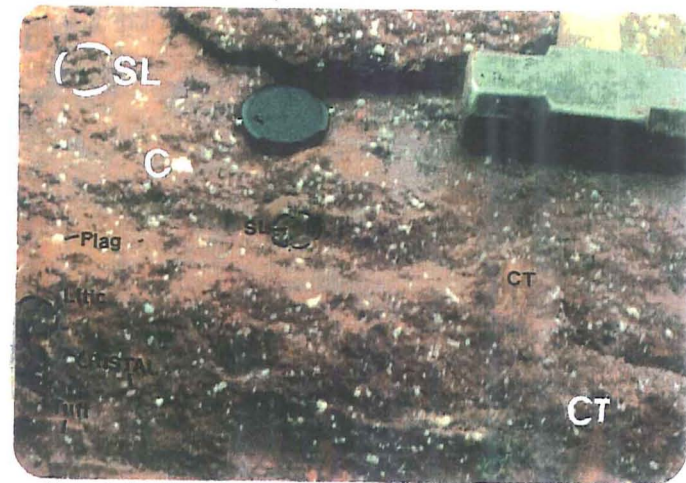


Fig. 2.37 Closer view of lithic tuff or red lithic crystal tuff (CT) flow exposed on south-western slopes of Mt. Pleasant. Note: the large plagioclase crystals (C) and scoriaceous lithics (SL). (GR, M36/875350) Lens cap=55 mm. Note: a deposit of fragmented scoria (SL) in fine



This flow is thick (about 3 metres) and contains large clinopyroxene (1 cm) phenocrysts. In general, field relationships suggest dikes were emplaced continuously throughout the history of the volcano and cover the full range of magma compositions seen in the flows.

#### 2.2.3.2 Intrusion and lava plug

*Intrusion:*-The Castle Rock intrusive dome cuts the Lyttelton main phase plagioclase-phyric hawaiiite lavas, and forms a prominent elongated ridge (Figs. 2.22, 2.28). The intrusion is trachytic in composition and elongated in the north-south direction. The geometry of the intrusion is related to the general trend of the radial dikes in the north eastern sector of the

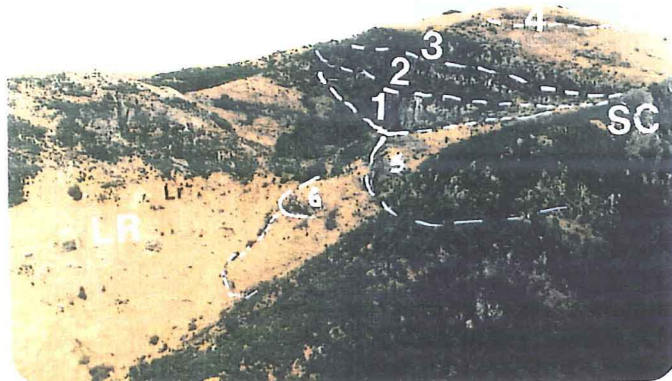


Fig. 2.38 A view of the southern slope of Mt Cavendish showing thick blocky lahar flow (key as for Fig. 2.40).



Fig. 2.40 Closer view of the southern slope of Mt Cavendish lava sequence.  
1-4= Mt. Cavendish lava sequence,  
MC= Mt. Cavendish, SC=scoria cone,  
LR=lahar, 5=layered scoria cone,  
6= lava flow.



Fig. 2.42 The sequence of lava flows (F) and red ash horizons (A) are typical characteristics of Lyttelton lava flows, exposed on the western side of Mt Cavendish.

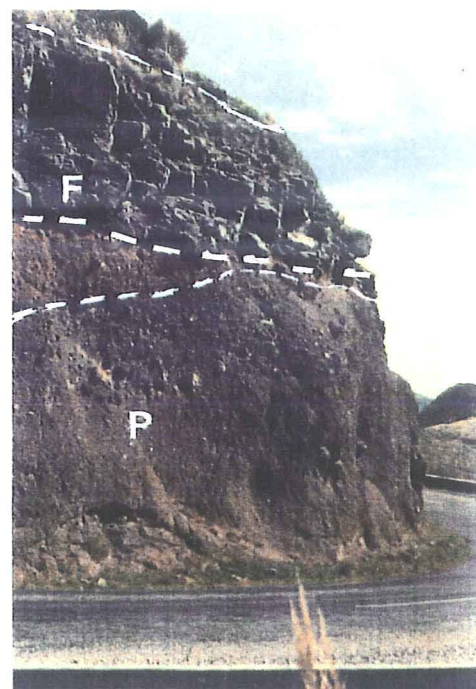


Fig. 2.39

Lava flow (F) overlying the red and red-brown pyroclastic deposit (p). Note: the contact between pyroclastic (P) and lava flow (F). The top flow is fed by a basaltic dike (Fig. 2.41) on the summit road. (GR, M36/870357)

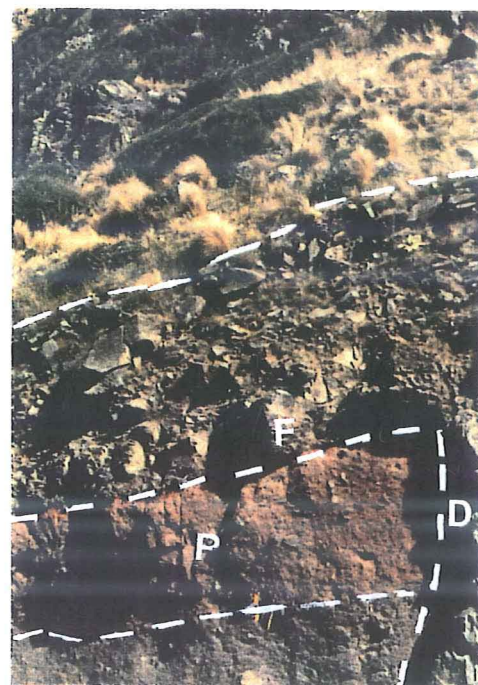


Fig. 2.41

Basaltic dike (left) intruding pyroclastic material (P) of Fig. 2.39. Note: the dike (D) feeding the basaltic flow (F). Summit road north of Mt Cavendish.

the main Lyttelton plagioclase-phyric hawaiite lava. The sill displays poor columnar jointing and its margins are chilled against hawaiite lava (country rock). The sill (Fig. 2.17) strikes in a NNE direction parallel to the radial dike trend in the mapped area.

## 2.3 VOLCANOLOGY

### 2.3.1 Main phase Lyttelton volcanics

The Lyttelton main phase plagioclase-phyric hawaiite lavas are of aa type and represent Hawaiian style activity. They are rubbly in character and have basal flow breccias and oxidized flow tops. Thin layers of red ash (<0.50 metre) are usually present between flows but these layers are often laterally discontinuous. The presence of thin pyroclastic horizons in most lava successions and coherent lava alternating with the pyroclastics, suggests an eruption cycle involving an initial vent clearing phase followed by lava effusion. The plagioclase-pyroxene-phyric benmoreite lava represents moderately viscous magma and forms cliff-like topography. The absence of pyroclastic material (ash and lapilli) beneath and the coherent nature of this flow suggest the a period of quiet lava effusion. A change in lithology from dominantly hawaiite to benmoreite may indicate a separate phase of eruption, probably following a period of quiescence which permitted magma to differentiate.

Moderately to strongly viscous magma which produced the Lyttelton main phase benmoreite lava flows suggest Vulcanian style of activity. The unusual occurrence of thick felsic lava flows without felsic pyroclastics can be explained by:- (i) the felsic flows represent flank eruptions (ii) the felsic pyroclastics were erupted from the main Lyttelton vent and their distribution was probably governed by prevailing wind and was strongly asymmetric (iii) the felsic pyroclastic materials were completely eroded before the eruption of felsic lava flows.

Individual lava flows vary in thickness and lateral extent. This is probably due to the variation in viscosity of the lavas and irregularities in underlying topography. In general main phase lava flows are originated from the main Lyttelton centre. This was situated around the Charteris





Fig. 2.43 Thick trachyte flow on the north-western slopes of Mt Cavendish fed by dike (MC=Mt Cavendish lava sequence, MP=Mt Pleasant, TF=trachyte flow, S=summit road). Note: (a) lithic-crystal tuff north of Mt Cavendish, and (b) horizontally or laterally branching dike to feed trachyte flow (TF).

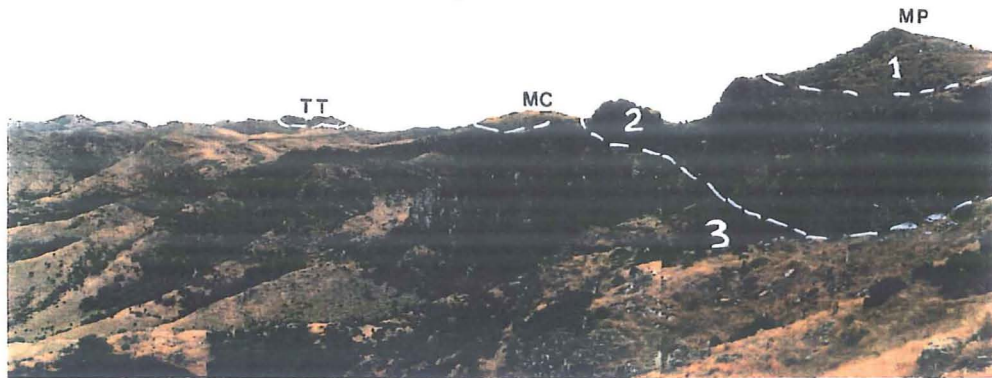


Fig. 2.44 Distant view of the Tors (TT) lava sequence, Mt Cavendish (MC) lava sequence and Mt Pleasant (MP). 1= the Mt. Pleasant peak hawaiiite lava sequence, 2= the Mt Pleasant plagioclase phyric trachyte lava flow, 3=Pyroclastics and the main phase Lyttelton lava flows.

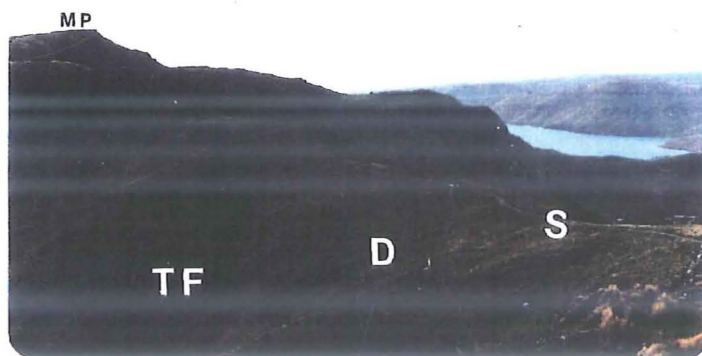


Fig. 2.45 Distant view of the south-eastern slopes of Mt Pleasant and remarkable dike (D) feeding the thick trachyte flow (TF) north of summit road (S).



Fig. 2.46 An example aa lava flow showing clinkery top or forming a mantle of crumble breccia (F=flow, C=clinkery top) GR, M36/862349.

Bay area on the basis of geomorphology and the geometry of the eroded Lyttelton volcano, together with the orientations of the radial dikes.

### 2.3.2 Late phase Lyttelton volcanics:-

Most of the late phase lava flow sequences are confined to the margin of Lyttelton crater. The coherent nature of the Tors, Mt Cavendish and Mt Pleasant hawaiite lava flows suggests an Hawaiian style of activity. The late phase volcanics represented by *Mt Pleasant Formation* are hawaiite to trachyte in composition. The change in lithology suggests a separate phase of eruption. The silicic (more viscous) magma which produced the benmoreite and trachyte lavas suggest Vulcanian style of eruption.

The Mt Cavendish and Mt Pleasant lithic-crystal tuffs which make up the parasitic scoria cones were eruption during Strombolian-style activity. The lahars around Mt Cavendish and the Tors area are characterized by (Figs. 2.30, 2.32) poor sorting, lack of structure and heterogeneous clast composition. These lahars represent volcanic debris flow. The lahars exposed on flat surfaces at present were deposited originally in a steeply incised valley. In general the lahars accumulated in major drainage channels that cut into the older lava sequence. The large clast size suggests a short distance of transport and proximity of the source area. The lahars are heterolithic and volcanoclastic (pyroclastic) in origin. The lahars overlie the main Lyttelton hawaiite lavas and they have the same age (stratigraphic position) in different parts of the mapped area.

### 2.3.3 Intrusives

Throughout the main and late phase volcanic history of the area, basaltic to trachytic radial dikes, sills and other intrusions were emplaced. In response to rising magma, the central area of the volcano was forced upwards into a dome and fractures developed radiating outwards. These fissures were filled by magma and the resulting radial dike swarm was then exposed by erosion. The width of the dikes is controlled by the size of the fissures.

The minor intrusives (dikes and sills) of the area show chilled (glassy character) margins and hence are fine to medium grained. The grain size variation across dikes and sills may provide information concerning the



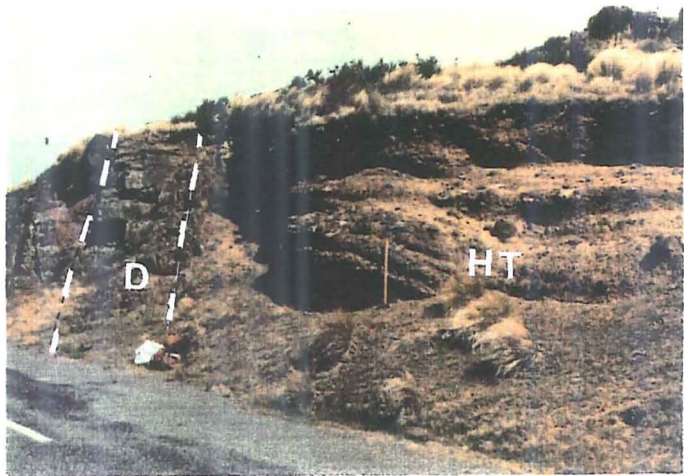


Fig. 2.47 3 m thick, brown-yellow low angle structureless heterolithic tuff breccia (HT). The dike (D) intrude the pyroclastic material (GR, M36/868350).

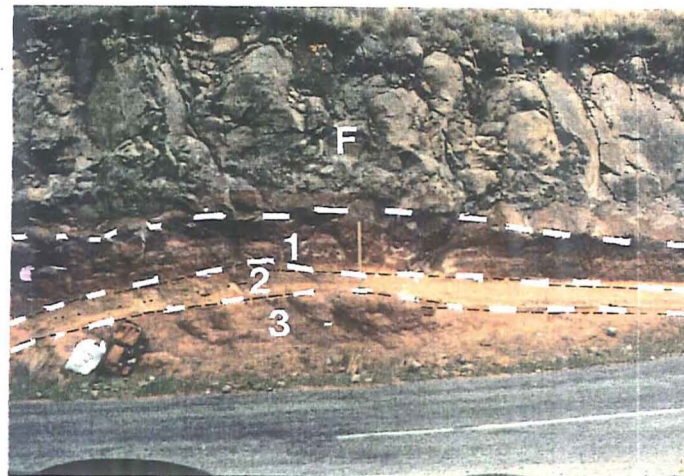


Fig. 2.48 Contact between plagioclase phyric basalt flow (F) and pyroclastic (1=red ash, 2=yellowish fine lapilli tuff, 3=red tuff unit). GR, M36/868351.

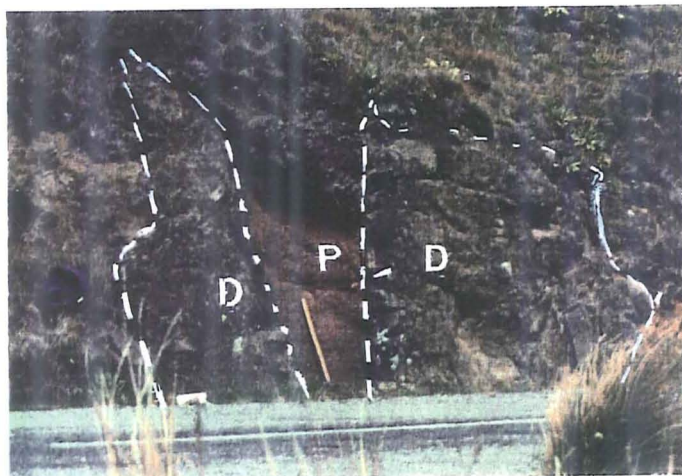


Fig. 2.49 Forked dike intruding the red crystal tuff (P). GR, M36/876355.



Fig. 2.50 Thin layer of heterolithic tuff breccia (HT) exposed near Bridle Path track. Note: the typical aa lava flow (F). The top of this flow shows clinker layer. Note: The thin lava flow on the left of the photograph (GR, M36/864348).



cooling of the intrusion, a larger variation in grain size implies emplacement of hotter magma into cooler country rocks. Intrusives with no chilled margins, imply that the dike or sill was emplaced into warm or hot country rocks. Sills may be easily confused with lava flows especially where both occur in the same sequence. However, they may be distinguished from flows, first by the absence of any internal characteristics of lava flows and second by the occurrence of fine grained glassy chilled margins (against the country rocks) at both lower and upper contacts. Compositionally, the dikes range from basalt to trachyte but the sills are solely trachytic in composition.

## 2.4 DISCUSSION

### 2.4.1 General

Long-lived Miocene volcanic activity constructed the Lyttelton volcanic cone. Most eruptions were of aa lava and the activity was Hawaiian in style but some felsic lavas suggest Vulcanian style. Occasional more explosive Strombolian eruptions produced scoria cones within the main crater and on the outer slopes. During the construction of the main cone, basalt to trachyte radial dikes and trachyte sills were emplaced. However, from field evidence, it seems likely that the dikes intruded the volcano throughout its volcanic history. The large valleys and the crater areas are the site of most lahar deposits which represent periods of degradation of the active cone.

Lyttelton crater is erosional in origin. The reasons for this conclusion are several: (i) there is no evidence of a caldera structure, (ii) most of the central part of the volcano is made up of relatively softer material, more erodable than the coherent flanks of the volcano, (iii) radial drainage systems cut deeply into the volcanics and dominant streams opened up the central part of the volcano. Lyttelton Harbour and various Bays around the flanks of the volcano are clearly also of erosion origin.

### 2.4.2 Stratigraphic Correlation

As shown on figure 2.51, the *Main phase Lyttelton volcanics* are the oldest rocks in the mapped area and show good stratigraphic correlation, except

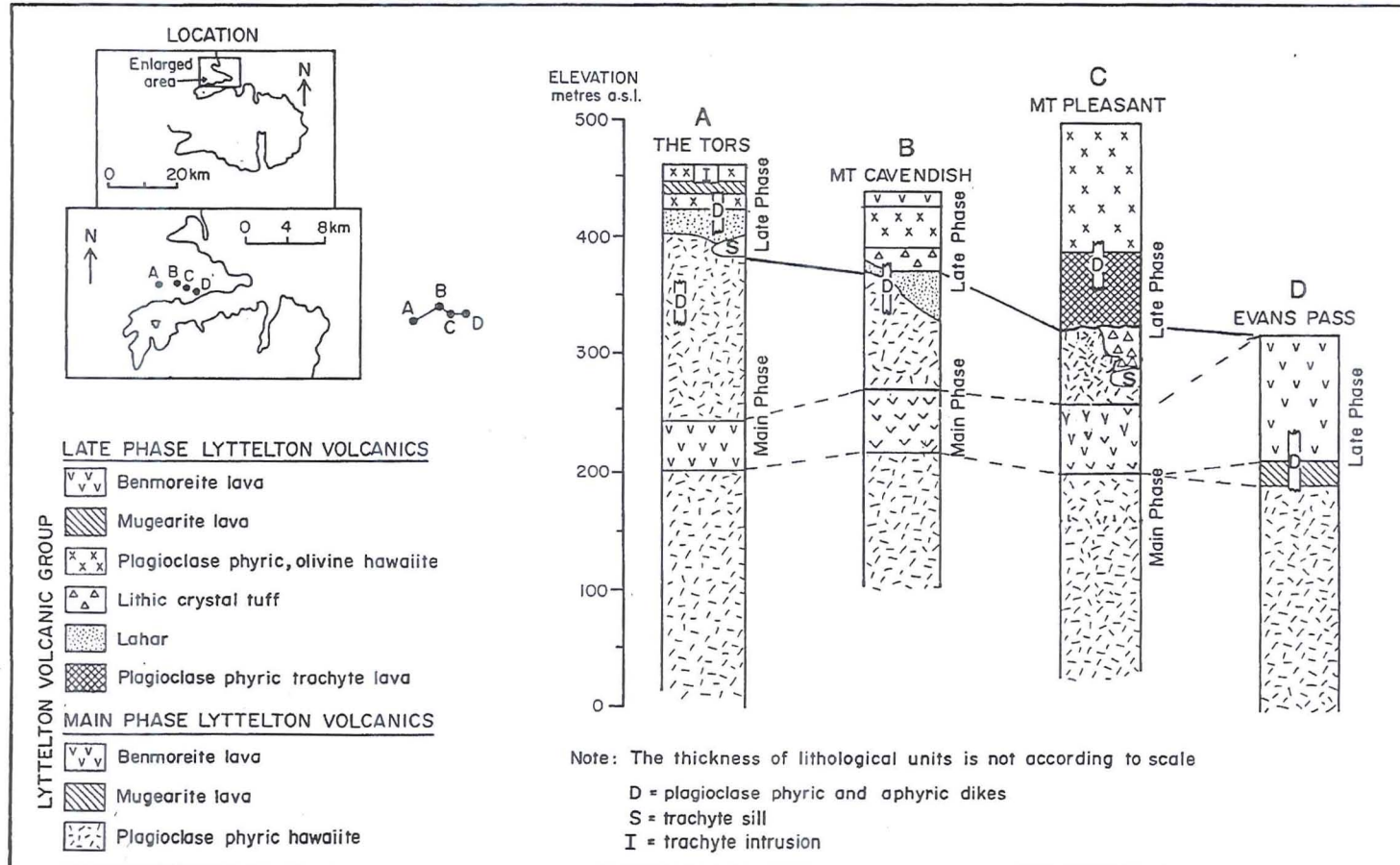


Figure 2.51: Simplified stratigraphic columns and correlation around the north-eastern sector of the Lyttelton volcano

the plagioclase-phyric mugearite. The plagioclase-phyric hawaiite lava flows have similar characteristics in different areas (Fig. 2.51). The plagioclase-phyric benmoreite lava flows display good correlation with measured sections in different localities whereas the plagioclase-phyric mugearite lava is confined only to the Evans Pass area. There is angular discordance between the main and late phase volcanics, and this is the main reason for division of the Lyttelton volcanics into two distinct phases.

The *late phase volcanics* activity probably started with Strombolian eruptions and the deposition of lithic-crystal tuffs of the scoria cones. These occupy the same stratigraphic position in different areas. The Mt Pleasant plagioclase-phyric trachyte flow is not exposed in the Tors and Mt Cavendish areas. The Mt Pleasant, the Tors and Mt Cavendish plagioclase-phyric hawaiite flows have similar characteristics and may be correlated. The aphyric mugearite and benmoreite flows of the Tors and Mt Cavendish sequence are probably contemporaneous in age (Fig. 2.51). The Tors-Mt Cavendish and Mt Pleasant areas late phase Lyttelton volcanics are not continuous laterally probably as the result of erosion. Thus although there are local variations in the stratigraphy of the different late phase sequences, there is sufficient justification to group them into a single lithostratigraphic unit, distinct from the main phase flows and here designated the "*Mt Pleasant Formation*".



## CHAPTER 3

### PETROGRAPHY

#### 3.1 INTRODUCTION

In this chapter the petrography of the north-eastern sector of Lyttelton volcano is discussed. The Lyttelton volcanic group has been described and classified in terms of main and late phase Lyttelton volcanics (*Mt Pleasant Formation*) mainly on the basis of field criteria. Both the main and late phase Lyttelton volcanics and the dikes comprise mafic, intermediate and felsic lava compositions. Sills are trachytic in composition. The main phase Lyttelton volcanics consists of approximately 55% hawaiite, 35% benmoreite and 10% mugearite lava flows in the mapped area. The late phase volcanics covers approximately 55% hawaiite, 22% trachyte, 5% mugearite, 3% benmoreite lava flows and 15% pyroclastic deposits. Rock nomenclature used here is based on petrographic and geochemical criteria (Chapter 4). Descriptions of samples are given in appendix II, and all thin sections are briefly described in appendix III a.

#### 3.2 MAIN PHASE LYTTTELTON VOLCANICS

This section describes the petrographic feature of extrusive rocks of the main phase Lyttelton volcanics.

##### 3.2.1 Mafic rocks

###### *Hawaiite lava flows:-*

The main phase hawaiites have holocrystalline, porphyritic, intergranular and sub-pilotaxitic textures. They contain phenocrysts of plagioclase (andesine), olivine, clinopyroxene and some Fe-oxide. Phenocrysts are dominated by plagioclase (An 60-40) which reaches up to 25 % (of total rock) in abundance. The groundmass contains plagioclase (andesine), olivine, colourless clinopyroxene (augite) and in some rocks pink clinopyroxene (Ti-augite) brown hornblende (kaersutite) and apatite are common. The main groundmass constituent is plagioclase (An 50-35) which is between

45-65 % in abundance.

Some lava flows contain partially corroded euhedral, and others have corroded and resorbed, olivine phenocryst (Fig. 3.1). Generally, olivine phenocrysts vary from partially altered to anhedral and strongly resorbed. In most hawaiites olivines are rarely fresh and show a range of alteration and replacement by the red-brown mineraloid iddingsite (Fig. 3.1) and Fe-oxide from replacement rims to complete pseudomorphs (Fig. 3.1). Pseudomorphs are recognized by combination of shape and other morphological characteristics together with a knowledge of alteration product each mineral, for example in some lavas euhedral to subhedral olivine has been pseudomorphed by iddingsite. Replacement of olivine crystals by Fe-oxide or/and iddingsite clearly starts at crystal margins and along fractures (Fig. 3.1). In some hawaiites olivine is altered to green and brown chloritic and serpentinous products (see section 3.5). Most olivines are altered and it was difficult to estimate the original olivine abundance in the groundmass, in particular. Some of the hawaiites have microphenocrysts of plagioclase and Fe-oxide embedded in olivine phenocrysts (Fig. 3.3), but also olivine crystals sometimes occur as inclusions in Fe-oxide.

Most clinopyroxenes are euhedral, colourless (augite) with thin iddingsite rims (Fig. 3.2) and some are pinkish presumably indicating Ti-augite. Some clinopyroxenes are zoned with darker mantles (Fig. 3.2). Two stages of clinopyroxene (augite) phenocryst growth can be recognized in some hawaiites (Fig. 3.2). The first stage is represented by subhedral to anhedral colourless crystals which have been resorbed and/or altered with the formation of Fe-oxide along cleavage planes and around the rims of the phenocrysts (Fig. 3.2). The second stage clinopyroxene phenocrysts are euhedral relatively fresh and colourless (Fig. 3.2).

Some hawaiites contain brown hornblende and apatite crystals in minor quantities (<3%). The brown hornblende is thought to be kaersutite xenocrysts and it is typically rich in  $TiO_2$  (Sewell, 1985). Calcite rarely occurs as pseudomorphs of clinopyroxene and olivine and as amygdules. In one hawaiite, groundmass minerals have been completely replaced by hydrothermal Fe-oxide (Fig. 3.4). In general, most olivine and clinopyroxene phenocrysts show a range of alteration and replacement by iddingsite and other secondary minerals such as clays and calcite.



Note: (a) All photomicrographs are taken under c.p.l (cross polarised light).  
 (b) Sample number for each photomicrograph is shown as M36B4003.  
 (c) Grid references are given in appendix II

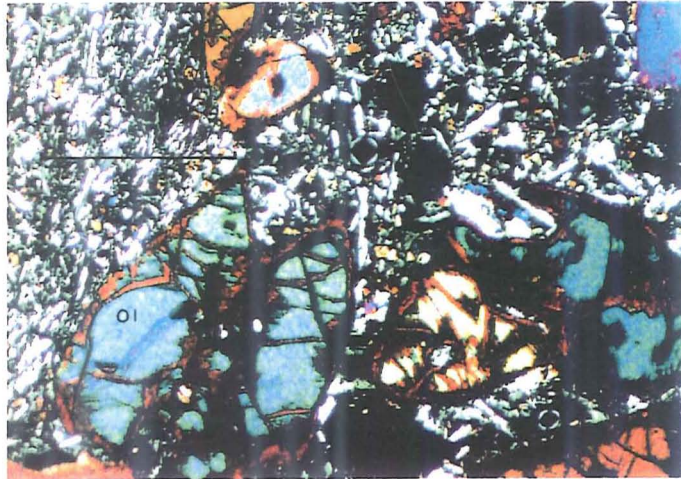


Fig. 3.1 Corroded and resorbed olivine (Ol) phenocrysts altered to iddingsite along cracks and margins in main phase Lyttelton hawaiite. M36B4902, (c.p.l) scale = 1 mm.

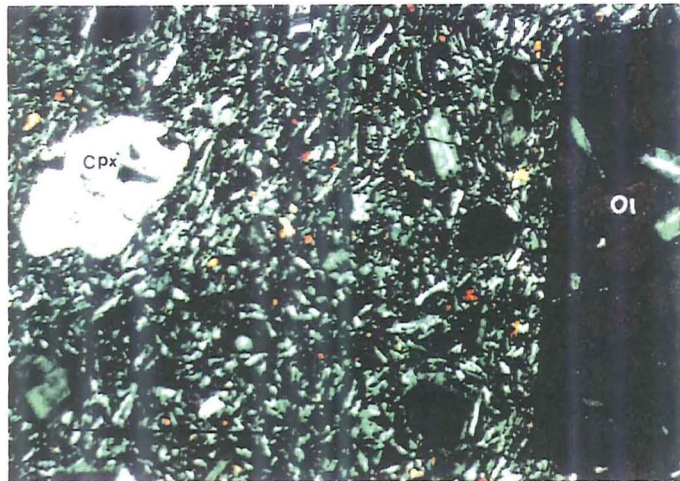


Fig. 3.3 Crystals of early plagioclase enclosed by prismatic euhedral olivine (Ol) phenocryst in main phase Lyttelton hawaiite. M36B4339 (c.p.l), scale = 1 mm

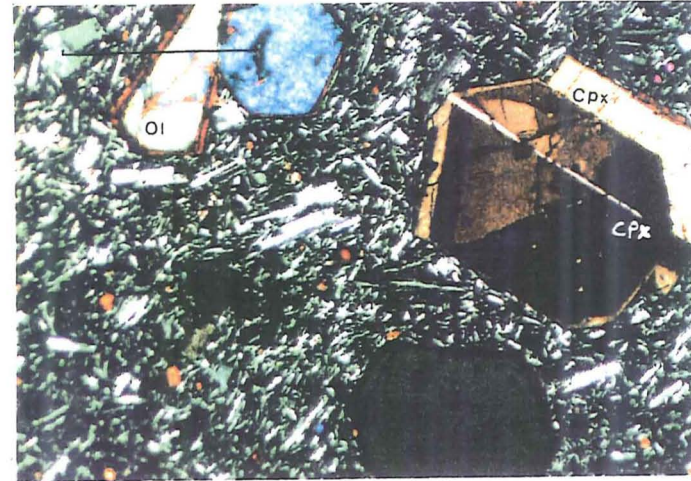


Fig. 3.2 Euhedral phenocryst of zoned clinopyroxene (Cpx) and euhedral olivine (Ol) with reaction rim of Fe-oxide and iddingsite in main phase Lyttelton hawaiite. M36B5853, (c.p.l) scale = 1 mm.

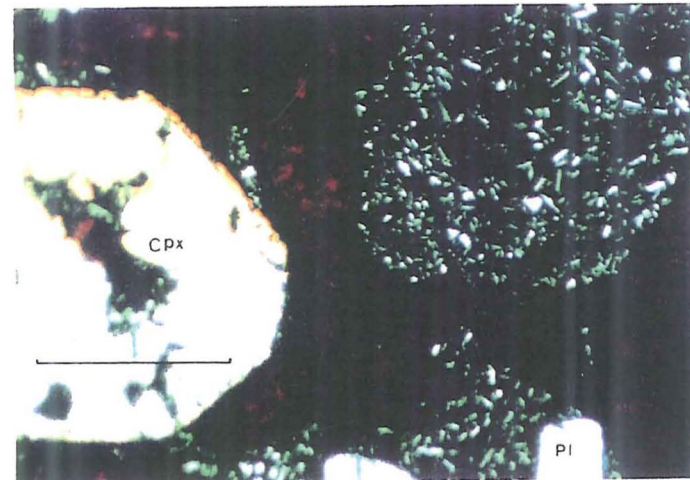


Fig. 3.4 Hydrothermal secondary Fe-oxide surrounding clinopyroxene (Cpx) and running through groundmass in main phase Lyttelton hawaiite. M36B2659



### 3.2.2 Intermediate rocks

#### *Mugearite Lava flows:-*

*Petrographic features:-*The textures of mugearites include intersertal, intergranular and aphanitic, but most mugearitic rocks are holocrystalline, porphyritic with sub-trachytoid groundmasses. Plagioclase (An 50-40) olivine, colourless clinopyroxene (augite) and Fe-Ti oxide are the common phenocryst phases. Groundmass minerals comprise plagioclase (An 40-30), augite, rare pale green clinopyroxene (ferroaugite), olivine and Fe-oxide together with glass.

In most mugearites olivine phenocrysts are usually euhedral and subhedral and partly or completely altered to iddingsite, but clinopyroxene phenocrysts are euhedral to subhedral and partly altered. Plagioclase phenocrysts have strong compositional zoning. Some mugearites contain rare brown hornblende and/or apatite. Most mugearites have more felsic groundmasses than those of hawaiites.

### 3.2.3 Felsic rocks

#### *Benmoreite lava flow*

*Petrographic features:-* The identification of benmoreite is based on chemical criteria (chapter 4). Benmoreite may appear as dark as mugearite or hawaiite in the field, but it has a noticeably lower colour index in thin section. The phenocryst content is more or less similar to mugearite. In some flows the groundmass of benmoreite resembles mugearite but has interstitial alkali feldspar.

Generally the benmoreites have holocrystalline, intergranular and sub-trachytoid texture. Some benmoreite lavas have a hyalopilitic texture in which microlites of feldspar and clinopyroxene float in a matrix of devitrified glass (Fig. 3.6).

Porphyritic benmoreites generally have subhedral plagioclase (albite to andesine) as the dominant phenocryst mineral with subordinate

clinopyroxene (ferroaugite) and Fe-oxide (Fig. 3.7). Groundmass minerals consist of dominantly plagioclase laths, altered or/and pale green clinopyroxene (ferroaugite), and variable amounts of glass. Most groundmasses contain Fe-oxide and altered clinopyroxene (Fig. 3.7). Some benmoreites contain subhedral brown hornblende phenocrysts (Fig. 3.5). In most benmoreite lavas fresh olivine is absent or rarely found. Most clinopyroxene and plagioclase phenocrysts have corroded surfaces (Fig. 3.8). Some benmoreites have microphenocrysts of fayalitic olivine and colourless clinopyroxene (augite) and Fe-oxide embedded in plagioclase phenocrysts (Fig. 3.8).

### 3.3 LATE PHASE LYTTTELTON VOLCANICS

#### 3.3.1 Mafic rocks

The late phase hawaiites include those of the Tors, Mt Cavendish and Mt Pleasant areas.

*Hawaiite lava flows*:-These are holocrystalline and porphyritic with intergranular textures. The phenocrysts are dominantly subhedral to euhedral plagioclase (An 65-40) with subordinate colourless clinopyroxene (augite), olivine and Fe-Ti oxide. Groundmass minerals comprise plagioclase (An 55-30), olivine, colourless clinopyroxene (augite) and some pinkish clinopyroxene (Ti-augite). In some samples olivine phenocrysts are present as elongate crystals. Some olivine phenocrysts are totally altered to the red-brown mineraloid iddingsite (Fig. 3.9) or display iddingsite rims. Clinopyroxenes are subhedral to euhedral and (Fig. 3.10) have colourless to pink titaniferous compositions. Most of the hawaiites contain partially resorbed kaersutite. Among the accessory minerals, oxides occur both as phenocrysts and in the groundmass in most hawaiites, but apatite is rare as a phenocryst. Secondary minerals such as calcite and clay minerals are common in some hawaiites. In some hawaiite lavas vesicles are filled by deuteritic minerals (zeolites).

#### 3.3.2 Intermediate rocks

The late phase mugearites are represented by the Tors area mugearite.



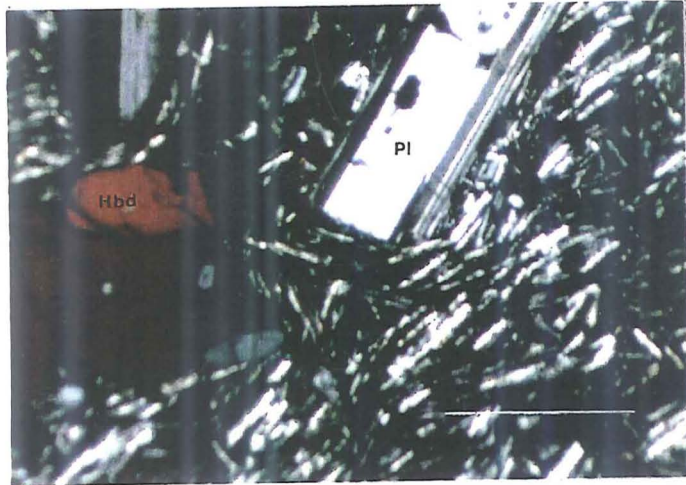


Fig. 3.5 Typical example of brown hornblende (Hbd) phenocryst in benmoreite lava flow. M36B5791 (c.p.l) scale = 1 mm.

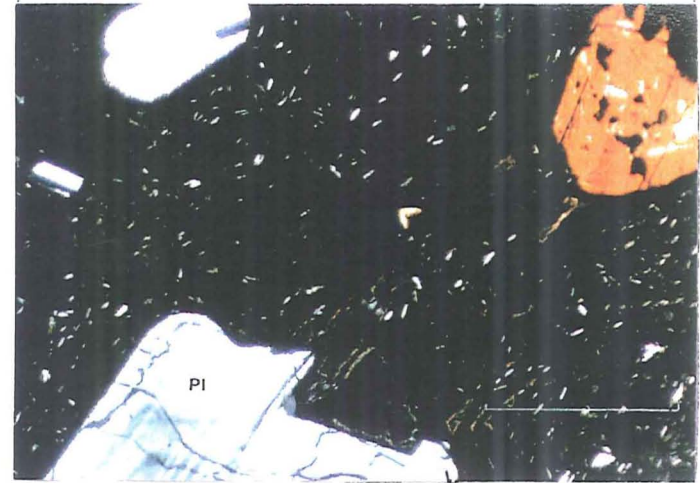


Fig. 3.6 An example of groundmass showing poorly developed feldspar microlites in Benmoreite lava flow. M36B5440 (c.p.l) scale = 1 mm.

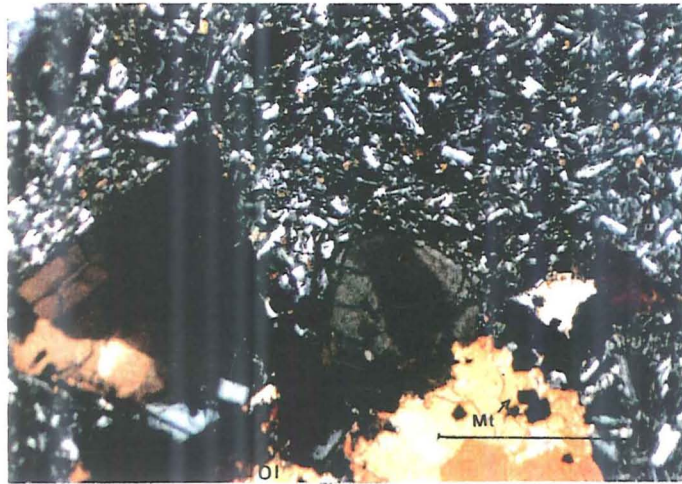


Fig. 3.7 Euhedral olivine crystals and anhedronal clinopyroxene with magnetite (Mt) microphenocryst in benmoreite lava flow. M36B4613, (c.p.l) scale = 1 mm.

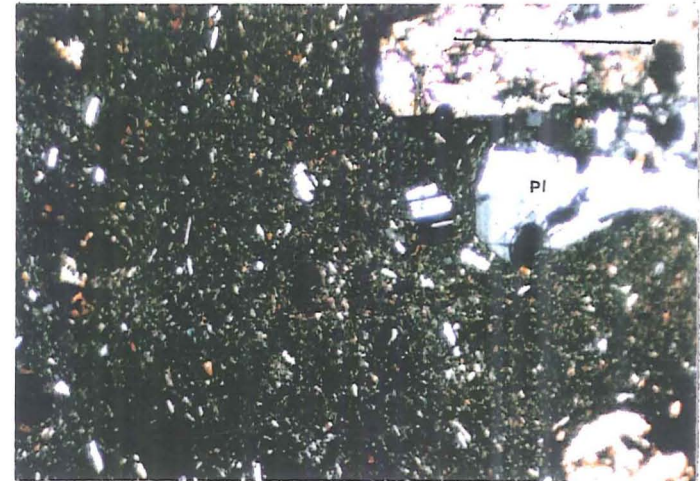


Fig. 3.8 An example of partially resorbed plagioclase phenocryst and complete replacement of clinopyroxene by Fe-oxide (left) in benmoreite lava flow. M36B5402 (c.p.l) scale = 1 mm.

#### *Mugearite lava flows:-*

The mugearites are hypocrySTALLINE, porphyritic or aphanitic, with intergranular or sub-trachytoid groundmasses. The dominant phenocryst phase is plagioclase (An 50-35) with subordinate clinopyroxene (augite) and olivine. The groundmass consists of plagioclase (An 40-30), colourless clinopyroxene (augite) and pale green clinopyroxene (ferroaugite) with olivine and Fe-oxide.

#### 3.3.3 Felsic rocks

The "Mt Pleasant Formation" felsic rocks include benmoreite and trachyte lavas of the Mt Cavendish and Mt Pleasant area respectively.

[A] *Benmoreite lava flows:* This flow is holocrystalline and porphyritic. The phenocryst minerals comprise plagioclase (anorthoclase to sodic plagioclase), pale green clinopyroxene (ferroaugite) and some augite and altered olivine. Groundmass phases are dominantly plagioclase with clinopyroxene and Fe-oxide and variable amount of glass. This benmoreite has similar petrographic features to the main Lyttelton benmoreite lava.

[B] *Trachyte lava flows:-*The lavas are generally holocrystalline, porphyritic with intergranular groundmasses. Most trachyte lavas are characterized by trachytic texture (Fig. 3.16). Euhedral to anhedral sodic plagioclase (albite or anorthoclase) is the dominant phenocryst phase (15-20%) with subordinate altered pale green clinopyroxene (ferroaugite) and rarely fayalitic olivine. The groundmass contains abundant sodic plagioclase, pale green clinopyroxene (ferroaugite) or green clinopyroxene (hedenbergite) and Fe-oxide (Fig. 3.11). Feldspar composition ranges from anorthoclase to andesine in both phenocryst and groundmass minerals. Altered clinopyroxene is the common mafic mineral in the groundmass. Some pale green clinopyroxene (ferroaugite) phenocrysts are anhedral and totally resorbed and/or altered with the formation of secondary minerals such as Fe-oxides. Fresh clinopyroxene phenocrysts are very rare in most trachytic lavas.



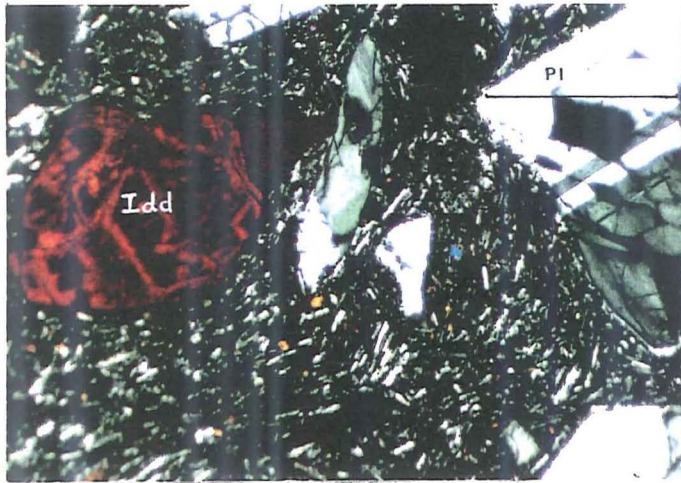


Fig. 3.9 Iddingsite (idd) pseudomorph after olivine in the late phase hawaiite. M36B4008. (c.p.l) scale = 1 mm.



Fig. 3.10 Euhedral clinopyroxene (augite) in late phase Lyttelton hawaiite M36B4018, (c.p.l) scale = 1 mm.



Fig. 3.11 Subhedral, corroded and resorbed clinopyroxene in crystalline groundmass of trachyte flow. M36B4003. (c.p.l) scale = 1 mm.

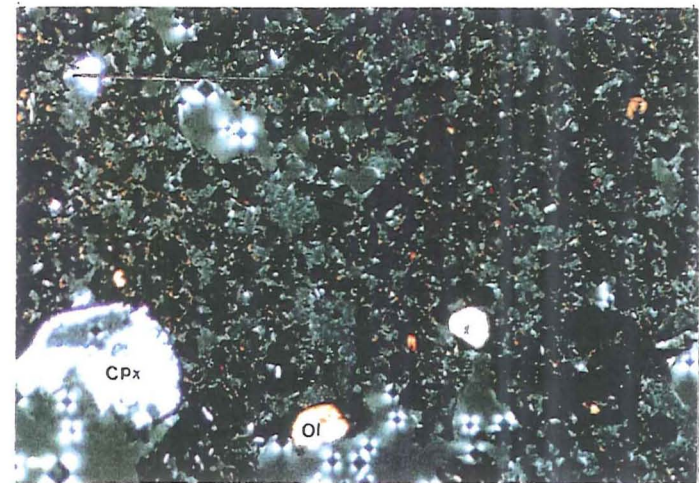


Fig. 3.12 An example of pyroclastic material (tuff) showing altered clinopyroxene and vesicular and glassy groundmass. M36B3205, (c.p.l) scale = 1 mm.



### 3.3.4 Pyroclastic rocks

[A] *Crystal tuffs*:- Generally have vitrophyric texture and are moderately vesicular. Vesicles are usually up to 0.1 mm in diameter. They contain plagioclase, some colourless clinopyroxene (augite) and olivine crystals embedded devitrified glass (Fig. 3.12).

[B] *Heterolithic tuff breccia (lahar)*:- The clasts are angular to sub angular lava lithologies. Individual clasts have mafic and intermediate compositions. The clasts consist of dominantly plagioclase and minor clinopyroxene and olivine crystals. The matrix is made up of plagioclase and glass together with some olivine and clinopyroxene crystals. These crystals (which were phenocryst in undisturbed magma) are themselves clasts.

## 3.4 INTRUSIVE ROCKS

Most of the mapped dikes were not thin sectioned, even though, based on a limited number of samples (around the Tors and some from Mt Pleasant areas) a general petrographic account of the dikes are presented below. Excepting the dikes, all sills and other intrusives in the mapped area have been thin sectioned.

Field descriptions and location of all dikes exposed in the mapped area and other intrusive rocks are given in appendix II and some of the thin sections examined are listed in appendix III. Chemical analysis of selected intrusives are given in appendix V and VI together with extrusive rocks.

### 3.4.1 Mafic intrusives

The mafic rocks among the intrusives are the olivine-basalt dikes of the radial swarm that cut the late phase volcanics (Mt Pleasant formation). These dikes are exposed around Mt Pleasant (M36B4016, M36B4034, M36B4036) and the Tors (M36B24) areas.

[a] *Olivine-basalt dikes*:- The dikes have holocrystalline, aphanitic and porphyritic textures. They contain phenocrysts of olivine and some colourless clinopyroxene (augite). Plagioclase phenocrysts are absent (Fig. 3.15) or less than 2% (Figs. 3.13 and 3.14) and olivine phenocrysts reach up



Fig. 3.13 Strongly embayed olivine phenocryst (ol) adjacent to clinopyroxene phenocryst (cpx) in olivine-basalt M36B4036, (c.p.l) scale = 1 mm.

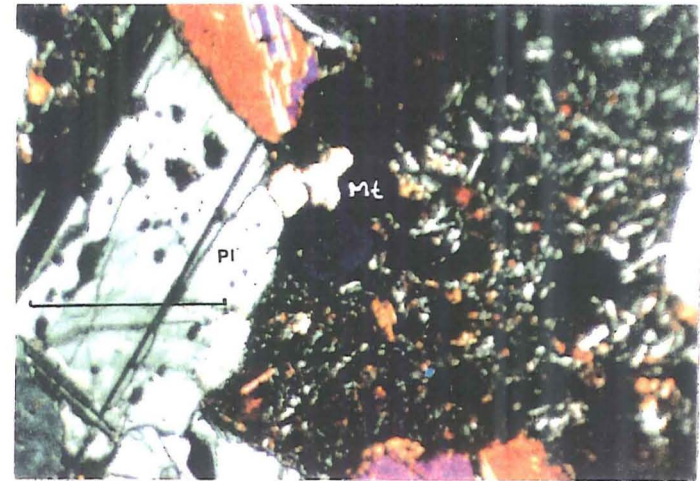


Fig. 3.14 Cumulophyric aggregate of plagioclase (pl), clinopyroxene and magnetite (Mt) in ol-basalt M36B4036, (c.p.l) scale = 1 mm.

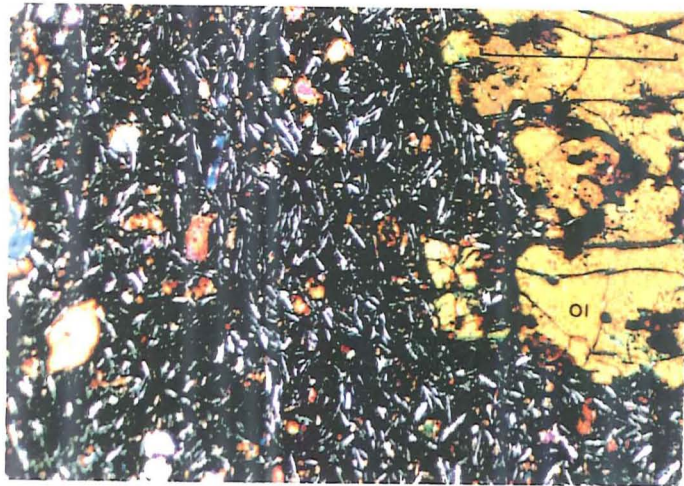


Fig. 3.15 Partially resorbed and corroded olivine phenocryst in olivine-basalt Intergranular olivine also occurs in the groundmass. M36B4034, (c.p.l) scale = 1 mm.

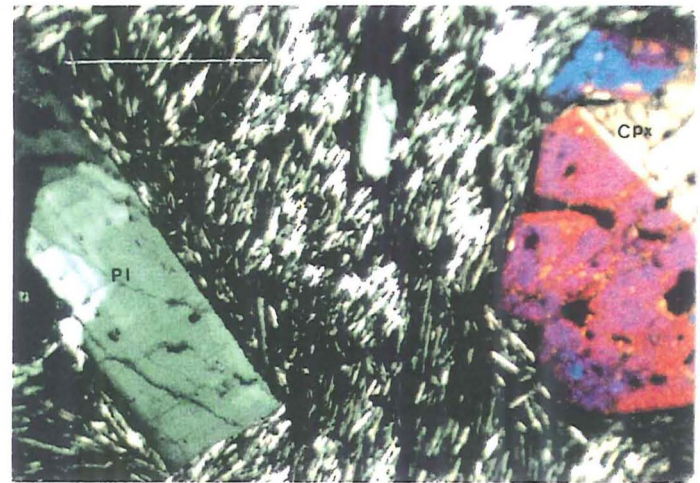


Fig. 3.16 An example of trachytic texture in trachyte dike. Note: Twinned, partly corroded clinopyroxene phenocryst. M36B3580



to 15 % of the total rock. Groundmass minerals are plagioclase (An 60-50), olivine, clinopyroxene (augite) and Fe-oxides. Olivine phenocrysts are subhedral and partially resorbed and corroded with thin rims altered to red/brown iddingsite (Fig. 3.15). Some of these dikes have euhedral, elongate olivine crystals partially replaced by Fe-oxide. The groundmass is rich in olivine with subordinate plagioclase, clinopyroxene and Fe oxide. Some dikes contain microphenocrysts of red or colourless apatite.

[b] *Hawaiite dikes*:-The dikes are holocrystalline, aphanitic and porphyritic with weakly intergranular textures. These contain phenocrysts of olivine in addition to plagioclase (An 65-40) and colourless clinopyroxene (augite). The groundmass minerals are olivine, plagioclase (An 55-35), clinopyroxene (augite and Ti-augite) and Fe-Ti oxide.

#### 3.4.2 Intermediate intrusives

*Mugearite dikes*:- Have similar petrographic features to the lava flows, but most dikes show sub-trachytoid texture. The dominant phenocrysts are plagioclase (60-35) with subordinate clinopyroxene, some olivine and Fe-oxides. The groundmass minerals comprise plagioclase (40-10), olivine, clinopyroxene and Fe-Ti oxides.

#### 3.4.3 Felsic intrusives

*Trachytic intrusive*:- Trachyte dikes, sills and intrusion have very similar petrographic features. The textures in the different intrusives varies, but most of the intrusives generally have holocrystalline, porphyritic and trachytoid textures (Fig. 3.16). Some trachytes are characterized by lath-like plagioclase in parallel alignment due to flow in the molten rock which is known as trachytic texture. This texture is not only confined to trachytes, it is also common in some mugearite and hawaiite lava flows and intrusives.

The phenocrysts are dominantly albite to anorthoclase, pale green clinopyroxene (ferroaugite), rare colourless clinopyroxene (augite) and Fe-oxide. Fresh euhedral clinopyroxenes (ferroaugite) are sometimes found in some dikes (Fig. 3.10). Fayalitic olivine occurs in some trachytic intrusives. The groundmass minerals comprise plagioclase (albite to anorthoclase), pale green clinopyroxene (ferroaugite), rare fayalitic olivine,



Fe-oxide together with devitrified glass. Some trachytes have flow textured groundmasses consisting of sodic alkali feldspar (anorthoclase), with subordinate clinopyroxene (augite) and sometimes brown hornblende. The groundmasses of some trachyte intrusives show conversion of anhydrous ferromagnesian silicates into chlorite and serpentine minerals, which gives a greenish colour to most trachytes under p.p.l (plain polarized light) and in the field.

### 3.5 SUMMARY AND DISCUSSION

It has been suggested by other researchers (Sewell, 1985, 1988 and Weaver and Sewell, 1986) that the Lyttelton rocks are distinguishable from other Banks Peninsula rocks (such as Akaroa, Mt Herbert etc.). The Lyttelton volcanic group consist dominantly of hawaiiite to trachyte lava flows (Sewell, 1988). The present study also supports this and shows the Lyttelton rocks consist of dominantly hawaiiite, with benmoreite next in abundance together with some trachyte and very minor mugearite lava flows. On the basis of field observations, the Lyttelton rocks have been divided into *Main* and *late* phase rocks (Chapter 2). Each phase is characterized by mafic to felsic lava compositions as discussed in earlier sections of this chapter.

The aims of this sub-chapter are to summarize:- (i) the petrographic aspect of lavas capable of giving information of petrogenetic significance (ii) the petrographic difference between the main and late phase rocks, (iii) the intrusives rocks and their relationship to extrusive rocks and/or comparison of Lyttelton rocks with other Banks Peninsula lavas.

#### [A] Petrographic observations and the possible petrogenetic significance:-

##### (i) *Primary igneous processes (corrosion and resorption).*

Phenocrysts crystallized in the intratelluric environment from liquid represented by their groundmasses after eruption. The petrographic evidence for this is the euhedral form of the crystals. Some of the phenocrysts, however show evidence of *reactions* with the liquid which usually manifests itself in *corroded* form or in the presence of a mantle (so-called reaction rim) of other phases armouring it and separating it from the groundmass.

In most Lyttelton lavas, petrographical evidence in the form of corrosion and partial resorption of some plagioclase, clinopyroxene and olivine phenocrysts suggests significant movement of phenocrysts relative to melt in a chemically zoned magma or low pressure disequilibrium between crystals and liquid. The resorbed feature in most olivines suggest reaction relationships with the liquid. *Reaction* can be caused by thermal (compositional) disequilibrium and by equilibrium resorption. It has been assumed that thermal (compositional) disequilibrium is one the most common causes of *resorption*. The other cause of resorptional features is by change of P-T conditions as magma moves towards the surface.

It seems likely that the brown hornblende which is thought to be kaersutite (Sewell, 1985) crystallized at relatively high pressure under hydrous conditions, and under low pressure conditions broke down to be resorbed and replaced by a magnetite - clinopyroxene assemblage. In general, resorption of phenocrysts in some lavas and the presence of kaersutite indicate *polybaric* fractionation and movement of phenocrysts relative to melt. Partially resorbed kaersutite megacrysts are common in younger Lyttelton mafic flows (Weaver et al. 1989 in prep.). Kaersutite megacrysts are not only found in younger (late phase) rocks, they are common in the older (main phase) felsic and mafic rocks as well.

(ii) *Secondary Igneous Process (alteration):-*

Some Lyttelton rocks are far from pristine (fresh), this is either because they are weathered or have undergone *late* or *post* magmatic alteration. Alteration minerals often pseudomorphed by low-temperature phases (such as chlorite, serpentine and opaques) or by high-temperature phases such as iddingsite. Most Lyttelton rocks (the main and late phase mafic and intermediate rocks) show marginal iddingsitisation of olivine phenocrysts accompanied by complete replacement of groundmass olivine. As discussed in several sections of this chapter, olivines shows characteristic shapes and are susceptible to marginal alteration. Of the common alteration products of olivine, apart from opaques (oxide), the red-brown mineraloid iddingsite is a ubiquitous product of high - temperature (magmatic) alteration. Olivine is often pseudomorphed by Fe-oxide and iddingsite and its presence is mainly inferred from euhedral olivine shapes of the pseudomorphs. The replacement of olivine phenocrysts and to a lesser extent clinopyroxene with iddingsite

rims probably indicates late stage magmatic oxidation (Weaver, pers. comm.). The occurrence of sparse subhedral red-brown apatite microphenocrysts in the lavas could be explained as the remains of high pressure crystallization or polybaric fractionation.

**[B] Petrographic differences between the main and late phase rocks:-**

The main and late phase (Mt Pleasant formation) rocks do not show major differences in petrography. Both are characterized by mafic to felsic lava compositions, but the main phase Lyttelton hawaiiite lavas can be distinguished from late phase hawaiiite by differences in the modal population of minerals. The main Lyttelton hawaiiites are more porphyritic in texture and have higher modal plagioclase phenocrysts (25%) than late phase hawaiiites. Amphibole is far more common in the late phase hawaiiites than in the main phase hawaiiites. There is no observable petrographic difference between the main and late phase mugearites and benmoreites. There is no trachyte lava flow in the main phase Lyttelton volcanics.

**[C] Intrusives and their relationship to extrusives and other Banks Peninsula rocks:-**

Among the intrusives, the olivine-basalt dikes are distinguished from the late and main hawaiiite flows by their high contents of olivine phenocrysts (typically 10-15%) and absence of plagioclase phenocrysts. These dikes intersect the late phase rocks and they are younger than the other dikes (intermediate and felsic dikes) and late phase lava flows. The olivine-basalt dike which cuts the Castle rock trachyte is correlated with the younger Church volcanics (Weaver and Sewell, 1986). Based on this fact, together with petrographic and field relationships, the olivine-basalts in the mapped area probably all belong to the Church volcanics (8.1-7.3 Ma). In general, the dikes range from mafic to felsic rocks as is the case of the lava flows. The sills and other intrusions are trachyte in composition.



## CHAPTER 4

### GEOCHEMISTRY

#### 4.1 INTRODUCTION

This chapter discusses the geochemistry of extrusive and intrusive rocks of the north-eastern sector of Lyttelton volcano. The objective of this chapter is:- (i) to classify and describe the rocks on the basis of their chemistry (ii) to determine the stratigraphic variation in major and trace elements and to assess chemical variation between the main and late phase (Mt Pleasant Formation) Lyttelton volcanics, (iii) to correlate lava flows and other units from different outcrops (iv) to make inferences concerning the petrogenesis of the Lyttelton volcanic group, (v) to assess the tectonic significance of the Lyttelton lavas by means of geochemical discrimination diagrams

The chapter discusses the main and late phase Lyttelton volcanics (Mt Pleasant Formation) under different headings. The first two sections deal with major and trace element classification and variations. These are followed by stratigraphic variation using geochemical parameters. The last section deals with petrogenesis of the lavas and their tectonic setting, together with a summary discussion on isotope geochemistry and comparison of Lyttelton rocks with other parts of Banks Peninsula.

Whole rock major element analyses and CIPW normative mineralogy for extrusive and intrusives are presented in appendix Vb. Trace element analyses and ratios are given in appendix VIb and other description of samples are found in appendix II.

#### 4.2 CHEMICAL CLASSIFICATION AND ASSOCIATIONS

##### 4.2.1 Nomenclature

Extrusive and intrusive rocks of the mapped area range in composition from ol-basalt to qz-trachyte and have silica abundances ranging from 47 to 67 Wt. %. Lyttelton volcanic rocks are here classified according to the scheme of Coombs and Wilkinson (1969). This classification is based on Differentiation Index versus normative plagioclase composition (Fig. 4.1).

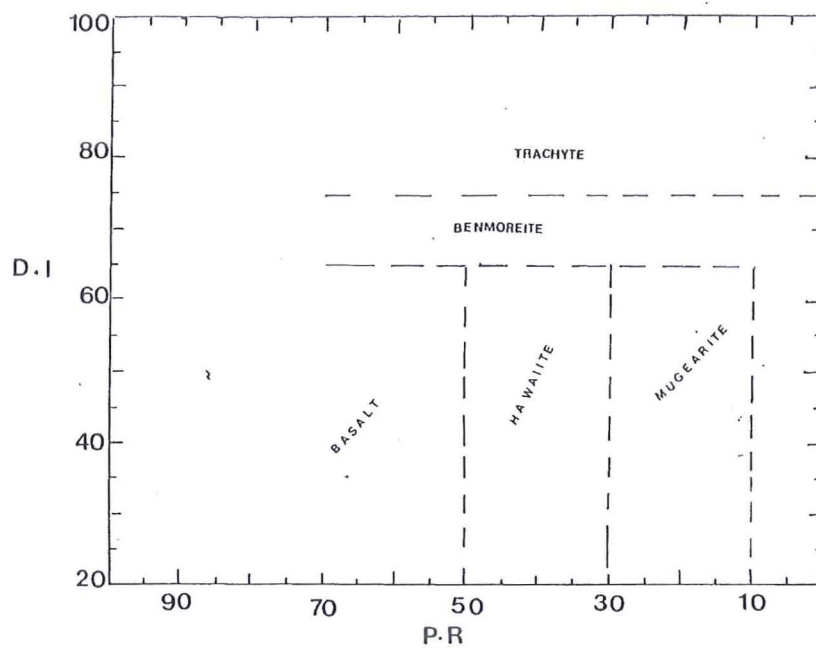


Fig. 4.1 Differentiation Index (D.I) versus normative plagioclase diagram, for classifying the rocks.

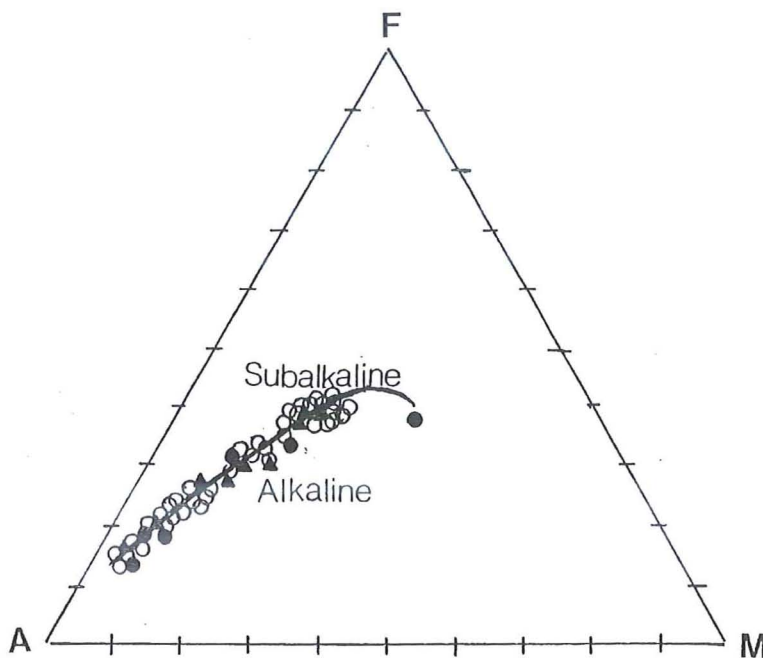


Fig. 4.2 AFM plot for Lyttelton rocks, solid line divides alkaline and subalkaline fields. (After MacDonald and Katsura, 1964).

KEY for Lyttelton rocks :-

- = Solid circles = Intrusive rocks.
- ▲ = Closed triangles = Late phase Lyttelton volcanics Lava flows.
- = Open circle = Main phase Lyttelton volcanics Lava flows.



Lyttelton rocks are classified accordingly as shown on figure 4.1 and rock names are prefixed by the normative minerals (*ne*, *hy* or *qz*); this indicates the degree of silica saturation (see section 4.7.2 and appendix Vb).

Some Lyttelton rocks are weathered, oxidized or altered, involving replacement by secondary minerals and mineraloids (see chapter 3). Such alteration directly affects the chemical classification of samples if the primary chemistry has changed. Most alteration involves oxidation and the conversion of iron from ferrous ( $Fe^{2+}$ ) to the ferric ( $Fe^{3+}$ ) state. In the CIPW norm such a change results in the formation of hematite at the expense of magnetite and under estimation of Fe silicates (olivine and pyroxenes). In effect  $SiO_2$  is "liberated" and normative *qz* and may be generated or normative *qz* and *hy* may be increased. To minimize this effect, normal practice, even when separate ferrous and ferric iron concentrations are available, is to calculate norms for a suite of rocks at a constant iron oxidation state. Here a ratio of  $Fe_2O_3 / FeO = 0.3$  is assumed (Weaver pers. comm.).

The degree of hydration of samples can be judged from the magnitude of the determined LOI. The norm calculation is of course independent of this variation. Other changes in primary chemistry can not be compensated for except that in field sampling, only the freshest rocks were chosen. The variable oxidation and hydration that has affected the Lyttelton rock is typically of pre-Quaternary volcanics and should not have biased the geochemical discussion presented here.

#### 4.2.2 Chemical associations

The Lyttelton volcanics plot on both sides of the boundary line (Fig. 4.3) separating alkaline and subalkaline compositions (Irvine and Barager, 1971). Likewise on the AFM plot, (Fig. 4.2), Lyttelton rocks straddle the division between alkaline and sub alkaline compositions (Macdonald and Katsura, 1964). Thus in general the Lyttelton suite is *transitional* in geochemical affinity.

Several felsic Lyttelton rocks (benmoreites and trachytes) plot in the subalkaline field (Figs. 4.3, 4.4). On the alkali silica plot, most mafic rocks (basalts and hawaiites) plot on the *alkaline* field and therefore appear to be

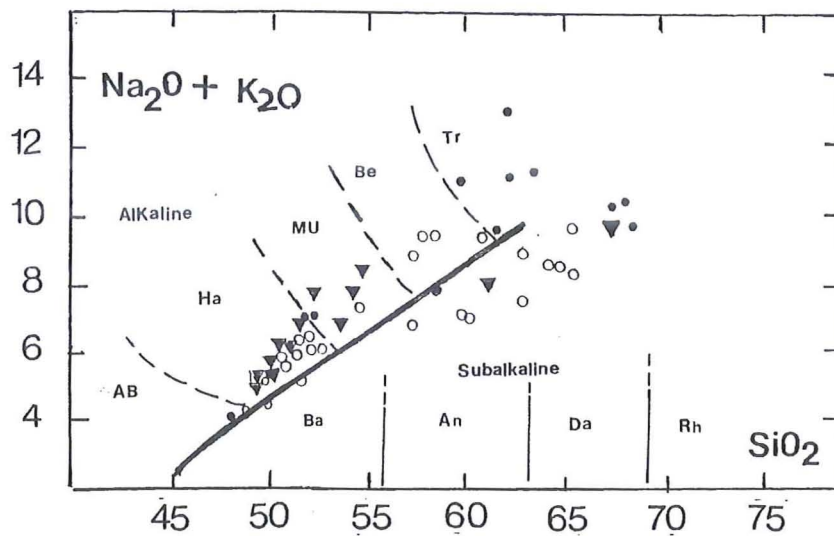
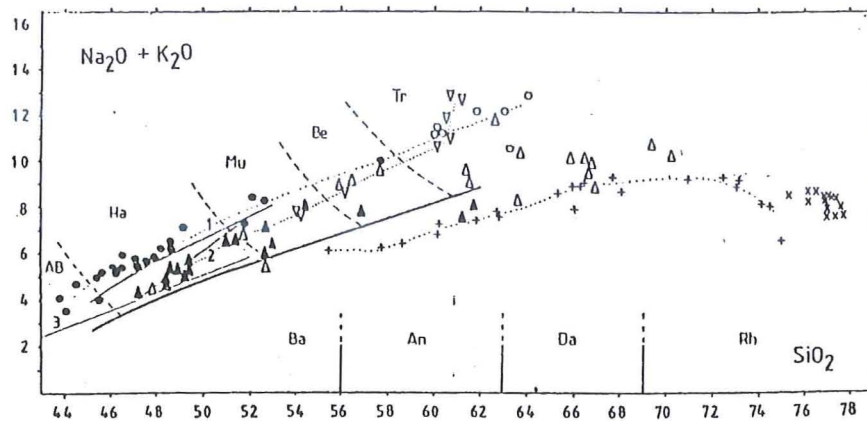


Fig. 4.3 Alkali Silica plot for Lyttelton rocks. After Weaver and Sewell, 1986. Thick solid line divides alkaline and subalkaline fields (Irvine and Barager, 1971). Nomenclature for alkaline (alkali basalt to trachyte) and subalkaline (basaltic andesite to rhyolite) association is indicated. (Ab=Alkali basalt, Ha=Hawaiite, Mu=Mugearite, Be=Benmoreite, Tr=Trachyte, Ba=Basaltic andesite, An=Andesite, Da=Dacite, Rh=rhyolite).

KEY for Lyttelton rocks :-

- Solid circles = Intrusive rocks.
- Closed triangles = Late phase Lyttelton volcanics Lava flows.
- Open circle = Main phase Lyttelton volcanics Lava flows.



Alkali - Silica plot for fractionated Banks Peninsula suites. Solid circles - Akaroa intrusive rocks; open circles - Akaroa flow rocks; closed triangles - Lyttelton flow rocks; open triangles - Lyttelton intrusive rocks; inverted open triangles - Castle Rock zoned intrusion, Lyttelton; + - Governors Bay Volcanics; X - Smoky Rhyolites. Dotted lines show main trends for Akaroa, Lyttelton and Governors Bay Volcanics. Thick solid line divides alkaline and subalkaline fields (Irvine & Barager 1971). Lines 1-3 separate ne from hy normative samples for Akaroa, Lyttelton and Skye (Thompson et al 1972) respectively. Nomenclature for alkaline (alkali basalt to trachyte) and subalkaline (basaltic andesite to rhyolite) associations is indicated.

Fig. 4.4 Alkali - Silica plot for Banks Peninsula suites. From Weaver and Sewell, 1986.



members of the alkali olivine basalt - hawaiite - mugearite - benmoreite - trachyte associations as defined by Coombs and Wilkinson (1969). This designation is consistent with the mineralogy of the rocks, that is the presence of a single Ca-rich clinopyroxene and abundant olivine and the absence of orthopyroxene and pigeonite. In addition to these features the Lyttelton rocks do not show any trends of Fe-enrichment characteristic of a *tholeiitic* suite (Fig. 4.2).

The intermediate and felsic Lyttelton rocks that plot in the subalkaline field (Fig. 4.3) are not related to the Governors Bay series as described by Weaver and Sewell, 1986 (Fig. 4.4). This study classified the Lyttelton rocks as benmoreite and trachyte (alkaline suite, sodic series) rather than dacite (subalkaline suite, potassic series). The reasons for this designation are:- (i) these rocks have typical *alkaline suite mineralogy* (as described above / see chapter 3). (ii) Some samples may plot in subalkaline field due to *alkali loss*.

As shown in figure 4.4 the Governors Bay Volcanic are a subalkaline potassic series Icelandate, K-dacite to peraluminous K-rhyolite (Weaver et al. in press). Akaroa volcanics are on alkaline, sodic series, alkali basalt to trachyte association (Fig. 4.4). In general the subalkaline potassic trend of the Governors Bay volcanics and the alkaline, sodic trends of Lyttelton and Akaroa volcanics are distinct on Figure 4.4. The presence of high silica felsic lava flows in Lyttelton is clearly distinguishes the Lyttelton volcanics from Akaroa volcanics (Figs. 4.3, 4.4).

### 4.3 CHEMICAL VARIATIONS

This section discusses major and trace element variation in Lyttelton volcanics. For this purpose, the discussion is based on two plots :- the first variation diagram is for extrusive and intrusive rocks and the second diagram covers extrusive rocks only. Both plots are presented side by side.

The reasons for selection of extrusive and intrusive plots together (i.e Figure numbers suffixed by letter "a") are :- (i) to show chemical variations or trends for the whole Lyttelton suite, (ii) to show relationships between the chemistry of the two groups of extrusive rocks and intrusive rocks, (iii) to show chemical variation within the intrusive rocks themselves. The reason

for plotting extrusive rocks separately (i.e Figure numbers suffixed by letter "b") is simply to assess clear chemical differences between the main and late phase Lyttelton volcanics (Mt Pleasant Formation) which have been separated on the basis of field relationships (see chapter 2).

#### 4.3.1 Major-element variation

Major elements are plotted against  $\text{SiO}_2$  as an index of differentiation. Firstly the major element variation of the whole Lyttelton suite is discussed below based on Figure 4.5a that covers both extrusive and intrusive rocks.

##### *Silica versus oxides variation:*

Major elements abundances plotted against Wt. %  $\text{SiO}_2$  show a wide range in abundances and display fractionation trends. The large scatter of points shown by main and late phase volcanics may be partly a consequence of the porphyritic nature of the samples. This problem is difficult to overcome because of the general highly porphyritic nature of most of the main phase Lyttelton lava flows. However despite the scatter of points on the variation diagrams fractionation trends are still apparent.

##### (i) $\text{SiO}_2$ versus $\text{MgO}$ and $\text{Fe}_2\text{O}_3$ :-

$\text{MgO}$  decreases with increasing  $\text{SiO}_2$  (Fig. 4.5a), reflecting fractionation of Mg-rich phases (olivine and clinopyroxene). The low MgO content and low Mg numbers are indicative of *fractionated rocks*. Even most Lyttelton basic rocks are highly fractionated relative to mantle-derived primary magmas. Like MgO, total  $\text{Fe}_2\text{O}_3$  decreases with increasing degree of differentiation (Fig. 4.5a), suggesting  $\text{Fe}_2\text{O}_3$  is controlled by fractionation of olivine, clinopyroxene and Ti-magnetite.

##### (ii) $\text{SiO}_2$ versus $\text{TiO}_2$ and $\text{CaO}$ :-

A decrease in  $\text{TiO}_2$  with increasing degree of differentiation (Fig. 4.5a) reflects fractionation of Ti-magnetite and to lesser extent titaniferous clinopyroxene.  $\text{CaO}$  shows a decrease with increasing degree of differentiation (Fig. 4.5a) reflecting the fact that CaO is removed by crystallization of clinopyroxene and calcic plagioclase.

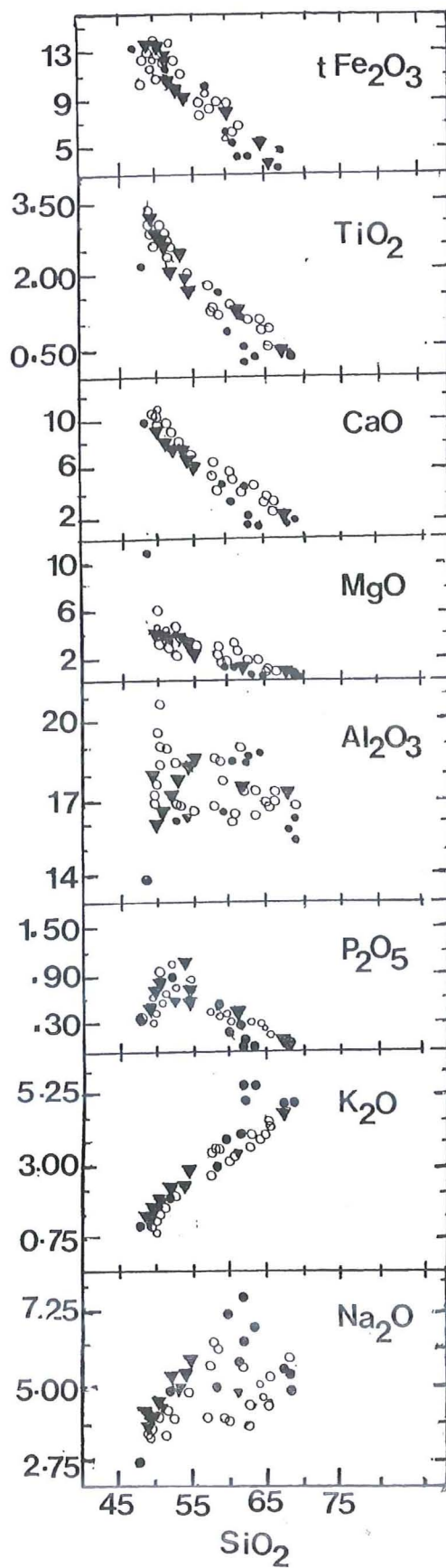


Fig. 4.5a  $\text{SiO}_2$  versus Wt. % oxides for extrusive and intrusive rocks. Key to symbols as for Fig. 4.3.

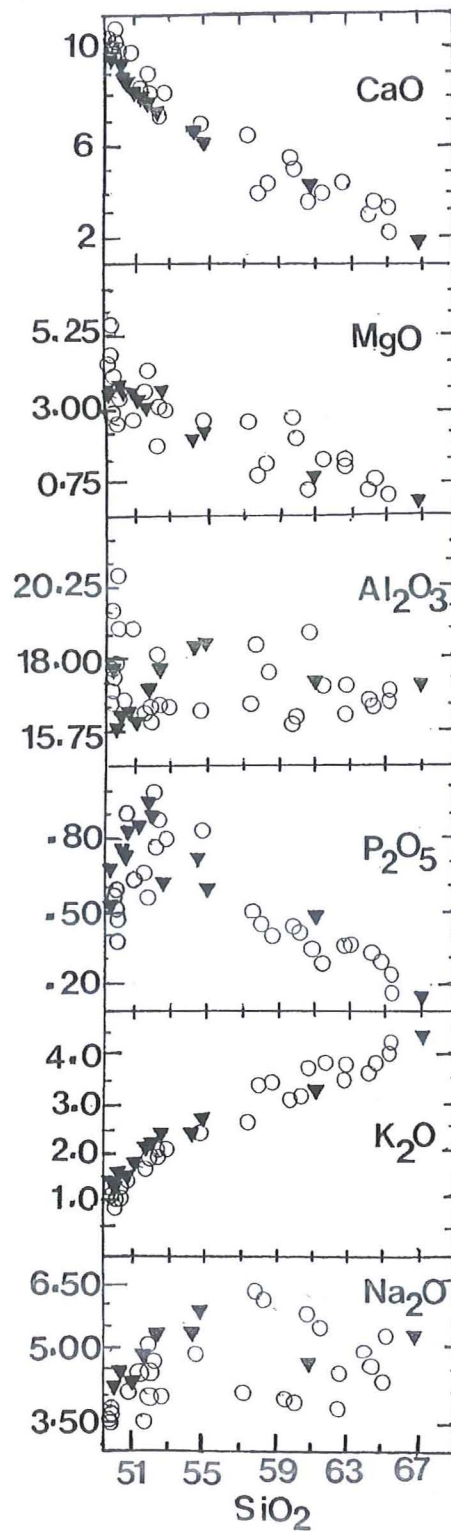


Fig. 4.5b  $\text{SiO}_2$  versus Wt. % oxides for extrusive rocks (main and late phase Lyttelton volcanics). Key as for Fig. 4.3.



(iii)  $SiO_2$  versus  $K_2O$  and  $Na_2O$ :-

The enrichment in  $K_2O$  with increasing  $SiO_2$  (Fig. 4.5a) indicates the absence of a fractionating K-rich mineral and that  $K_2O$  is acting as an incompatible element throughout the range of magma compositions studied here. The behaviour of  $Na_2O$  is more complex. In basic magma compositions it behaves incompatibly like  $K_2O$  and is strongly enriched. However,  $Na_2O$  peaks in abundance in intermediate rocks, and is relatively depleted in lavas of the most evolved composition (trachytes). This reflects the fractionation of intermediate and sodic plagioclase. Clearly the composition of fractionating plagioclase is the main control on the  $Na_2O/K_2O$  ratio of the lavas which is relatively constant in mafic rocks but drastically reduced as plagioclase become more sodic.

(iv)  $SiO_2$  versus  $Al_2O_3$  and  $P_2O_5$ :-

$P_2O_5$  and  $Al_2O_3$  show dispersed trends (Fig. 4.5a). Initially an increase in abundance is followed by decrease at higher levels of fractionation.  $Al_2O_3$  shows dispersed enrichment with increase in  $SiO_2$ , reflecting a lack of plagioclase fractionation in basic rocks but increasingly significant fractionation in intermediate and felsic rocks. The concentration of  $Al_2O_3$  is highly sensitive to the abundance of plagioclase phenocrysts, therefore, the scatter in basic rocks could be partly due to this variable.

As shown on the variation diagram,  $P_2O_5$  initially increases then decreases (Fig. 4.5a). The peak clearly corresponds to the incoming of apatite as a fractionating phase, although trace apatite has been detected in some mafic rocks (chapter 3).

In *conclusion*, the general trend through the fractionation series is the increase in  $K_2O$  and  $Na_2O$ , and a decrease  $MgO$ ,  $Fe_2O_3$ ,  $TiO_2$ ,  $CaO$  and  $P_2O_5$  (Fig. 4.5a). This suggests that the main process controlling the variation in the magma chemistry is *fractional crystallization* of phenocryst phases, namely of olivine, clinopyroxene and plagioclase together with Ti-magnetite (the common phenocrysts in most rocks). Thus most of the *chemical variations* in Lyttelton lavas can be ascribed to *low pressure fractionation*, presumably in a crustal magma chamber, rather than mantle

processes involving different degree of partial melting.

#### 4.3.2 Trace-element variation

Trace-elements are plotted against Zirconium to assess chemical variations within Lyttelton volcanics. Trace element data and selected trace element ratio are presented in appendix VIb.

##### (i) Zirconium versus trace elements.

*Zirconium* is chosen as an index of fractionation because: (a) it shows wide variation in these lavas and may be determined with high precision (b) because of its low bulk distribution coefficient in basaltic suites, it behaves as an incompatible element with low crystal-melt partition coefficients in most igneous minerals (c) The concentration of Zr is very sensitive to partial melting and/or differentiation and it is insensitive to alteration (Tarney et al.1977).

*Zr versus Sr*:- Strontium abundance increases slightly, but becomes depleted in more evolved (felsic) rocks as zirconium increases (Fig. 4.6a). This suggests that *Sr* was concentrated in the early stages of fractionation by crystallization and removal of olivine and clinopyroxene, but in later stages was removed by plagioclase. The dispersion of points partly reflects the porphyritic nature of some samples rich in plagioclase phenocrysts.

*Zr versus Ni, Cr and V*:- The behavior of the *compatible* trace-elements Ni, Cr and V supports the crystal fractionation of olivine, clinopyroxene and magnetite. For example, *Ni* decreases with increasing differentiation (Fig 4.6a), this suggests fractionation of olivine. *Cr* also decreases with increasing Zr, suggesting mainly clinopyroxene fractionation. The decrease in *V* with increasing Zr (Fig. 4.6a) suggests fractionation of magnetite.

*Zr versus Rb, Nb, Ce and Ba* These elements behave *incompatibly* and are enriched with differentiation. Rb, Nb, Ce and Ba increase with increasing Zr content (Fig. 4.6a). A flattening out of the trends for *Rb, Ba* and *Ce* is apparent for the most evolved (high Zr) compositions. This suggests that in felsic compositions, these elements are less incompatible than Zr and that partition coefficients are increasing. This may reflect the crystallization of

● Intrusive  
 ○ Main phase  
 ▲ Late phase

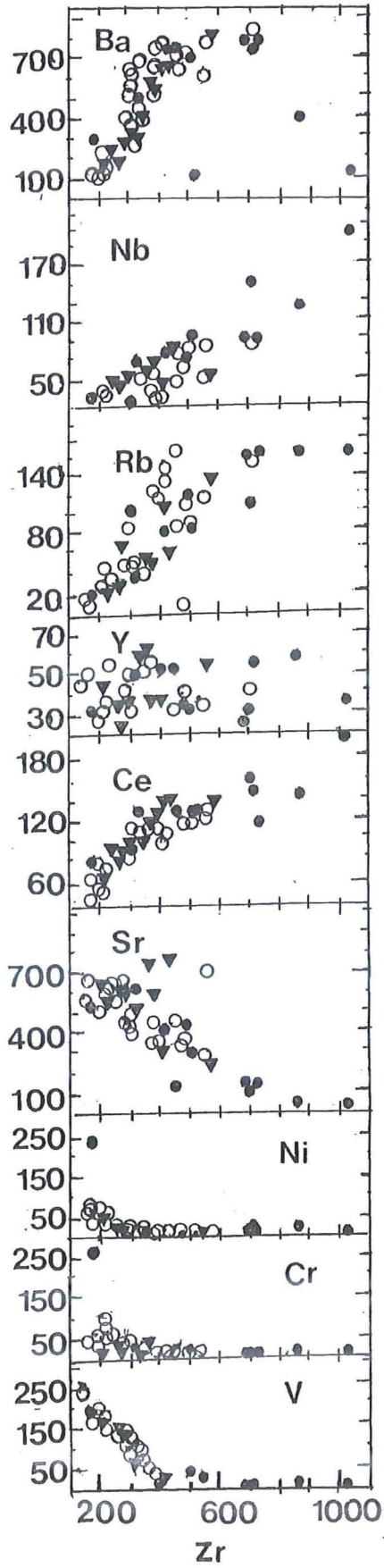


Fig. 4.6a Zr versus trace elements for extrusive and intrusive rocks. Key as for Fig. 4.3.

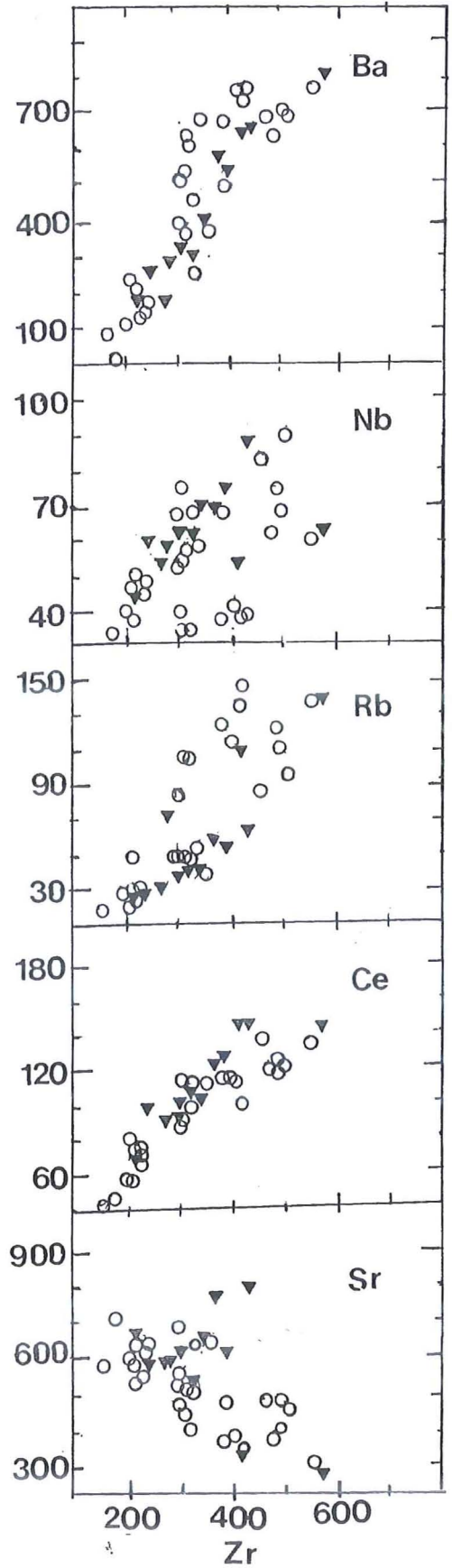


Fig. 4.6b Zr versus trace elements for extrusive rocks (main and late phase Lyttelton volcanics). Key as for Fig. 4.3



sodic plagioclase and ternary feldspars which can incorporate *Ba* and *Rb*, and probably apatite which incorporates *Ce*.

*Zr versus Y*:- The behavior of *Y* is very erratic. There is an initial tendency to increase, but *Y* concentrations in felsic rocks are very variable. Further work including the analysis of full Rare Earth Element patterns is necessary to investigate this behavior.

#### 4.3.3 Oxides and trace-element variations

##### (a) Zirconium versus major elements

*MgO*, *CaO*, *TiO<sub>2</sub>* decrease with increasing *Zr*, but *K<sub>2</sub>O* and *Na<sub>2</sub>O* increase linearly with *Zr* (Fig 4.7a). *K<sub>2</sub>O* versus *Zr* suggests that *K* is acting as a strongly incompatible element. The dispersion in *Na<sub>2</sub>O* relative to *K<sub>2</sub>O* indicates that *Na* is behaving less incompatibly than *K* (Fig. 4.7a). The observed trend of *MgO* versus *Zr* (Figs. 4.7a) suggests that the fractionation is probably caused by olivine removal, but the scatter probably reflects variation in the degree of olivine fractionation or the existence of a number of *subsidiary trends* (different lines of liquid descent). The trend shown by *Zr* versus *CaO* and *TiO<sub>2</sub>* suggest crystal fractionations. *P<sub>2</sub>O<sub>5</sub>* initially increases and then decreases with increasing *Zr* (Fig. 4.7a) suggesting that *P* is controlled by the removal of apatite in the middle stages of the fractionating sequence.

##### (b) Silica versus trace-element variation.

*Zr*, *Ba* and *Rb* increase with increasing *SiO<sub>2</sub>* whereas *Sr* decreases with increasing silica (Fig. 4.8a). The behaviour shown by *Sr* suggests that plagioclase crystallization is the controlling factor. *Nb* initially increases but then decreases at higher levels of differentiation. On Figure 4.8a and 4.8b it is apparent that a group of felsic main phase rocks have particularly low *Nb* contents. These rocks also have low *Sr* and in these respects there is a similarity to felsic rocks of the Governors Bay Volcanic Group. Thus these rocks may represent a subsidiary or separate geochemical trend. Clearly (further) more detailed investigation is needed to clarify this issue.

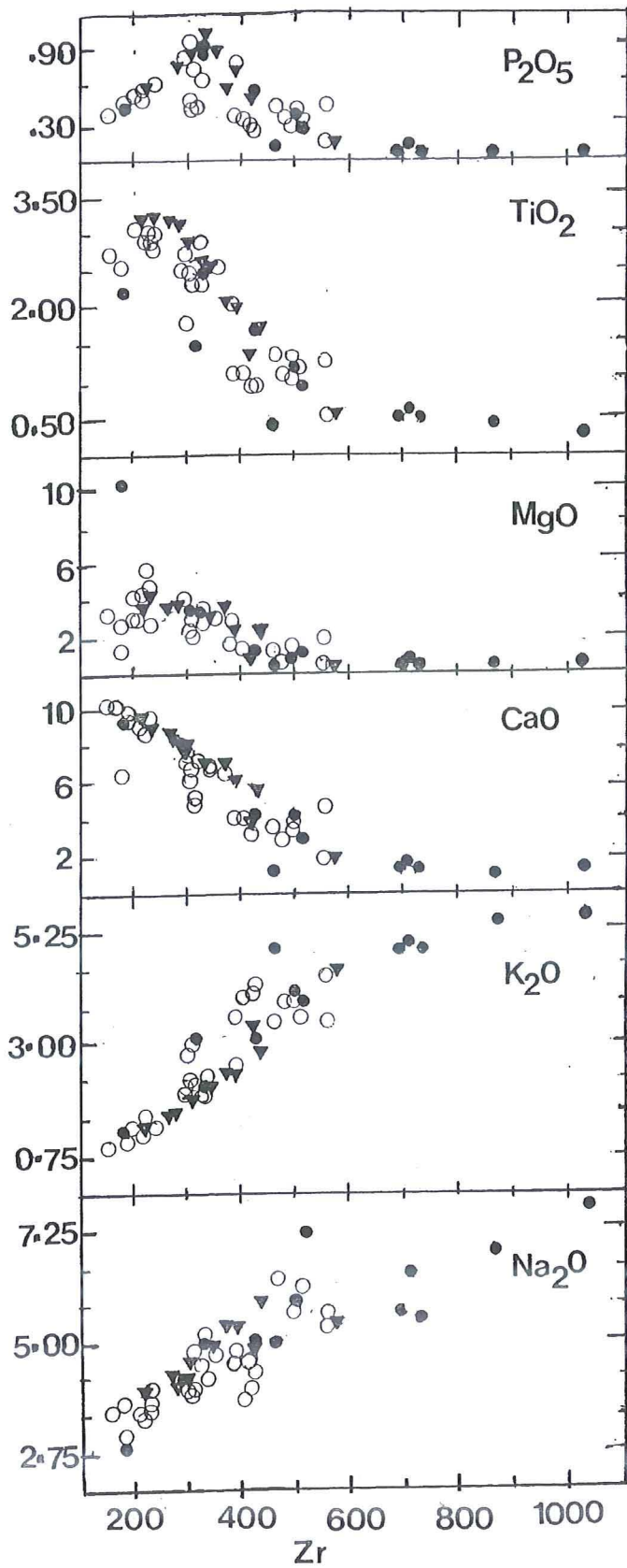


Fig. 4.7a Zr versus Wt. % oxides for extrusive and intrusive rocks. Key as for Fig. 4.3.

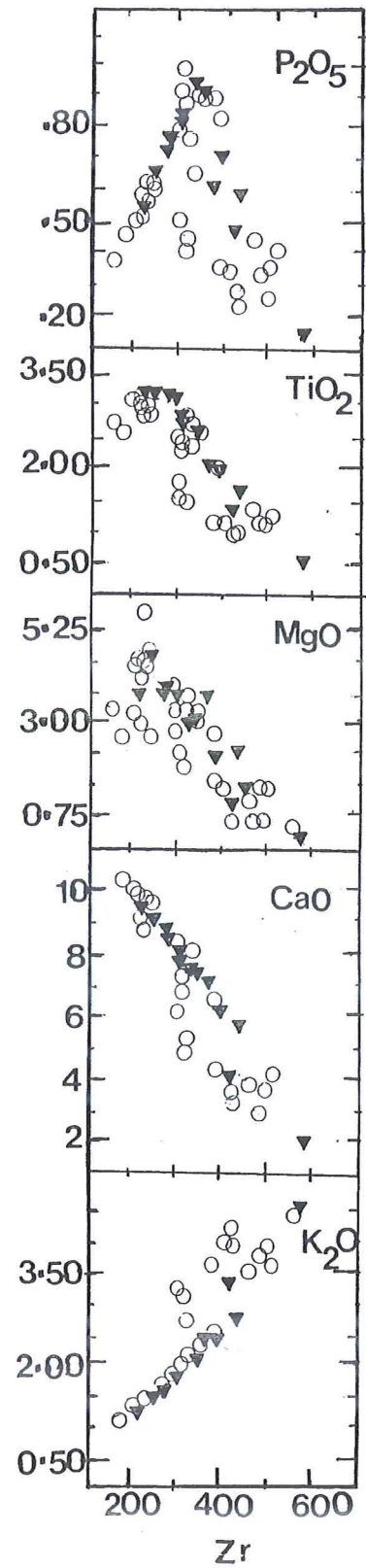


Fig. 4.7b Zr versus Wt. % oxides for extrusive rocks (main and late phase Lyttelton volcanics). Key as for Fig. 4.3.

#### 4.4 MAIN AND LATE PHASE (MT PLEASANT FORMATION) ROCKS GEOCHEMICAL DIFFERENCES

Some of the major and trace-element variation plots demonstrate two separate fractionation trends. These are the main phase trend and late phase (Mt Pleasant Formation) fractionation trend.

(i) *Major elements*:- Two fractionation trends are apparent in Lyttelton rocks as shown by CaO and  $K_2O$  versus  $SiO_2$  (Fig. 4.5b). Most of main phase Lyttelton volcanics have slightly higher CaO: $SiO_2$  ratios and lower  $K_2O$ : $SiO_2$  ratios at a given level of differentiation (Fig. 4.5ba), also main phase mafic rocks have lower  $Na_2O$ : $SiO_2$  ratios compared with late phase rocks (Mt Pleasant Formation).

(ii) *Trace elements*:- Two trends are observed in Lyttelton rocks on a plot of Rb versus Zr (Fig. 4.6b). Most of the main phase volcanics have relatively higher Rb:Zr ratios compared with late phase rocks. Most of the main phase rocks have relatively lower Sr:Zr and Ce:Zr ratios and higher Ba:Zr ratios (Figs. 4.6b) than late phase (Mt Pleasant Formation) rocks.

(iii) *Subsidiary fractionation trends identified in the Lyttelton volcanics*:-

The  $K_2O$  versus Zr, plot shows 3 weakly defined trends not seen on other plots (Figs 4.7b). This suggests different subsidiary trends with different  $K_2O$ :Zr ratios. Clearly the main phase has higher  $K_2O$ :Zr than the late phase but there is a transition from one to the other. This variation strongly suggests that  $K_2O$ :Zr of parental magmas changed through time. Either the mantle source is heterogenous with respect to  $K_2O$ :Zr or, if late stage volcanics represent slightly smaller percentages of partial melting, a mantle K-phase (phlogopite) becomes increasingly refractory holding back K and decreasing the  $K_2O$ :Zr ratio (Weaver pers. comm.).

The range of silica contents of late phase Lyttelton volcanics is larger (48 to 66 Wt. %), than the main phase rocks (48-64 Wt. %). Major oxides and trace-elements are fractionated within both phases at a given level of differentiation, there are identifiable separate trends for the main and late phase volcanics as discussed previously.



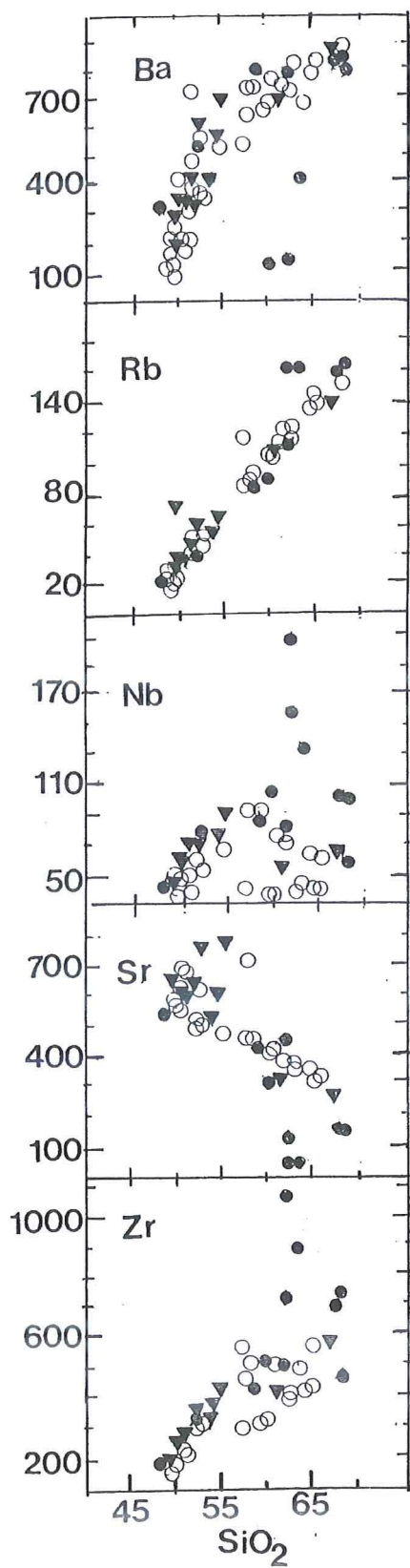


Fig. 4.8a  $\text{SiO}_2$  versus trace elements for extrusive and intrusive rocks. Key as for Fig. 4.3.

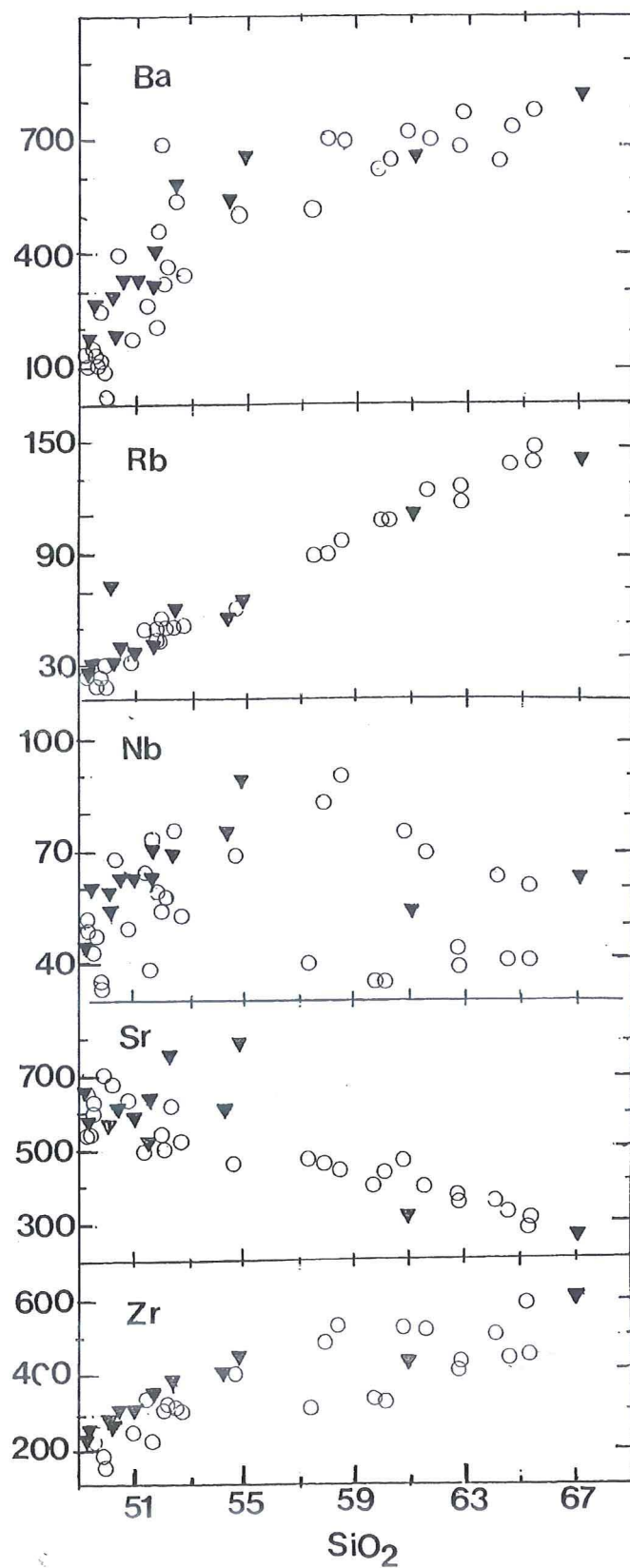


Fig. 4.8b  $\text{SiO}_2$  versus trace elements for extrusive rocks (main and late phase Lyttelton volcanics). Key as for Fig. 4.3.

#### 4.5 STRATIGRAPHIC VARIATION AND CORRELATION USING GEOCHEMICAL PARAMETERS

By correlating stratigraphy and major element geochemistry a chemical variation with time is observed. The measured stratigraphic section is from chapter 2. Selected oxides, elements and samples are plotted to assess the variation (Fig. 4.9).  $SiO_2$ ,  $K_2O$ ,  $CaO$ ,  $Rb$  and  $Zr$  were chosen for this purpose. Descriptions of the samples are listed in appendix IIa and appendix IIIb, and chemical data are in appendix Vb and VIb.

In Figure 4.9 the Wt. % of selected oxides and trace-elements in ppm have been plotted against elevation in metres. The plot can be compared directly with those of the mineral abundances in chapter 3. The chemical data show an overall stratigraphic change in composition. As shown in figure 4.9, the late phase mafic rocks have higher  $K_2O$  and low  $CaO$  than the main phase. The main phase (Mt Pleasant Formation) mafic rocks have lower  $Rb$  and  $Zr$  than late phase rocks (Fig. 4.9). This conclusion is also supported by chemical variation plots of major oxides and trace-elements (see section 4.3 and 4.4).

This variation in composition is directly related to magmatic processes and variation in mineral abundances. These overall trends reflect *cyclic differentiation* within the Lyttelton volcanics. The term *cyclic differentiation* describes the progressive change from basic to felsic composition. The return to a basic composition marks the beginning of a new cycle. Thus 2 major cycles are recognized and these correspond to the main and late phase Lyttelton volcanics. In terms of the range of compositions they are more or less similar with only slight variation in chemistry and mineralogy.

#### 4.6 INTRUSIVE ROCKS

As for the extrusives, the intrusives are subdivided in to main and late phase intrusives on the basis of chemical criteria. The assessment and/or designation of main and late phases for intrusives are mainly done by correlating the chemical trend of the late phase (younger) and the main phase (older) volcanics with the trends of intrusive rocks. For example, intrusives that fall on the late phase fractionation trends are assumed to be

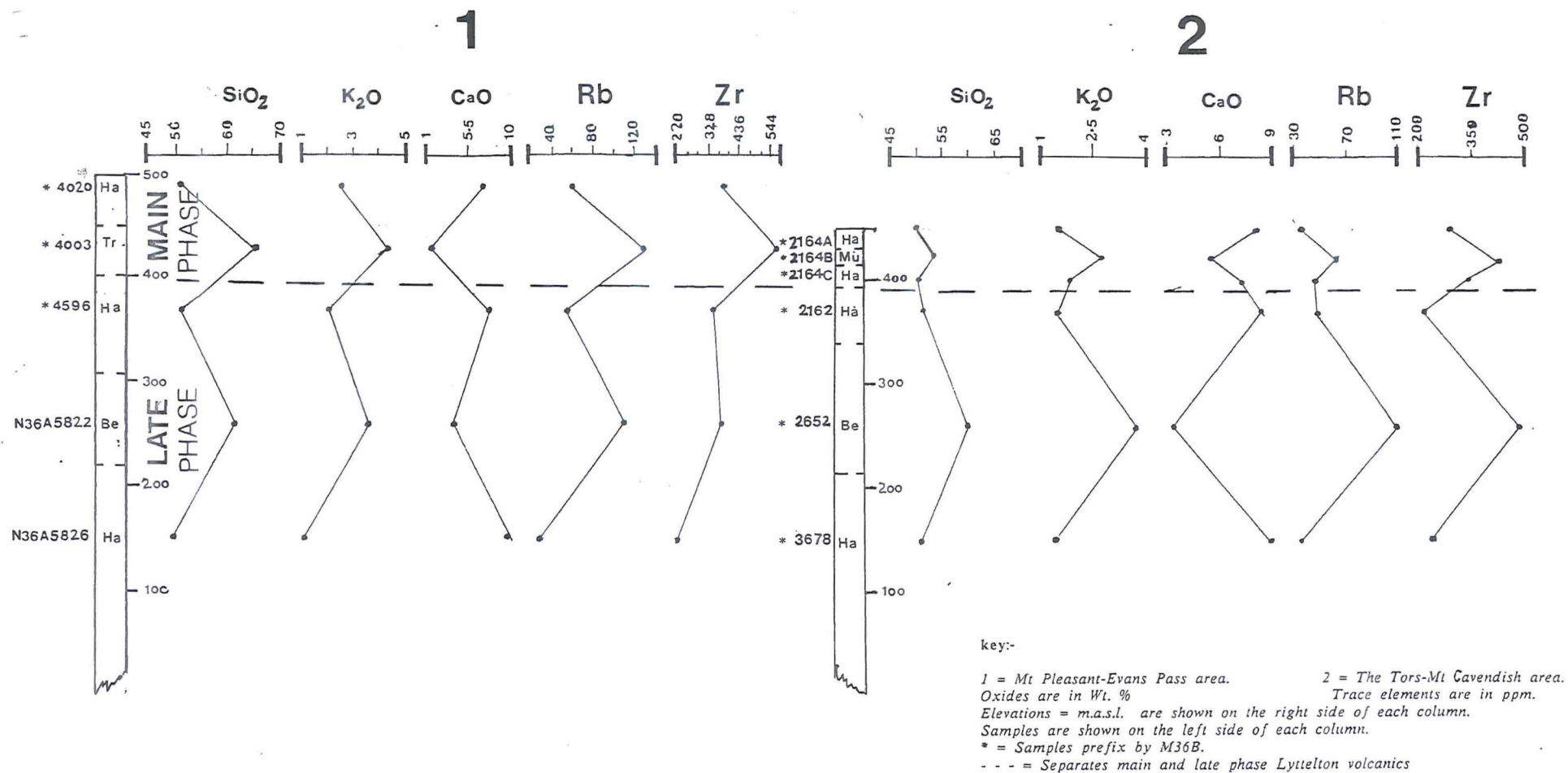


Fig. 4.9 Selected major and trace elements versus stratigraphic height.



late phase intrusives and vice versa. The age and classification of the intrusives is based on limited chemical and petrographic data together with their field relationships with extrusive rocks. Shelley (1988) concluded that Lyttelton dikes are derived from two centres of different age mainly on the basis of study of dike orientations. The two centres of dikes with different age probably correspond to main and late phase intrusives. Since most intrusives are not chemically studied more chemical data on intrusives together with dikes orientations conform the above conclusions.

*(i) Major and trace elements*

The chemical trends of the intrusive rocks are similar to the main and late phase trends for Lyttelton lavas and can be explained in terms of crystal fractionation. Generally, the compositional range and major element variation of the intrusive rocks are similar to the extrusive rocks. The intrusives cover a wide compositional range from nepheline normative to quartz normative (Fig. 4.3a). The most evolved intrusives (sills and some dikes) have lower  $\text{TiO}_2:\text{SiO}_2$  and  $\text{MgO}:\text{SiO}_2$  ratios but higher  $\text{K}_2\text{O}:\text{SiO}_2$  ratios consistent with their trachytic composition (Fig. 4.5a). These chemical trends indicate that the most evolved intrusive fractionation series have undergone considerable degrees of crystal fractionation by removal of olivine and clinopyroxene. Some dikes are enriched in MgO, this suggests these dikes are less evolved than the other rocks. The MgO-rich dikes (mafic dikes) are chemically distinct from mafic Lyttelton rocks. The petrography of these dikes support the conclusion that they are representative of the "Church volcanics" (Sewell, 1985).

*(ii) Main phase intrusives*

As shown on Figures 4.5a, 4.6a, 4.7a and 4.8a, variation diagrams of major and trace elements for extrusive and intrusive rocks enable classifications as younger (late) and older (main) intrusives to be made. Some intrusives have similar compositions to the main phase extrusives and are classified as older intrusives (main phase intrusives), on the basis of their chemistry. Trachyte dikes (samples M36B60 and M36B53) and sills (M36B56 and M36B5563) are examples of main phase (older) intrusives (Fig. 4.5a;  $\text{SiO}_2$  versus CaO or  $\text{K}_2\text{O}$ , Fig. 4.6a; Zr versus Nb, Fig. 4.7a, Zr versus  $\text{TiO}_2$  or  $\text{K}_2\text{O}$ , Fig. 4.8a;  $\text{SiO}_2$  versus Zr). Field relations (that is older intrusives intrude the

older extrusives) and petrography support this conclusion

(iii) Late phase intrusives

Intrusives that have similar chemistry to late phase extrusives are classified as late phase intrusives. Castle Rock trachyte intrusion (M36B6a), lava plug (M36B2151) and basaltic dikes (M36B24) are examples of younger intrusives (Fig. 4.5a;  $\text{SiO}_2$  versus  $\text{K}_2\text{O}$  or  $\text{CaO}$ , Fig. 4.6a; Zr versus Nb, Fig. 4.7a, Zr versus  $\text{TiO}_2$  or  $\text{K}_2\text{O}$  Fig. 4.8a;  $\text{SiO}_2$  versus Zr).

(iv) Summary

Based on field relations, limited geochemical data and petrography the following conclusions concerning the intrusives can be drawn :- (a) Dikes intruded the late and main phase extrusives throughout the history of the volcano. Based on the field relationships the sills could be main phase or late phase. (b) Dikes are related to the main and late phase extrusives and can be classified as younger and older dikes. (c) Most basaltic dikes are younger than intermediate dikes/felsic dikes. Examples of late phase basalt dikes which can be correlated with "Church volcanics" are M36B24, M36B4016, M36B4034 and M36B4036 which have similar petrographic characteristics (Chapter 3). (d) Intermediate and felsic dikes are mostly related to the main phase volcanics.

## 4.7 PETROGENESIS

### 4.7.1 General

This sub-chapter mainly assesses the petrogenetic processes which have produced the suite of Lyttelton rocks. The first part deals with the degree of silica saturations of mafic rocks expressed in terms of their normative mineralogy. This is followed by attempts to model petrogenetic processes. The last section in this chapter assesses the tectonic significance of Lyttelton lavas by means of geochemical discrimination diagrams.

#### 4.7.2 CIPW normative mineralogy

The CIPW mineralogy demonstrate the degree of *silica-saturation* in rocks. Representative analyses of samples having differentiation index (D.I) < 50% (basic rocks) and those that are considered to be fresh are plotted in Figure 4.10a. Figure 4.10b from Weaver and Sewell (1986) is presented to compare other Banks Peninsula rocks with the present results (Fig. 4.10a). The Figure has cotectic curves for 1 atmosphere and 9 kb (Thompson, 1982). The arrows show the directions of falling temperature on these cotectics (cotectics are for plagioclase, olivine, clinopyroxene and basic liquid).

Basic rocks of the main and late phase extrusive and intrusive rocks have compositions closer to the 1 atm. cotectic and equilibria at low pressure (Figs. 4.10a, 4.10b). On the CIPW normative diagram the other volcanic groups such as the Akaroa Group indicate deep crustal equilibration plotting closer to the 9 kb cotectic, whereas the Lyttelton lavas plot nearer the 1 atmosphere cotectic reflecting shallower crustal equilibration. Furthermore, the normative composition of Akaroa lava contrasts with those of Lyttelton in being mostly nepheline normative. The majority of Lyttelton mafic lavas are hypersthene normative, where as a few are quartz normative (Fig. 4.10b). The Lyttelton group hawaiites plot nearer the 1 atmosphere cotectic curve determined experimentally for basic liquids (Thomson et al 1983) than the hawaiites of the other volcanic groups (Fig 4.10b). The trend shown by Lyttelton lava suggests the magmas have equilibrated at a low pressure of 5 Kb. As shown on figure 4.10b the Lyttelton volcanics are chemically distinguishable from other volcanic groups on Banks Peninsula.

As shown on Fig. 4.10a Lyttelton mafic rocks are scattered between the Di-Ol and the Di - Hy joins. The majority of main phase samples plot close to the Di - Hy join. The composition of the Lyttelton rocks suggest they range from alkali to tholeiitic basalt. Mt Herbert and Akaroa samples are dominantly alkali basalt (Fig. 4.10b). Church and Stoddart samples are mostly basanite and have higher diopside/olivine ratio than other Banks Peninsula rocks (Fig 1. 10b).

The normative compositions of the main phase Lyttelton volcanics show slight contrast with those of the late phase in being mostly quartz and hypersthene normative, whereas the late phase volcanics are olivine or weakly nepheline



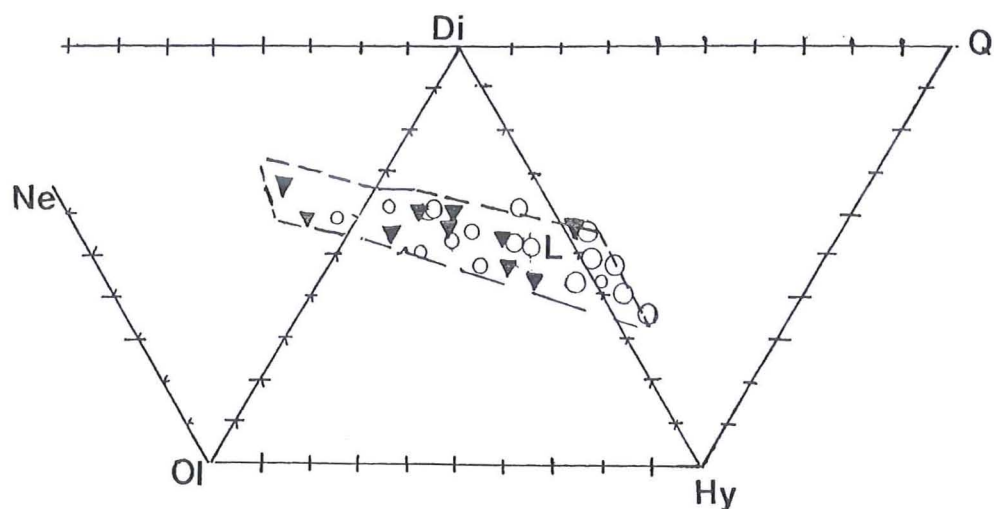


Fig. 4.10a Normative, Diopside - Olivine - Hypersthene - Nepheline - Quartz diagram for Lyttelton basic rocks. Key as for Fig. 4.3

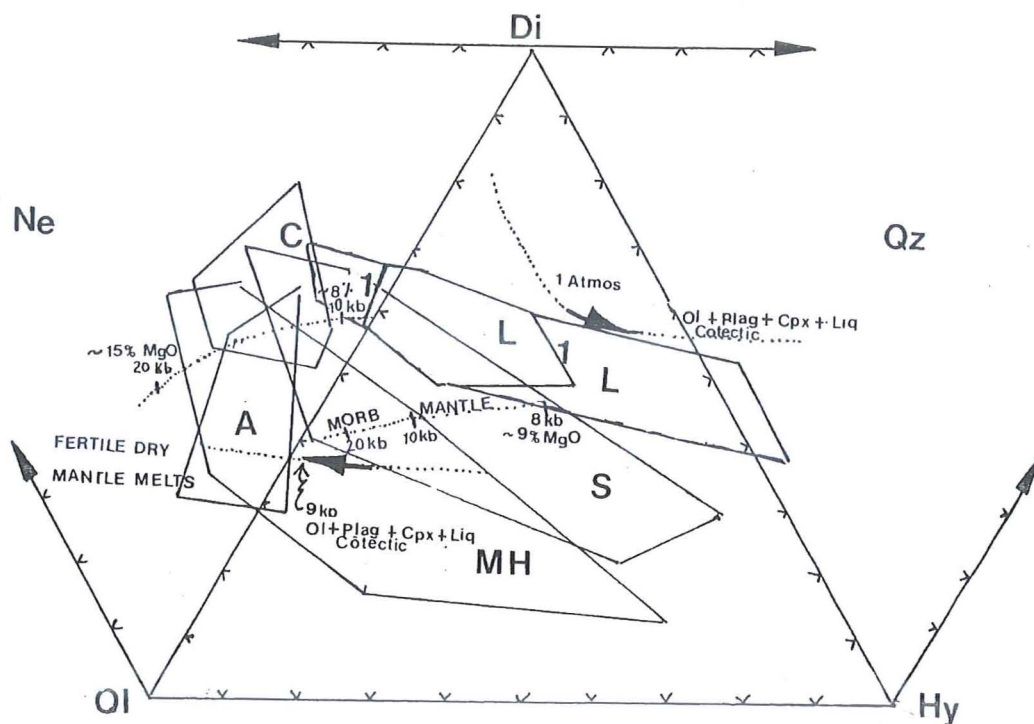


Fig. 4.10b Normative, Diopside - Olivine - Hypersthene - Nepheline - Quartz in Banks Peninsula basaltic rocks. Norm calculated with standard values of  $Fe_2O_3$  according to the scheme of Thompson et al (1972). Sample having Differentiation Index  $< 50\%$  have been used to define the fields for different volcanic groups: -L=Lyttelton, A=Akaroa, MH=Mount Herbert, C=Church and S=Stoddart. The loci of initial melts from fertile, anhydrous lherzolite and form depleted, MORB - source mantle are shown, together with the 1 atmosphere and 9 kb cotectic curves for basaltic liquids in equilibrium with olivine + plagioclase + clinopyroxene (Thompson et al 1983). Source of figure and data for other volcanic groups from Weaver and Sewell, 1986. Number 1 represents Lyttelton volcanic group boundary (Weaver and Sewell, 1986).

normative (see appendix V b). Thus, there appears to be a trend from transitional to more alkaline (undersaturated) composition with time.

#### 4.7.3 Modeling of petrogenetic processes

##### 4.7.3.1 *General.*

The objective of this section is to assess the major petrogenetic processes (such as crystal fractionation or crustal contamination) that produced the range of mafic to felsic compositions of the main and late phase (Mt Pleasant Formation) volcanics.

Any assessment of the composition of mantle parental magmas is difficult due to the absence of Mg-rich basic rocks in Lyttelton volcano. Major and trace element variations in Lyttelton rocks have been evaluated and interpreted in terms of crystal fractionation as the dominant influence on magmatic differentiation (see section 4.3).

##### 4.7.3.2 Crustal assimilation in modification of Lyttelton magmas

Chemical parameters known to be indicative of crustal contamination are high initial strontium isotopic ratios which usually correlate with high  $\text{SiO}_2$ , K/Na and low Nb/Th and Nd isotopic ratios. According to Weaver et al. (in press.) Sr isotopic ratios for most Lyttelton rocks are low (range 0.7030 -0.7035). Only in evolved rocks such as trachytes which have low Sr and are susceptible to crustal contamination are Sr ratios elevated above 0.7035 (Fig. 4.12). Many intermediate and evolved rocks have Sr ratios <0.7035 (see section 4.8.1 and Fig. 4.12). Isotopic data on Lyttelton lavas by Weaver et al. (in press.) suggest negligible or minor crustal contamination.

No isotopic data are available for Lyttelton lavas sampled in this study. Other authors have calculated that the main petrogenetic process in the Lyttelton magmas is crystal fractionation. This will be evaluated in the next section.

#### 4.7.3.3 Modelling of fractional crystallization:

The major element composition of proposed parent and daughter magmas and the composition of co-existing mineral phases was used to assess least squares models of crystal fractionation. The models are acceptable if the sum of the squares of the residuals is less than 2. It should be noted that such mass balance calculations are general only approximations. Their applicability may also be judged by checking whether the calculated proportions of mineral phases involved resemble those observed petrographically (chapter, 3).

Six models were used to assess the petrogenetic relationships within  $\text{SiO}_2$  range (49-66 wt. %) and the MgO range (0.1-5.0 wt%) for main and late phase Lyttelton samples. Of these, three models used for main phase and the other three were for late phase modelling. These models test the hypothesis that chemical variation in the lavas can be explained by crystal fractionation of the observed phenocryst phases.

Mineral chemistry (microprobe analyses) data were taken from Sewell (1985) and Deer et al. (1966). The minerals were selected on the basis of close petrographic and chemical similarity of rock types. Selected analyses of main and late phase rocks are given in appendix 7a and representative mineral analyses are presented in appendix 7b.

##### (a) Least squares models of crystal fractionation for main phase rocks:

*Model - 1* :- Relates a main phase Mg-rich hawaiiite (M36B4301) to a low-MgO evolved hawaiiite (N36A5826). This model show sum of squares of residuals (R) of 0.09 and involves crystal fractionation of olivine, clinopyroxene and plagioclase (Table 4.1).

*Model - 2* :- Assesses the relationship of the evolved hawaiiite (N36A5826) to the mugearite (N36A5824). This model has sum of squares of residuals of 0.45. This model indicates the importance of plagioclase and clinopyroxene fractionation in the evolution of mugearite.

*Model - 3* :- Demonstrates the relationship of mugearite (N36A5824) to benmoreite (N36A5822). This model shows an R value of 1.52 (Table 4.1). The largest residual error is  $\text{P}_2\text{O}_5$  and



Table 4.1 Results of least squares models of crystal fractionation for main phase Lyttelton rocks.

Model-1

WEIGHTED INPUT DATA:

	PARENT	Cpx.2	01.3	Pl.2	11.2	DAUGHTER
SI02	49.52	51.05	36.74	62.63	0.51	50.09
TI02	2.74	1.28	0.07	0.05	50.48	2.78
AL203	16.57	3.14	0.25	22.67	0.00	18.19
FEO	11.20	5.98	31.65	0.27	46.37	10.20
MNO	0.17	0.19	0.88	0.00	1.45	0.18
MGO	5.45	15.44	29.88	0.01	0.46	3.61
CAO	8.98	22.59	0.39	5.11	0.72	9.47
NA2O	3.53	0.33	0.04	8.40	0.00	3.73
K2O	1.26	0.01	0.10	0.86	0.00	1.19
P2O5	0.59	0.00	0.00	0.00	0.00	0.57

(PARENT-MINERALS-DAUGHTER)

PARENT: 4301  
DAUGHTER: 5826

SOL'N % CUMULATE

	4301	1.000
Cpx.2	-0.031	20.842
01.3	-0.065	42.960
Pl.2	-0.040	31.914
11.2	-0.006	4.284
5826	0.849	

R SQUARED = 0.093

	PARENT ANALYSIS	DAUGHTER ANALYSIS	DAUGHTER CALC	WEIGHTED RESID
SI02	49.52	50.09	50.13	-0.04
TI02	2.74	2.78	2.79	-0.01
AL203	16.57	18.19	18.11	0.08
FEO	11.20	10.20	10.19	0.01
MNO	0.17	0.18	0.11	0.07
MGO	5.45	3.61	3.57	0.04
CAO	8.98	9.47	9.42	0.05
NA2O	3.53	3.73	3.67	0.06
K2O	1.26	1.19	1.43	-0.24
P2O5	0.59	0.57	0.69	-0.13

Model-2

WEIGHTED INPUT DATA:

	PARENT	Cpx.1	01.1	Pl.1	11.1	DAUGHTER
SI02	50.09	48.88	39.26	50.01	0.10	54.78
TI02	2.78	1.74	0.02	0.09	26.40	1.98
AL203	18.19	4.16	0.06	30.28	1.51	16.36
FEO	10.20	7.62	14.86	0.48	68.50	9.89
MNO	0.18	0.10	0.19	0.00	0.75	0.15
MGO	3.61	14.58	45.37	0.11	2.57	2.59
CAO	9.47	22.49	0.23	14.70	0.05	6.18
NA2O	3.73	0.44	0.00	4.18	0.11	4.77
K2O	1.19	0.00	0.81	0.15	0.00	2.48
P2O5	0.57	0.00	0.00	0.00	0.00	0.81

(PARENT-MINERALS-DAUGHTER)

PARENT: 5826  
DAUGHTER: 5824

SOL'N % CUMULATE

	5826	1.000
Cpx.1	-0.084	19.708
01.1	-0.016	3.813
Pl.1	-0.276	64.429
11.1	-0.052	12.050
5824	0.572	

R SQUARED = 0.453

	PARENT ANALYSIS	DAUGHTER ANALYSIS	DAUGHTER CALC	WEIGHTED RESID
SI02	50.09	54.78	54.84	-0.06
TI02	2.78	1.98	2.16	-0.18
AL203	18.19	16.36	16.36	-0.00
FEO	10.20	9.89	9.82	0.07
MNO	0.18	0.15	0.23	-0.08
MGO	3.61	2.59	2.56	0.03
CAO	9.47	6.18	6.09	0.10
NA2O	3.73	4.77	4.41	0.37
K2O	1.19	2.48	2.00	0.48
P2O5	0.57	0.81	0.99	-0.18

Model - 3

WEIGHTED INPUT DATA:

	PARENT	Cpx.4	01.3	Pl.4	11.1	DAUGHTER
SI02	54.78	47.00	36.74	57.95	0.10	62.26
TI02	1.98	1.19	0.07	0.00	26.40	1.03
AL203	16.36	3.50	0.25	26.37	1.51	16.01
FEO	9.89	21.16	31.65	0.28	68.50	6.12
MNO	0.15	1.12	0.88	0.00	0.75	0.14
MGO	2.59	7.33	29.88	0.03	2.57	1.38
CAO	6.18	17.38	0.39	7.81	0.05	3.87
NA2O	4.77	1.05	0.04	6.46	0.11	4.92
K2O	2.48	0.27	0.10	1.10	0.00	3.67
P2O5	0.81	0.00	0.00	0.00	0.00	0.60

(PARENT-MINERALS-DAUGHTER)

PARENT: 5824  
DAUGHTER: 5822

SOL'N % CUMULATE

	5824	1.000
Cpx.4	-0.104	21.849
01.3	-0.030	6.350
Pl.4	-0.289	60.925
11.1	-0.052	10.876
5822	0.525	

R SQUARED = 1.516

	PARENT ANALYSIS	DAUGHTER ANALYSIS	DAUGHTER CALC	WEIGHTED RESID
SI02	54.78	62.26	62.11	0.14
TI02	1.98	1.03	0.98	0.05
AL203	16.36	16.01	16.11	-0.10
FEO	9.89	6.12	6.13	-0.01
MNO	0.15	0.14	-0.05	0.19
MGO	2.59	1.38	1.54	-0.16
CAO	6.18	3.87	4.13	-0.26
NA2O	4.77	4.92	5.41	-0.49
K2O	2.48	3.67	4.12	-0.45
P2O5	0.81	0.60	1.55	-0.95

Model - 1: Main phase Mg rich hawaiite to low-Mg (evolved) hawaiite.

Model - 2: Main phase evolved hawaiite to mugearite

Model - 3: Main phase mugearite to benmoreite.

clearly this would be significantly reduced if apatite were included in the model (see table 4.1 model -3).

Generally all main phase models have sum of squares of residuals less than 1.52 and give petrographically acceptable results. Therefore, the following *conclusions* are particularly important regarding magmatic differentiation by modelling crystal fractionation:- (i) The major element modelling demonstrates the importance of olivine, clinopyroxene and plagioclase crystallization in the fractionation of the Lyttelton magmas. (ii) The calculated proportions of mineral phases involved are in good agreement with petrographic observations (chapter, 3). Thus, the likely petrogenetic process which accounts for the range of compositions in the main phase Lyttelton rocks is *crystal fractionation*.

(b) Least squares models of crystal fractionation for late phase rocks (Mt Pleasant Formation):-

*Model - 1* :- Relates a late phase hawaiiite (M36B4021) to mugearite (N36B2164B). This model has the sum of squares of residuals of 0.70 (Table 4.2), and indicates plagioclase, clinopyroxene and olivine fractionation in the production of the mugearite.

*Model - 2* :- Assesses the relationship of the late phase mugearite (M36B2164B) to a low-silica trachyte dike (M36B53). This low-silica trachyte dike was chosen due to the absence of a suitable low-silica trachyte flow within the Late phase volcanics. The model gave a sum of squares of residuals of 2.28.

*Model - 3* :- Demonstrates the relationship of the low-silica trachyte dike (M36B53) to a silica-rich trachyte lava flow (M36B4003). The sum of squares of residuals for this model is 1.88.

Generally most of the Late phase volcanics have sums of squares of residuals less than 2, except model 2. The highest residuals in model-2 are for the alkalis and  $P_2O_5$ . The inclusion of apatite in the modelling would certainly reduce the R value. Alkali loss or migration may be responsible for the relatively poor fit.

Table 4.2 Results of least squares models of crystal fractionation for late phase Lyttelton rocks.

Model - 1

WEIGHTED INPUT DATA:

	PARENT	CPX.3	01.2	PI.3	11.1	DAUGHTER
S102	50.62	50.13	37.18	54.07	0.10	54.97
T102	2.76	1.09	0.04	0.11	26.40	1.64
AL203	16.31	2.91	0.06	28.20	1.51	18.39
FEO	11.93	9.93	26.82	0.54	68.50	8.21
MNO	0.22	0.46	0.48	0.00	0.75	0.15
MGO	3.40	12.32	33.16	0.03	2.57	2.22
CAO	7.77	22.35	0.23	11.85	0.05	5.45
NA2O	4.49	0.79	0.02	4.91	0.11	5.71
K2O	1.68	0.00	0.00	0.29	0.00	2.69
P2O5	0.80	0.00	0.00	0.00	0.00	0.57

(PARENT-MINERALS=DAUGHTER)

PARENT: 4021  
DAUGHTER: 2164B

	SOL'N	% CUMULATE
4021	1.000	
CPX.3	-0.120	40.462
01.2	-0.008	2.831
PI.3	-0.103	34.491
11.1	-0.066	22.216
2164B	0.702	

R SQUARED = 0.702

	PARENT ANALYSIS	DAUGHTER ANALYSIS	DAUGHTER CALC	WEIGHTED RESID
S102	50.62	54.97	54.97	-0.00
T102	2.76	1.64	1.23	0.41
AL203	16.31	18.39	18.41	-0.02
FEO	11.93	8.21	8.37	-0.16
MNO	0.22	0.15	0.16	-0.01
MGO	3.40	2.22	2.08	0.14
CAO	7.77	5.45	5.47	-0.03
NA2O	4.49	5.71	5.52	0.19
K2O	1.68	2.69	2.35	0.34
P2O5	0.80	0.57	1.14	-0.58

Model - 2

WEIGHTED INPUT DATA:

	PARENT	CPX.4	01.4	PI.4	11.1	DAUGHTER
S102	54.97	47.00	34.43	57.95	0.10	61.71
T102	1.64	1.19	0.43	0.00	26.40	1.15
AL203	18.39	3.50	0.92	26.37	1.51	18.28
FEO	8.21	21.16	42.16	0.28	68.50	4.11
MNO	0.15	1.12	0.69	0.00	0.75	0.08
MGO	2.22	7.33	20.55	0.03	2.57	0.77
CAO	5.45	17.38	0.82	7.81	0.05	4.04
NA2O	5.71	1.05	0.00	6.46	0.11	5.68
K2O	2.69	0.27	0.00	1.10	0.00	3.85
P2O5	0.57	0.00	0.00	0.00	0.00	0.32

(PARENT-MINERALS=DAUGHTER)

PARENT: 2164B  
DAUGHTER: 53

	SOL'N	% CUMULATE
2164B	1.000	
CPX.4	-0.033	7.425
01.4	-0.063	13.887
PI.4	-0.317	70.178
11.1	-0.038	8.510
53	0.549	

R SQUARED = 2.276

	PARENT ANALYSIS	DAUGHTER ANALYSIS	DAUGHTER CALC	WEIGHTED RESID
S102	54.97	61.71	61.48	0.23
T102	1.64	1.15	1.07	0.07
AL203	18.39	18.28	18.39	-0.11
FEO	8.21	4.11	4.13	-0.01
MNO	0.15	0.08	0.08	-0.00
MGO	2.22	0.77	1.12	-0.35
CAO	5.45	4.04	4.42	-0.38
NA2O	5.71	5.68	6.77	-1.09
K2O	2.69	3.85	4.32	-0.48
P2O5	0.57	0.32	1.05	-0.73

Model-3

WEIGHTED INPUT DATA:

	PARENT	CPX.4	PI.4	11.2	DAUGHTER
S102	61.71	47.00	57.95	0.51	67.19
T102	1.15	1.19	0.00	50.48	0.49
AL203	18.28	3.50	26.37	0.00	17.04
FEO	4.11	21.16	0.28	46.37	3.70
MNO	0.08	1.12	0.00	1.45	0.03
MGO	0.77	7.33	0.03	0.46	0.11
CAO	4.04	17.38	7.81	0.72	1.69
NA2O	5.68	1.05	6.46	0.00	5.25
K2O	3.85	0.27	1.10	0.00	4.37
P2O5	0.32	0.00	0.00	0.00	0.12

(PARENT-MINERALS=DAUGHTER)

PARENT: 53  
DAUGHTER: 4003

	SOL'N	% CUMULATE
53	1.000	
CPX.4	-0.045	14.374
PI.4	-0.254	80.996
11.2	-0.015	4.630
4003	0.686	

R SQUARED = 1.876

	PARENT ANALYSIS	DAUGHTER ANALYSIS	DAUGHTER CALC	WEIGHTED RESID
S102	61.71	67.19	67.02	0.17
T102	1.15	0.49	0.55	-0.06
AL203	18.28	17.04	17.13	-0.09
FEO	4.11	3.70	3.63	0.07
MNO	0.08	0.03	0.01	0.02
MGO	0.77	0.11	0.65	-0.53
CAO	4.04	1.69	1.94	-0.25
NA2O	5.68	5.25	5.96	-0.72
K2O	3.85	4.37	5.29	-0.92
P2O5	0.32	0.12	0.48	-0.36

Model-1 Late phase hawaiite to mugearite.

Model-2 Late phase mugearite to low-silica trachyte.

Model-3 low-Silica trachyte to silica-rich trachyte.



(c) Summary and conclusion

Least Squares modelling of crystal fractionation successfully accounts for the chemical variations in both the main and late phases of Lyttelton volcanics.

The main phase models give better results (lower R values) than the late phase models (Mt Pleasant Formation). Mass balance calculations for some models gave relatively higher R values particularly for the intermediate and felsic rocks of late phase models. This is probably caused by one of the following reasons: (a) The mineral analyses used are not from Lyttelton rocks, all mineral microprobe analyses were obtained from other sources (Sewell, 1985 and Dear et al. 1966), because no mineral data on Lyttelton rocks were available. (b) The effect of weathering and alteration in rocks can also affect the modelling. (c) Largest errors are observed mostly for alkalis, (Tables 4.1, 4.2), and this may be due to losses in alkalis. (d) Apatite is not included in the models. Nevertheless, most models of both phases suggest crystal fractionation of the observed phenocryst phases and are petrographically acceptable. In *conclusion* the major petrogenetic process, that produced the range of mafic to felsic compositions of the late and main phase volcanics is *crystal fractionation* rather than crustal contamination or crustal fusion (see later discussion).

4.7.4 Tectonic implications

Discrimination diagrams based upon incompatible and geochemically immobile elements have been used to determine the tectonomagmatic environment of basaltic rocks. *Zr*, *Ti*, *Y* and *Nb* contents in mafic rocks from different tectonic setting have been used to construct ternary plots (Figs. 4.11a, 4.11b) in which tectonic environments can be identified. Lyttelton basic rocks are classified using one of the  $Zr - Ti/100 - 3*Y$  ternary plot (Fig. 4.11a) developed by Pearce and Cann (1973) and the new discrimination diagram, the  $Zr/4 - 2 Nb - Y$  ternary plot (Fig. 4.11b) of Meschede (1986).

Pearce and Cann (1973) tectonic discrimination diagram (Fig. 4.11a) assigns Lyttelton mafic rocks to the field of *within plate magma type* (i.e Ocean Island or continental basalt). But this classification does not discriminate between Oceanic Island or continental basalt type. According to the Meschede (1986) classification scheme, the mafic Lyttelton volcanics are

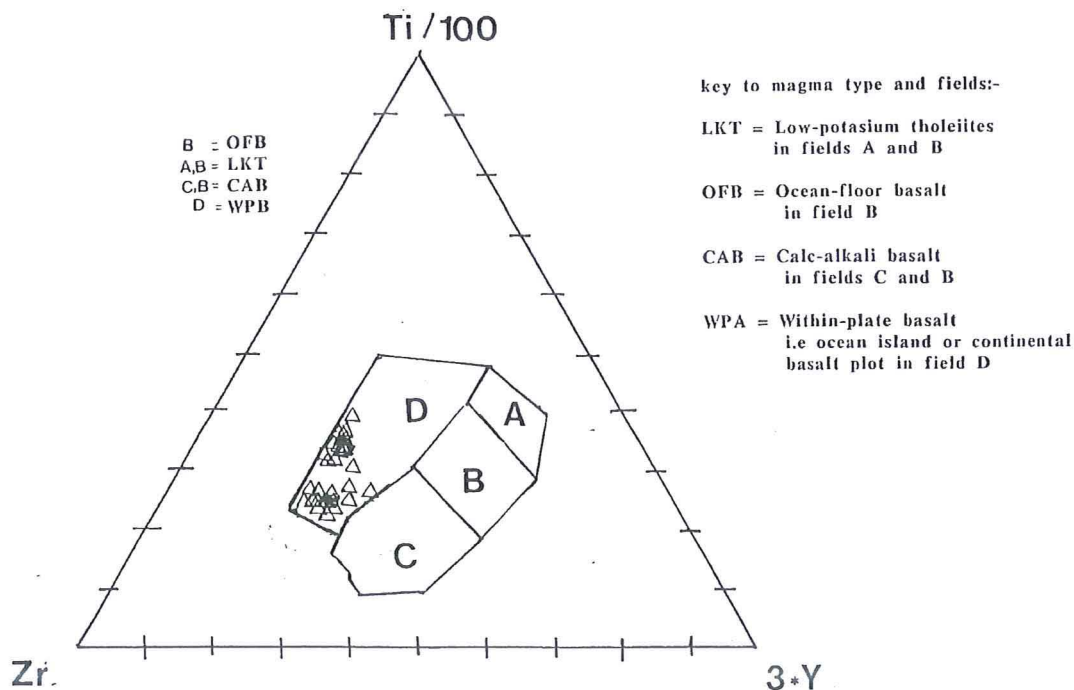


Fig. 4.11a Tectonic discrimination diagram using Ti, Zr and Y for Lyttelton basic rocks. After Pearce and Cann, 1973.

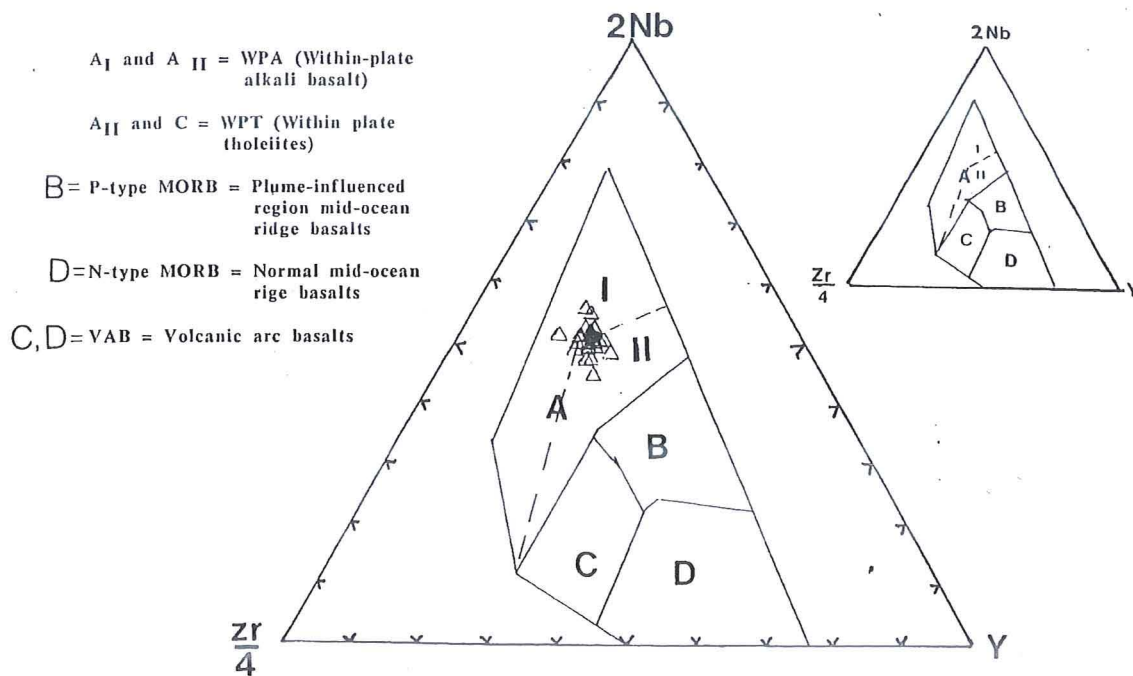


Fig. 4.11b Tectonic discrimination diagram using Nb, Zr and Y for Lyttelton basic rocks. After Meschede, 1986.

*within plate alkali basalt* (Fig. 4.11b). Both methods are effective in determining the tectonic setting of Lyttelton basic rocks.

In *conclusion*, the Meschede (1986) classification is a better discriminator for Lyttelton rocks than the Pearce and Cann (1973) diagram, and the basic Lyttelton rocks are of *within plate continental alkali basalts* affinity.

## 4.8 DISCUSSION

### 4.8.1 General

The discussion below summarizes isotope geochemistry which supports conclusions made in earlier sections of this chapter and compares Lyttelton rocks with other Banks Peninsula rocks. The last part of this section is summary and conclusion of the Lyttelton volcanics.

### 4.8.2 Isotope Geochemistry

All Banks Peninsula rocks have initial  $^{87}\text{Sr}/^{86}\text{Sr}$  Sr values greater than 0.7029 (Weaver et al in press. and Fig. 3.13). The mafic rocks of Lyttelton volcano have similar isotopic ratios (0.7029-0.7032) to Diamond Harbour and Mt Herbert rocks (range up to 0.7038). Felsic rocks (trachyte) of Lyttelton volcano have higher average  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (up to 0.7052) compared with intermediate and mafic rocks (initial  $^{87}\text{Sr}/^{86}\text{Sr}$  Sr value less than 0.7032). This suggests most mafic rocks are mantle-derived magmas which have not been contaminated significantly by continental crust. The higher initial  $^{87}\text{Sr}/^{86}\text{Sr}$  values in felsic rocks reflects the susceptibility of low-Sr magmas to upper-crustal contamination (Weaver et al. in press.).

As discussed in earlier sections (see section 4.2.2) the relationship between the subalkaline Governors Bay volcanics and transitional Lyttelton mafic rock is still uncertain. Weaver et al. in press. suggest that the transitional Lyttelton mafic magmas become contaminated on their way through continental crust. Lyttelton felsic rocks are derived by crystal fractionation from their intermediate and mafic members based on XRF chemical data, but the isotopic data suggest significant *crustal contamination* in the genesis of the felsic Lyttelton rocks. As shown on Figure 4.13 the felsic rocks of Lyttelton rocks extend outside the mantle array and this indicates interaction with



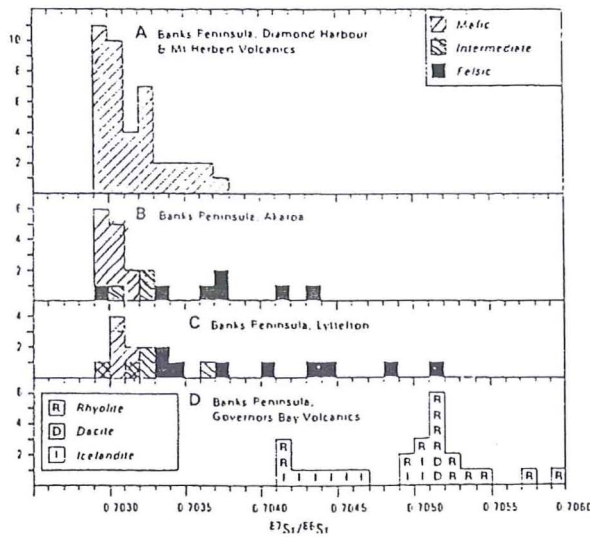


Fig. 4.12 Histograms of initial  $^{87}\text{Sr}/^{86}\text{Sr}$  values for Banks Peninsula. Data source from (Weaver et al. in press.).

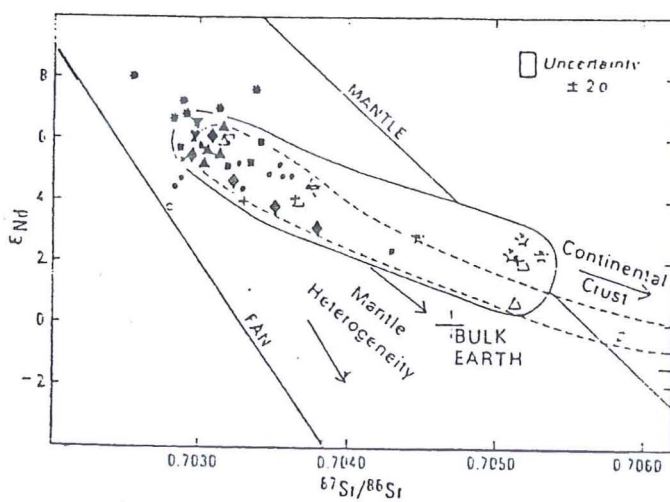


Fig. 4.13 Nd- ( $\epsilon_{\text{Nd}}$  units) and initial Sr-isotopic relationships for New Zealand intraplate volcanic rocks. Closed symbols represent mafic rocks and open symbols intermediate to felsic ones. The boundaries of the mantle fan are taken from Hawkesworth et al. (1987). Data sources are Coombs et al. (1986), McDonough et al. (1986), and Weaver, Pankhurst, Gamble, and Smith (unpublished data). Felsic rocks of the Governors Bay and Lyttelton groups extend outside the array, and are indicative of significant interaction with continental crust (solid field boundary). Samples of the Auckland Islands extend to even more extreme compositions (dashed field boundary). Data from (Weaver et al. in press.).

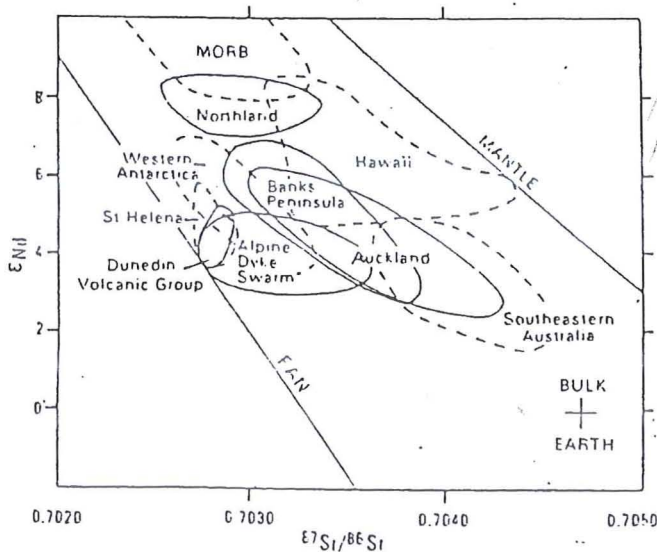


Fig. 4.14 Generalised Nd- and Sr-isotopic compositional fields for New Zealand intraplate and other volcanic areas. New Zealand data sources are Coombs et al. (1986), Cooper (1986), Barreiro & Cooper (1987), and Smith and Weaver (unpublished data). Other data sources are: Western Antarctica — Futa & LeMasurier (1983); St Helena — White & Hofmann (1982); Cohen & O'Nions (1982a); southeastern Australia — McDonough et al. (1985); Hawaii and MORB — Hawkesworth et al. (1987). Data from (Weaver et al. in press.).

continental crust.

*Combined assimilation fractional - crystallisation* (AFC) is the more acceptable petrogenetic process for all mafic to felsic suites (Fig. 4.13). The  $\epsilon_{\text{ND}} - ^{87}\text{Sr}/^{86}\text{Sr}$  covariation (Fig. 4.13) demonstrates that all felsic rocks (Lyttelton and Akaroa trachytes and Governors Bay rhyolites) trend away from the mantle fan in a direction consistent with crustal contamination. The basic rocks in figure 4.13 have positive  $\epsilon_{\text{ND}}$  values and initial  $^{87}\text{Sr}/^{86}\text{Sr}$  values less than that of bulk earth. This indicates a mantle source that has time-integrated depletion in large - Ion - Lithophile elements and light REE (Weaver et al. in press.).

As shown on Figure 4.14 mafic volcanic rocks in New Zealand have time-integrated light-REE depleted and low Rb/Sr mantle source characteristics. The light-REE enriched composition of mafic magmas and their depleted isotopic data correspond to mantle source region that has undergone relatively recent episodes of metasomatism and incompatible - element enrichment (Weaver et al. in press.). Furthermore differences in isotopic composition as shown in Fig. 4.14 are evidence for some mantle heterogeneity beneath the New Zealand region (Weaver et al. in press.).

#### 4.8.3 Comparison of Lyttelton lavas with other Banks Peninsula lavas

The main lineage of Lyttelton rocks is a sodic series from alkali and transitional basalt to high silica trachyte lava flows. The presence of high silica trachytes (part of the late phase) is one of the features which distinguishes the Lyttelton suite from the Akaroa suite. These silica rich (66 Wt. %) trachyte flows have higher silica than the dikes. However, the majority of mafic and intermediate Lyttelton rocks are chemically and mineralogically similar to Akaroa. Both are different from Diamond Harbour rocks, which consist mainly of basanites and represent the youngest rocks on Banks Peninsula (Weaver et al. in press.).

The Lyttelton Volcanics Group is chemically distinguished from other volcanic groups in Banks Peninsula (Akaroa and Mt Herbert) in having (i) a high range in abundance of  $\text{SiO}_2$  (46-66 wt. %) and (ii) high abundances of incompatible trace element in felsic rocks. These characteristics indicate that the Lyttelton Volcanic Group is more strongly differentiated than the other

groups on Banks Peninsula. (iii) Lyttelton mafic rocks are transitional in geochemical affinity and they straddle alkaline and transitional tholeiite rock compositions.

#### 4.8.4 Summary and conclusion

The Lyttelton rocks are *alkaline and subalkaline compositions and transitional in geochemical affinity*. Most mafic Lyttelton rocks are alkaline rocks of a sodic series and members of the alkali olivine basalt - hawaiiite - mugearite - benmoreite - trachyte association and this designation is consistent with mineralogy. For example, petrographically, the main and late phase volcanics contain clinopyroxene (titaniferous clinopyroxene) and olivine phenocrysts. In addition, Lyttelton rocks show no trend of Fe - enrichment, characteristic of true tholeiitic suites. Some Lyttelton intermediate and felsic rocks are related to a subalkaline potassic series (for example, trachyandesite, dacite compositions of the Governors Bay series) and they could be called dacite, but they are classified as trachyte in this study. The reason for this is their mineralogy such as the presence of clinopyroxene and abundance of olivine, and absence of orthopyroxene and pigeonite.

Lyttelton volcanics are characterized by mafic to felsic lavas and sub volcanic intrusions of mildly under saturated to transitional compositions. Hawaiiite lava flows predominate in the main and late phase Lyttelton lava successions. Benmoreite is the second most abundant rock type in main phase lava flows but high silica trachyte lava flow are second in abundance in the late phase volcanics after hawaiiite. Mugearite lava compositions are the least abundant in both phases.

The predominance of hawaiiite in both phases suggests fractionation of more primitive mantle-derived basaltic magma during the rise through continental crust and within the crustal magma chamber. In addition, the absence of mantle derived xenoliths from the Banks Peninsula volcanoes and their restriction to small monogenetic vents of strongly alkaline composition (Weaver et al. in press.) are supportive evidence for the above conclusion.

The distinguishing features between the main and late phase Lyttelton volcanics on the basis of geochemistry are:- (i) Most late phase (Mt Pleasant Formation) rocks have lower Rb:Zr ratios and slightly higher Nb:Zr ratios.



(ii) Late phase volcanics (Mt Pleasant Formation) have slightly higher  $K_2O:Zr$  ratios than the main phase. (iii) The less evolved late phase volcanics have higher  $Zr:SiO_2$  ratios than the main phase. (iv) The late phase volcanics have slightly lower  $CaO:SiO_2$  ratios and higher  $K_2O:SiO_2$  ratios. The distinguishing features in terms of normative mineralogy between the main and late phase Lyttelton volcanoes are:- (i) the main phase mafic rocks are mostly quartz and hypersthene normative and rarely olivine normative, but the late phase (Mt Pleasant Formation) mafic lava flows are weakly nepheline and olivine normative. (ii) The intermediate and felsic rocks of the main Lyttelton phase are hypersthene and quartz normative, but the late phase intermediate rocks are olivine normative. There are no nepheline normative trachyte and benmoreite lava flows in either phase however, intrusions such as Castle Rock trachyte are nepheline normative. Felsic lava flows and intrusive (dike and sills) are quartz or hypersthene normative. Some mafic dikes are olivine normative.

The geochemistry of the late and main phase *mafic to intermediate rocks* are successfully reproduced by of crystal fractionation modelling (see section 4.7.3.3) and confirm that the main petrogenetic process in the evolution of Lyttelton rocks is *fractionation* of the observed phenocryst phases. The *isotopic* and *trace element* compositions of Lyttelton mafic rocks suggest that *crustal contamination has been minimal*.

Chemical variation in the *intermediate and felsic rocks* again suggests that the main petrogenetic process is *crystal fractionation*. However, the fact that felsic and intermediate rocks have slightly higher initial  $^{87}Sr/^{86}Sr$  values (Weaver et. al in press.) suggests that a limited amount of crustal contamination is involved and that combined assimilation-crystal-fractionation models are the most realistic.

Mafic volcanic rocks of the North - Eastern sector of Lyttelton volcano are "*within plate*" *alkali basalt*, judged by trace-element discrimination diagrams. This is consistent with position of Banks Peninsula situated on *continental crust* at the western end of the Chatham Rise and distant from geologically active or recently active plate boundaries.

## CHAPTER 5

### GEOLOGICAL HISTORY AND CONCLUSIONS

In this chapter the geologic history of the Lyttelton volcano is summarized and the results of this study are presented as a number of conclusions.

#### 5.1 VOLCANIC AND GEOLOGICAL HISTORY

Lyttelton volcano is constructed on basement rock, consisting of Triassic sandstones, mudstones and cherts (Torlesse Group), Cretaceous Volcanics (McQueens andesite and rhyolite), early to middle Tertiary sandstones (Charteris Bay sandstone) and middle Miocene Governors Bay Volcanics (see section 1.7.1)

The Lyttelton volcano was active between 11-10 Ma (Stipp and McDougal, 1968). Over a period of about 2 million years, Lyttelton lavas built up the symmetrical cone which probably reached a height of about 1500 metres a.s.l. Then the Lyttelton cone was deeply dissected by erosion. The lava cone was breached by erosion along radial stream channels in the three places. Gebbies Pass where basement is exposed, Mt Herbert-Mt Bradley sector which is now filled by Mt Herbert Group lavas, and along the line of the Present Lyttelton Harbour. Erosion exposed lava necks and intrusives (dike and sills) down to the present height which is approximately 500 metres a.s.l. It is known that volcanoes may go through a number of geomorphological stages during the course of erosion and weathering:- These are, (i) gullied stage, (ii) residual stage (volcano dissected by large valleys) and (iii) skeletal stage (many intrusives bodies exposed as a result of deep erosion). Thus at present, the morphology and surface expression of the Lyttelton volcano is approaching the "skeleton stage".

The Lyttelton volcano is largely made up of the products of Hawaiian style activity (i.e represented by mafic flows erupted in the aa condition), with some Vulcanian style activity that is represented by felsic lava flows. In addition, Strombolian style activity, produced the lithic-crystal tuffs at local centres. Within the Lyttelton volcanic group two stratigraphically and petrologically distinct phases of volcanism are recognized. There is an angular discordance between these phases and this is the main reason for

division of the volcanics into two distinct phases, and here designated as the main and late phase (Mt Pleasant Formation) volcanics.

The main phase rocks flows are laterally persistent and may be correlate between different localities however, there is some local variation in the stratigraphy. The late phase volcanics are not laterally continuous largely as a result of erosion. Thus, although there are local variations in the stratigraphy of the different late phase lava sequences, there is sufficient justification to group them into single lithostratigraphic unit distinct from the main phase Lyttelton lava flows and here designated the *Mt Pleasant Formation*. The main phase Lyttelton volcanics consist of hawaiiite, mugearite and benmoreite lava flows. The late phase Lyttelton volcanics (Mt Pleasant Formation) comprises, hawaiiite, mugearite, benmoreite and trachyte and including pyroclastic rocks (lithic-crystal tuffs).

The main phase Lyttelton activity started with the extrusion of mafic lavas of basalt-hawaiiite composition. Following this, crystal fractionation within the magma chamber produced the more evolved intermediate rocks (mugearite). The magma evolved further by crystal fractionation and felsic rocks benmoreite were produced. It is thought the magma was extruded from an upper crustal reservoir in which most of the crystal fractionation occurred.

The late phase (Mt Pleasant Formation) volcanism probably started after erosion and lahar deposition and Strombolian eruptions from local centres. The magma which produced the main phase benmoreite, probably evolved further and eventually the chamber emptied by the extrusion of the late phase high-silica trachyte flow. Later, the magma chamber was replenished from the upper mantle and the next period of activity started with the eruption of hawaiiite, followed by mugearite and benmoreite flows. The late phase activity terminated by extruding hawaiiite lava flows.

Both phases represent successive eruptions and they range from mafic to felsic composition. The late phase (Mt Pleasant Formation) covers the same compositional range and is characterized by high silica trachyte. A change in lithology from dominantly mafic to felsic rocks may indicate a period of quiescence which permitted magma to differentiate.



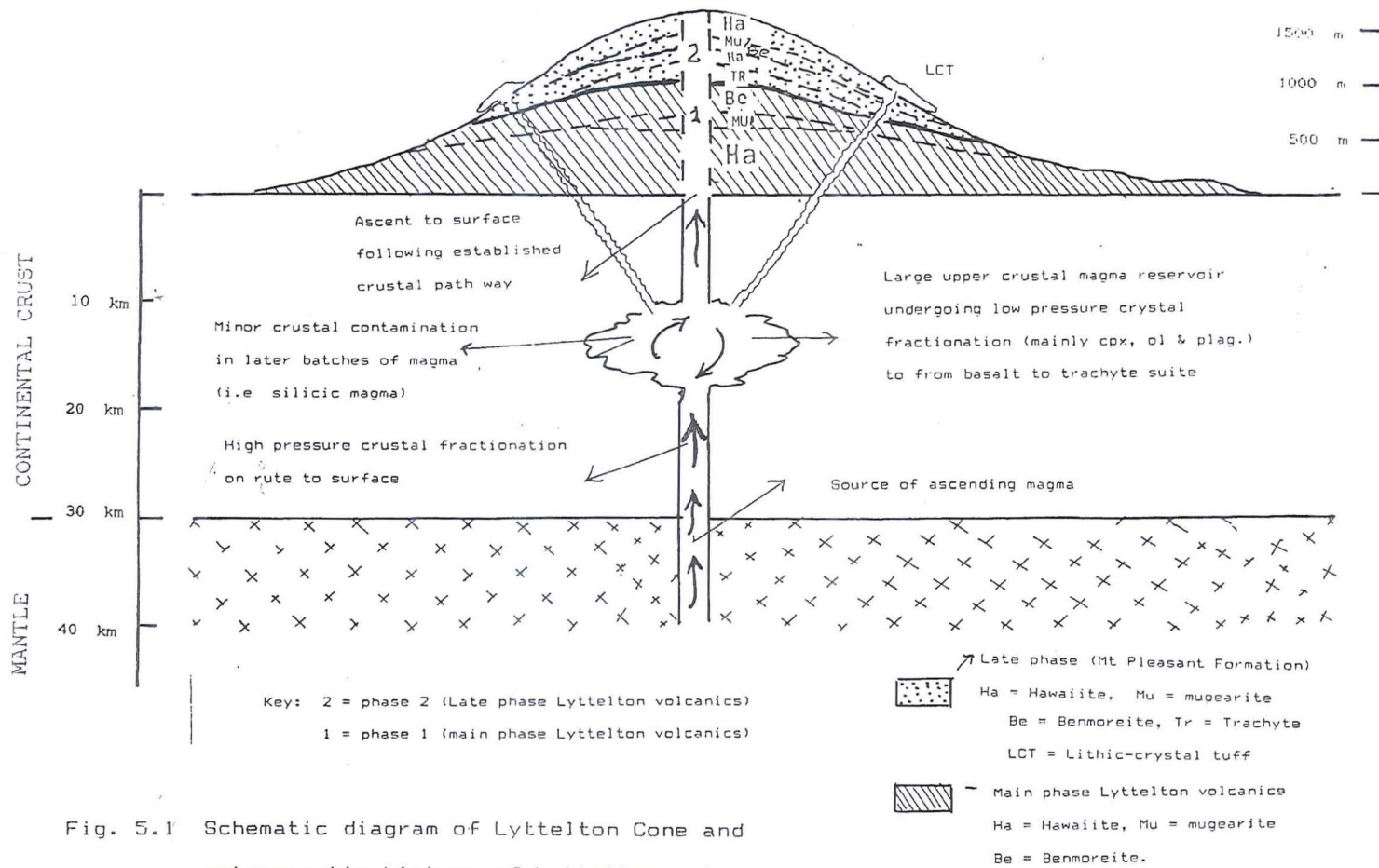


Fig. 5.1 Schematic diagram of Lyttelton Cone and petrogenetic history of Lyttelton volcano.

During and after the construction of the Lyttelton volcanic cone, basalt to trachyte radial dikes and trachyte sills were emplaced.

## 5.2 PETROGENESIS

The Lyttelton volcanics were probably derived from partial melting of a mantle source, which produced an alkaline basaltic magma. This magma rose into the upper crust beneath Lyttelton volcano where it underwent differentiation. Subsequent fractionation of the magma was dominated by low pressure crystal fractionation of olivine, clinopyroxene, plagioclase and some Ti-magnetite in upper crustal reservoir.

Generally, major element compositions reflect shallow crustal evolution by fractional crystallization from the basalt-trachyte suite (see chapter 4). There is isotopic evidence of minor but measurable crustal contamination in felsic Lyttelton rocks. The petrogenetic scheme described above is summarized in Figure 5.1.

The predominance of hawaiite in the Lyttelton volcano suggests fractionation of more primitive basaltic magma during its rise through continental crust.

## 5.3 RECOMMENDATIONS FOR FURTHER WORK.

This study provides a geological map of the area at a 1:10,000 scale and on this basis further work can be initiated in adjacent sector of the Lyttelton volcano. At present the absolute age differences between of the main and late phase volcanics are not known and geochronological data to establish absolute ages and to conform the stratigraphic groupings proposed here.

Isotopic and REE data together with mineral analyses are necessary in any detailed quantitative modelling of petrological evolution of the Lyttelton volcanics.

## 6. ACKNOWLEDGEMENTS

This work was financed by Geothermal Exploration Project, Ethiopian Institute of Geological Survey.

I would especially like to thank my principal supervisor Dr. S.D Weaver for initiating this project, for his continued encouragement and fruitful discussion. My thanks to my second advisor Prof. J.W Cole, Head of Geology Dept. for his helpful assistance throughout the course of my study. I would also like to thank Dr. D. Shelly for his useful discussion, especially in petrography, and Dr. R.J. Sewell and G.F Coates (New Zealand Geological Survey) for their valuable help and interest.

My gratitude goes to the staff of Geology Department for their collaboration and generous assistance. Special thanks are due to the technical staff of the Geology Department, University of Canterbury, for their valuable help and support during this study. Finally I wish to extend my sincere thanks to all people, who contributed their help towards this study.



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## APPENDIX I

FIELD METHODS

## [A] MAPS AND AERIAL PHOTOGRAPHS

Mapping was carried out using enlarged topographic maps and aerial photographs at a scale of 1:10,000. Published topographic maps of the study area include:-

1:50,000 NZMS 270 (sheet M36B and N36A).

1:25,000 NZMS 270 (sheet M36B).

Compilation of the base map was from the 1:10,000 field sheets, M36B6, M36B12 and N36A10. Aerial photographs used during field work are: Run SN2634: M/46-38, N/41-38, O/14-8, P/6-1, Q/5-1, R/3-1.

## [B] MAPPING AND SAMPLING

Mapping was carried out during the winter and spring of 1987. The area was mapped and sampled by dividing it into four blocks (Fig.1). Block A consists of volcanics exposed around the Tors area, block B includes the Mt Cavendish area, Block C comprises the largest portion of the field area and occupies an area around Mt.P easant, and Block D includes a number of scattered localities (Sumner, Taylors Mistake and the area east of Lyttelton Harbour).

Sampling of individual lava flows, intrusive and pyroclastic rocks was designed to recover the freshest possible specimens. Sampling was done at regular stratigraphic intervals. About 300 samples were collected for petrographic and chemical analysis. 200 samples were selected for thin section study, 75 for X-Ray fluorescence analysis. An Additional 29 thin sections and 15 X-Ray Fluorescence data were studied around The Tors and Castle Rock areas.

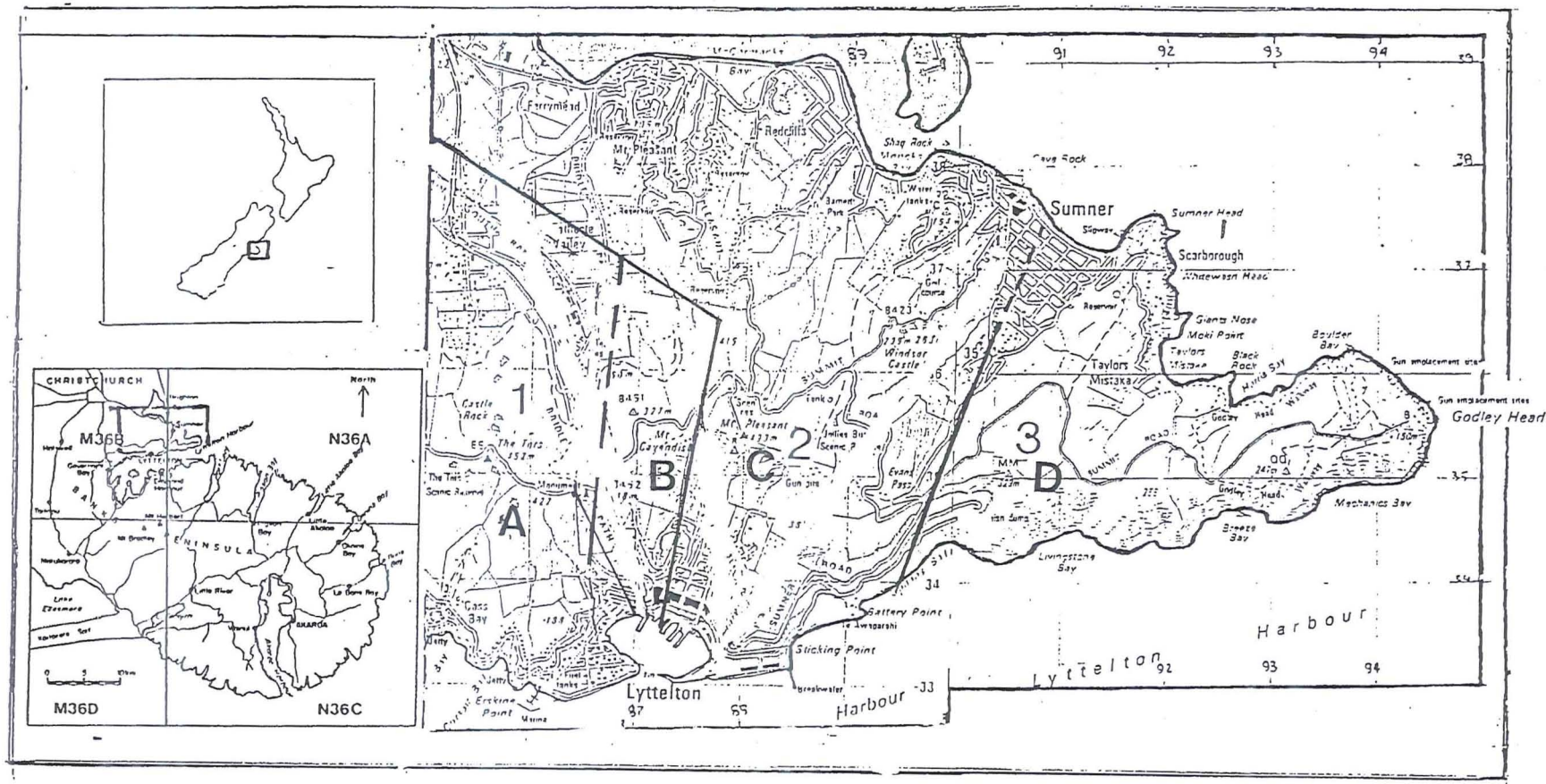


Fig. 1 Location map showing sampling, and simplified geological map presented in the thesis.

Key = Sample localities  
 A = The Tors  
 B = Mt Cavendish  
 C = Mt Pleasant  
 D = Scattered localities

Simplified geological maps:-  
 1 = The Tors-mt Cavendish area  
 2 = Mt Pleasant area  
 3 = East of Evans Pass

## APPENDIX II

SAMPLE LOCATIONS AND FIELD DESCRIPTIONS

This appendix contains the general information concerning the rock samples used in this thesis and the description of samples based on field observations.

Sample numbers are ordered numerically and are prefixed by 1:50,000 New Zealand Map Series (NZMS) 260 reference code for Banks Peninsula. The mapped area is on sheets M36B and N36A.

e.g sample number M36B2255

M36B = Reference code (sheet)

B = Quadrant

2255 = Sample number

Grid references are prefixed by the same code (M36 or N36).

Sample numbers between 2000-2999 refer to the Tors area (Block A), 3000-3999 refer to Mt Cavendish area (Block B), 4000-4999 refer to the Mt Pleasant area (Block C) and 5000-5999 refer to scattered localities (Block D and Fig.1).

Table II-A listing type of analyses performed on each sample, field descriptions and locations of sample.

*Abbreviations used for table II-A:-*

HTB = Heterolithic tuff breccia	XRF = X-Ray Fluorescence
INT = Intrusion	MP = Microprobe analyses
LP = Lava plug (neck)	+ = Data from S D Weaver
TS = Thin section	( ) = S D Weaver sample number

*Numbers :- 1=Sample, 2=Rock type, 3=Analysis, 4=exposure / Field description, 5=Locality, 6=Grid reference*



TABLE OF SAMPLE LOCATION AND FIELD DESCRIPTIONS

SAMPLE	TYPE	ANALYSIS	EXPOSURE/DESCRIPTION	LOCALITY	GRID REFERENCE
1	2	3	4	5	6
M36B2046A (M36B6a)	INT	TS	25 M THICK, COLUMNAR JOINTED, GREY GREEN, FRESH, FINE-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	CASTLE ROCK	M36/856354
M36B2046B (M36B62b)	INT	TS, XRF +	AS FOR M36B2046A	CASTLE ROCK	M36/856354
(M36B24)	INT	TS, XRF +	SAMPLE FROM TOP RIDGE	CASTLE ROCK	M36/856354
M36B2047	DIKE	TS	1.00 M WIDE, PLAGIOCLASE-PHYRIC LAVA	THE TORS	M36/856353
(M36B29)	DIKE	TS, XRF +	1.00 M WIDE, PYROXENE-PLAGIOCLASE-PHYRIC BASALT	CASTEL ROCK	M36/853353
M36B2048 (M36B29)	FLOW	TS	DARK GREY, MODERATELY WEATHERED, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/855351
M36B2049	LAHAR		1 M THICK, YELLOW-BROWN, STRUCTURELESS, CLAST-SUPPORTED POLYHICT BOULDER, BRECCIA AND CONGLOMERATE	THE TORS	M36/855352
M36B2051	FLOW	TS	DARK RED BROWN, WEATHERED, VESICULAR, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/856354
M36B2052 (M36B50)	DIKE	TS	8 M WIDE, DARK GREEN-GREY, WEATHERED, VESICULAR, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-PHYRIC BASALT	THE TORS	M36/857351
M36B2054	DIKE	TS, XRF +	2 M WIDE, DARK GREEN-GREY, WEATHERED, FINE-GRAINED, VESICULATED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/857351
M36B2055	DIKE	TS	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	BRIDLE PATH TRACK	M36/864349
M36B2056	FLOW	TS	DARK RED, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	BRIDLE PATH TRACK	M36/864348
M36B2059	FLOW	TS	DARK, FRESH, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	EAST OF THE TORS	M36/863348
M36B2060	DIKE	TS	1 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE PHYRIC BASALT	EAST OF THE TORS	M36/864348
M36B2061	DIKE	TS	1 M WIDE, GREY GREEN, FINE-GRAINED, PLAGIOCLASE PHYRIC TRACHYTE	EAST OF THE TORS	M36/863347
M36B2062	LAHAR		3 M THICK, ORANGE YELLOW-BROWN RED, STRUCTURELESS (UNBEDDED) MATRIX SUPPORTED BOULDER BRECCIA AND CONGLOMERATE WITH COARSE SAND AND PEBBLE SIZE LITHICS	EAST OF THE TORS	M36/862347
M36B2063 (M36B37)	DIKE	TS	0.50 M WIDE, DARK GREY WEATHERED, MEDIUM-GRAINED PLAGIOCLASE- PYROXENE-OLIVINE-PHYRIC BASALT	EAST OF THE TORS	M36/862347
M36B2066	DIKE	TS, XRF +	AS FOR M36B2052	THE TORS	M36/856351
M36B2067	DIKE	TS	AS FOR M36B2052	THE TORS	M36/856350
M36B2068	FLOW	TS	WEATHERED, DARK, MEDIUM-GRAINED, VESICULAR, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/855351
M36B2069	FLOW	TS	DARK GREY, FRESH, FINE-GRAINED, APHYRIC BASALT	THE TORS	M36/854349
M36B2071	FLOW	TS	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/854350
M36B2072	FLOW ?	TS, XRF	DARK, FRESH, FINE-GRAINED, PLAGIOCLASE-PHYRIC	THE TORS	M36/852351

1	2	3	4	5	6
(M36B33)	FLOW	TS, XRF +	BASALT		
M36B2073	FLOW	TS	DARK, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/853352
M36B2074	FLOW	TS	AS FOR M36B2073	THE TORS	M36/858351
M36B2076 (M36B56)	SILL	TS	15 M THICK, GREY GREEN, WEATHERED, FINE-GRAINED PLAGIOCLASE-PHYRIC TRACHYTE	THE TORS	M36/858353
M36B2078	SILL	TS, XRF +	5-8 M THICK, GREY GREEN, WEATHERED, MEDIUM-GRAINED PLAGIOCLASE-PHYRIC TRACHYTE	THE TORS	M36/857350
M36B2078B (M36B52)	DIKE	TS	5 M WIDE, GREY-GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	THE TORS	M36/858350
M36B2082 (M36B53)	DIKE	TS	2.50 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED PLAGIOCLASE-PYROXENE-PHYRIC BASALT	THE TORS	M36/859349
M36B2083	DIKE	TS, XRF +	DARK, FRESH, FINE-GRAINED, PLAGIOCLASE-APHYRIC BASALT	THE TORS	M36/862348
M36B2085	FLOW	TS	DARK, FRESH, FINE-GRAINED, PLAGIOCLASE-APHYRIC BASALT	THE TORS	M36/862348
M36B2087	DIKE	TS	0.50 M WIDE, DARK GREY, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/855351
M36B2087 (M36B31)	FLOW	TS, XRF +	GREY RED-BROWN, VESICULAR, WEATHERED COARSE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/853352
M36B2088	FLOW	TS	AS FOR M36B2087	THE TORS	M36/852351
M36B2089	FLOW	TS	DARK GREY, MODERATELY WEATHERED, COLUMNAR TO IREGULAR JOINTED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/864355
M36B2091	FLOW	TS, XRF	DARK RED-BROWN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	BRIDLE PATH TRACK	M36/862352
M362094	FLOW	TS	AS FOR M36B2091	BRIDLE PATH TRACK	M36/862350
M36B2096	DIKE	TS	0.80 M WIDE, DARK GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	EAST OF THE TORS	M36/862350
M36B2099	DIKE	TS	1.20 M WIDE, DARK GREY GREEN, FRESH, MEDIUM-GRAINED PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	BRIDLE PATH TRACK	M36/863349
M36B2100B	FLOW	TS	DARK GREY, MODERATELY WEATHERED, FINE-GRAINED, APHYRIC BASALT	EAST OF THE TORS	M36/864349
M36B2101	HTB	TS	1.00 M THICK, BROWN-YELLOW, STRUCTURELESS, UNSORTED, MODERATELY WELDED AND COMPACTED, HETEROLITIC-TUFF-BRECCIA	EAST OF THE TORS	M36/865349
M36B2102	FLOW	TS	DARK BROWN, MODERATELY WEATHERED, FINE-MEDIUM GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	EAST OF THE TORS	M36/863348
M36B2103A	FLOW	TS	AS FOR M36B2102	THE TORS	M36/864349
M36B2103B	FLOW	TS	AS FOR M36B2091	THE TORS	M36/864349
M36B2104	DIKE	TS	1 M WIDE, GREY-GREEN, WEATHERED, PLAGIOCLASE-PHYRIC TRACHYTE	EAST OF THE TORS	M36/857350
M36B2105A	FLOW	TS,	DARK, FRESH, COLUMNAR TO TABULAR JOINTED, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	EAST OF THE TORS	M36/862349
M36B2105B	FLOW	TS	AS FOR M36B2105A		M36/862349
M36B2107	DIKE	TS	AS FOR M36B2061	THE TORS	M36/862348
M36B2108	DIKE	TS	AS FOR M36B2104	THE TORS	M36/861350
M36B2115	DIKE	TS	AS FOR M36B2082	THE TORS	M36/860350
M36B2117A	FLOW	TS, XRF	2-10 M THICK, GREY DARK, COLUMNAR TO TABULAR	EAST OF	M36/861350

1	2	3	4	5	6	1	2	3	4	5	6
			JOINTED VESICULAR, MODERATELY WEATHERED, MEDIUM-GRAINED PLAGIOCLASE-PHYRIC BASALT	THE TORS					FRESH, DARK GREY, FINE-GRAINED, APHYRIC BASALT (AS FOR M36B2069)		
M36B2117B	FLOW	TS	AS FOR M36B2117A	THE TORS	M36B/861350	M36B2165C	FLOW	TS	AS FOR M36B2071	THE TORS	M36/854349
M36B2118	DIKE		3-5 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	EAST OF THE TORS	M36/861350	M36B2166	FLOW	TS	10 M THICK, MODERATELY COLUMNAR TO TABULAR JOINTED, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT (AS FOR M36B2162)	THE TORS	M36/852346
M36B2124	DIKE		AS FOR M36B2060	THE TORS	M36/863347	M36B2648	FLOW		GREY DARK-BROWN, VESICULAR, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/861342
M36B2126	DIKE		AS FOR M36B2118	THE TORS	M36/863346	M36B2652	FLOW	TS, XRF	MODERATELY TABULAR TO KNOBBLY JOINTED, DARK YELLOW-BROWN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	N-W OF LYTTTELTON HARBOUR	M36/862341
M36B2133	DIKE		AS FOR M36B2082	THE TORS	M36/860347	M36B2658	DIKE		3 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	NORTH OF LYTTTELTON	M36/862341
M36B2139	FLOW	TS	3 M THICK, MASSIVE, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	THE TORS	M36/859343	M36B2659	FLOW	TS, XRF	DARK RED-BROWN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	N-W OF LYTTTELTON	M36/862388
M36B2148	DIKE		0.50 M WIDE, TRACHYTE DIKE	THE TORS	M36/857350	M36B2671	DIKE		1 M WIDE, GREY GREEN, WEATHERED, PLAGIOCLASE-PHYRIC TRACHYTE	NORTH OF LYTTTELTON	M36/863338
M36B2149	DIKE		1 M WIDE, DARK GREY-GREEN, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	THE TORS	M36/857350	M36B2672	FLOW		AS FOR M36B2659	NORTH OF LYTTTELTON	M36/868342
M36B2150A	DIKE		AS FOR M36B2149	THE TORS	M36/857350	M36B2714	FLOW	TS	DARK GREY-RED, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	HEATHCOTE VALLEY	M36/861364
M36B2150B	DIKE		AS FOR M36B2149	THE TORS	M36/857350	M36B2732	FLOW	TS	DARK GREY, WEATHERED, FINE-MEDIUM GRAINED, PLAGIOCLASE-PHYRIC BASALT	CORSAIR BAY	M36/855333
M36B2151 (M36B46a)	LP	XRF TS, XRF +	ABOUT 12 M LONG, 10 M WIDE DARK FRESH, FINE-GRAINED, PLAGIOCLASE-APHYRIC BASALT	THE TORS	M36/857350	M36B2744	LAHAR		AS FOR M36B2153	LYTTTELTON HARBOUR	M36/866366
M36B2152	DIKE		1.50 M WIDE, DARK-GREY, FINE-GRAINED APHYRIC TRACHYTE	THE TORS	M36/857350	M36B2745	FLOW	TS	DARK BROWN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	LYTTTELTON HARBOUR	M36B/865335
M36B2153	LAHAR		DARK YELLOW-RED, STRUCTURELESS, MATRIX-SUPPORTED TO CLAST-SUPPORTED WITH COARSE SANDS	THE TORS	M36/856350						
M36B2154	LAHAR		AS FOR M36B2153	THE TORS	M36/857349						
M36B2155	FLOW	TS	DARK, GREY, MODERATELY WEATHERED, MEDIUM GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/858348						
M36B2156A	FLOW	TS	5 M THICK, MODERATELY COLUMNAR TO TABULAR JOINTED, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE- OLIVINE PHYRIC BASALT	THE TORS	M36/857347						
M36B2156B	FLOW	TS	AS FOR M36B2155	THE TORS	M36/857347	M36B3143 (M36B61a)	DIKE	TS, XRF +	7 M WIDE, GREY GREEN, WEATHERED, PLAGIOCLASE-PHYRIC TRACHYTE	MT CAVENDISH	M36/865349
M36B2157	FLOW	TS	AS FOR M36B2156	THE TORS	M36/855347	M36B3145	DIKE		1 M WIDE, GREY GREEN, WEATHERED, PLAGIOCLASE-PHYRIC TRACHYTE	MT CAVENDISH	M36/867349
M36B2158A	FLOW	TS	DARK BROWN-RED, VESICULAR, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/854348	M36B3174	DIKE		6 M WIDE, MODERATELY WEATHERED, GREY GREEN, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	WEST OF MT CAVENDISH	M36/865348
M36B2158B	FLOW	TS	AS FOR M36B2156A	THE TORS	M36/854348	M36B3179	DIKE		2 M WIDE, GREY GREEN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	WEST OF MT CAVENDISH	M36/866348
M36B2162	FLOW	TS, XRF	3 M THICK, MODERATELY TABULAR TO COLUMNAR JOINTED, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE PHYRIC BASALT	THE TORS	M36/853348	M36B3180	DIKE		AS FOR M36B3145	WEST OF	M36/867347
M36B2163	FLOW	TS, XRF	2 M THICK, MODERATELY TABULAR TO COLUMNAR JOINTED, DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT (AS FOR M36B2162)	THE TORS	M36/852347	M36B3184	DIKE		AS FOR M36B3145	WEST OF MT CAVENDISH	M36/867346
M36B2164A (M36B49)	FLOW	TS, XRF	2-4 M THICK, MODERATELY COLUMNAR TO TABULAR JOINTED, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	THE TORS	M36/855351	M36B3192	FLOW	TS	1.50 M WIDE, MODERATELY TABULAR JOINTED, FRESH, DARK, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	WEST OF MT CAVENDISH	M36/868347
M36B2164B (M36B48a)	FLOW	TS, XRF	3 M THICK, MODERATELY COLUMNAR TO TABULAR JOINTED, FRESH, DARK GREY, FINE-GRAINED BASALT (AS FOR M36B2060)	THE TORS	M36/857350	M36B3193	FLOW		AS FOR M36B3192	WEST OF MT CAVENDISH	M36/868349
M36B2164C	FLOW	TS, XRF	AS FOR M36B2071	THE TORS	M36/853350	M36B3195	FLOW		DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	WEST OF MT CAVENDISH	M36/868349
M36B2165A	FLOW	TS	AS FOR M36B2164A	THE TORS	M36/854349	M36B3198	HTB		AS FOR M36B2101	WEST OF MT CAVENDISH	M36/868350
M36B2165B	FLOW	TS	2 M THICK, MODERATELY COLUMNAR TO TABULAR JOINTED,	THE TORS	M36/854349	M36B3199	DIKE		2 M WIDE, GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	WEST OF MT CAVENDISH	M36/867350



1	2	3	4	5	6
M3683201	TUFF		RED CRYSTAL TUFF	MT CAVENDISH	M36/868350
M3683202	FLOW		AS FOR M3683195	WEST OF MT	M36/868351
M3683205	TUFF	TS	RED, WEATHERED, CRYSTAL TUFF	WEST OF MT	M36/868352
M3683208	DIKE		4 M WIDE, GREY GREEN, MODERATELY WEATHERED, PLAGIOCLASE-PHYRIC TRACHYTE	WEST OF MT CAVENDISH	M36/868351
M3683211	LAHAR		RED-BROWN YELLOW-BROWN, STRUCTURELESS TO WEAKLY BEDDED, MATRIX-SUPPORTED TO CLAST-SUPPORTED, POLYMICT PEBBLE BRECCIA AND CONGLOMERATE	MT CAVENDISH	M36/870352
M3683213	LAHAR		AS FOR M3683211	MT CAVENDISH	M36/870354
M3683214E	DIKE		0.50 M WIDE, GREY GREEN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	MT CAVENDISH	M36/870355
M3683215	DIKE		4 M WIDE, GREY GREEN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	MT CAVENDISH	M36/870356
M3683216	TUFF		AS FOR M3683205	MT CAVENDISH	M36/870357
M3683218	FLOW		MODERATELY KNOBBLY JOINTED, WEATHERED, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/870356
M3683225	FLOW		GREY PINK, FRESH, COURSE-GRAINED PLAGIOCLASE PHYRIC BASALT	MT CAVENDISH	M36/871353
M3683228	DIKE		AS FOR M3683215	MT CAVENDISH	M36/871351
M3683229	LAHAR		RED BROWN-YELLOW, UNSORTED, STRUCTURELESS, CLAST-SUPPORTED, POLYMICT BOULDER BRECCIA AND CONGLOMERATE	MT CAVENDISH	M36/870351
M3683230	FLOW		AS FOR M3683225	MT CAVENDISH	M36/869351
M3683231	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/870350
M3683232	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/871353
M3683233	FLOW		MODERATELY TABULAR JOINTED, DARK, FRESH, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	WEST OF MT CAVENDISH	M36/869350
M3683237	FLOW		DARK GREY, WEATHERED MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/870353
M3683239	DIKE		4 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	WEST OF MT CAVENDISH	M36/875355
M3683241	DIKE		AS FOR M3683148	MT CAVENDISH	M36/872355
M3683242	FLOW		DARK GREY, FRESH, VESICULAR, MEDIUM-GRAINED PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/872355
M3683244	FLOW		DARK, FRESH, FINE GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/871354
M3683245	DIKE		AS FOR M3683241	MT CAVENDISH	M36/871355
M3683247	LAHAR		RED, STRUCTURELESS UNSORTED POLYMICT PEBBLE BRECCIA	MT CAVENDISH	M36/870355
M3683248	FLOW		DARK GREY, MODERATELY WEATHERED, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE PHYRIC BASALT	MT CAVENDISH	M36/873353
M3683249	FLOW		DARK, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE PHYRIC BASALT	MT CAVENDISH	M36/872353
M3683250	FLOW	TS, XRF	1 M THICK, MODERATELY TABULAR JOINTED, DARK GREY BROWN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/871353

1	2	3	4	5	6
M3683251	FLOW		GREY DARK, WEATHERED, FINE-MEDIUM GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/871352
M3683252	DIKE		1 M WIDE, DARK, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/872352
M3683253	LAHAR		AS FOR M3683247	MT CAVENDISH	M36/871352
M3683254	DIKE		DARK GREY, FRESH, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/872351
M3683256	FLOW		DARK GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/872351
M3683257	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/870350
M3683261	FLOW		MODERATELY COLUMNAR JOINTED, DARK, FRESH, FINE-MEDIUM GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/870350
M3683262	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/871351
M3683263	FLOW		DARK BROWN, WEATHERED MEDIUM, GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/870349
M3683264	FLOW		AS FOR M3683263	MT CAVENDISH	M36/872350
M3683266	FLOW		AS FOR M3683263	MT CAVENDISH	M36/873350
M3683267	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/872352
M3683268	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/872351
M3683270	FLOW		5 M THICK, MODERATELY COLUMNAR JOINTED, DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/872353
M3683271	FLOW	TS, XRF	2 M THICK, DARK BROWN, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/873354
M3683272	FLOW	TS, XRF	3 M THICK, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/872353
M3683273	FLOW		DARK GREY, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/874354
M3683276	FLOW		AS FOR M3683273	MT CAVENDISH	M36/875354
M3683277	TUFF		RED CRYSTAL TUFF/SCORIA	MT CAVENDISH	M36/873353
M3683279	TUFF		RED, MONOLITHIC CRYSTAL TUFF	MT CAVENDISH	M36/873352
M3683280	FLOW	TS	DARK GREY BROWN, WEATHERED, VESICULAR, PLAGIOCLASE-PHYRIC BASALT	MT CAVENDISH	M36/874351
M3683281	FLOW	XRF	MODERATELY TABULAR JOINTED, GREY RED-DARK, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/873351
M3683282	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/874352
M3683283	FLOW		AS FOR M3683263	MT CAVENDISH	M36/874352
M3683284	FLOW		DARK GREY, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/875352
M3683285	LAHAR		AS FOR M3683229	MT CAVENDISH	M36/875350
M3683286	FLOW	TS, XRF	MODERATELY COLUMNAR TO TABULAR JOINTED DARK GREY, FRESH, PLAGIOCLASE-PHYRIC BASALT	SOUTH OF MT CAVENDISH	M36/876350
M3683572	FLOW	XRF	5 M THICK, MODERATELY COLUMNAR JOINTED, DARK GREY-GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC-TRACHYTE	WEST OF MT CAVENDISH	M36/867352
(M36860)	DIKE	TS, XRF +	TRACHYTE DIKE AT QUARRY FACE	WEST OF	M36/867352



1	2	3	4	5	6
M36B3580	FLOW	TS	AS FOR M36B3572	MT CAVENDISH MT CAVENDISH	M36/866352
M36B3581	DIKE		1 M WIDE, MODERATELY WEATHERED, GREY GREEN, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	MT CAVENDISH	M36/867355
M36B3582	FLOW	TS	DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE- PYROXENE-OLIVINE-PHYRIC BASALT	MT CAVENDISH	M36/867355
M36B3594	DIKE		2 M WIDE, GREY GREEN, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	MT CAVENDISH	M36/866353
M36B3677	FLOW	TS, XRF	DARK, MODERATELY WEATHERED, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	SOUTH OF MT CAVENDISH	M36/872348
M36B3678	FLOW	TS, XRF	DARK GREY, VESICULAR PLAGIOCLASE-PHYRIC BASALT	SOUTH OF CAVENDISH	M36/872347
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M36B4001	FLOW	TS	DARK, MODERATELY WEATHERED, MEDIUM-GRAINED PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/876355
M36B4002	FLOW	TS	DARK, FRESH, FINE-GRAINED, PLAGIOCLASE-PHYRIC- BASALT	MT PLEASANT	M36/875354
M36B4003	FLOW	TS, XRF	3.5 M THICK, COLUMNAR TO TABULAR JOINTED, MODERATELY WEATHERED, GREY RED-BROWN (YELLOW- BROWN), MEDIUM-COARSE-GRAINED, PLAGIOCLASE- PHYRIC BASALT, TRACHYTE	MT PLEASANT	M36/876354
M36B4004	FLOW	TS	AS FOR M36B4003	MT PLEASANT	M36/876356
M36B4005	FLOW	TS	DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE- PHYRIC BASALT	MT PLEASANT	M36/877355
M36B4006	FLOW	TS	AS FOR M36B4005	MT PLEASANT	M36/878355
M36B4007	FLOW	TS	DARK GREY, MODERATELY WEATHERED, MEDIUM-GRAINED PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/877355
M36B4008	FLOW	TS	AS FOR M36B4007	MT PLEASANT	M36/878355
M36B4009	FLOW	TS, XRF	AS FOR M36B4005	MT PLEASANT	M36/878355
M36B4012	FLOW	TS, XRF	AS FOR M36B4005	MT PLEASANT	M36/877355
M36B4013	FLOW	TS	DARK GREY, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/878355
M36B4014	FLOW	TS	AS FOR M36B4007	MT PLEASANT	M36/878355
M36B4015	FLOW	TS	GREY, FINE-MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/878355
M36B4016	DIKE	TS	1.50 M WIDE, GREY, MODERATELY WEATHERED, FINE- MEDIUM GRAINED, OLIVINE-PYROXENE-PLAGIOCLASE- PHYRIC BASALT	MT PLEASANT	M36/878355
M36B4017	FLOW	TS	AS FOR M36B4015	MT PLEASANT	M36/878355
M36B4018	FLOW	TS	AS FOR M36B4013	MT PLEASANT	M36/879353
M36B4019	FLOW	TS	AS FOR M36B4013	MT PLEASANT	M36/879353
M36B4020	FLOW	TS, XRF	DARK GREY, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/879354
M36B4021	FLOW	TS, XRF	AS FOR M36B4013	MT PLEASANT	M36/879352
M36B4023	FLOW	TS	AS FOR M36B4020	MT PLEASANT	M36/881354
M36B4024	FLOW	TS, XRF	DARK GREY, MODERATELY WEATHERED, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/881353

1	2	3	4	5	6
M36B4025	FLOW	TS	AS FOR M36B4020	MT PLEASANT	M36/881353
M36B4026	FLOW	TS	GREY, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/882354
M36B4027	FLOW	TS	AS FOR M36B4024	MT PLEASANT	M36/882353
M36B4028	FLOW	TS	AS FOR M36B4003	MT PLEASANT	M36/82352
M36B4029	FLOW	TS	AS FOR M36B4020	MT PLEASANT	M36/881354
M36B4030	FLOW	TS	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/883355
M36B4031	FLOW	TS	AS FOR M36B4030	MT PLEASANT	M36/885355
M36B4032	FLOW	TS	DARK GREY RED-BROWN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/884354
M36B4033	DIKE	TS	GREY, MODERATELY WEATHERED, FINE-MEDIUM GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/885353
M36B4034	DIKE	TS	1 M WIDE, MODERATELY WEATHERED, GREY, FINE- MEDIUM-GRAINED, OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/885352
M36B4035	FLOW	TS	DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE PHYRIC BASALT	MT PLEASANT	M36/885352
M36B4036	DIKE	TS	5 M WIDE, DARK, MEDIUM-GRAINED, PLAGIOCLASE- OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/885353
M36B4037	FLOW	TS	AS FOR M36B4035	MT PLEASANT	M36/881355
M36B4038	FLOW	TS	AS FOR M36B4032	MT PLEASANT	M36/881354
M36B4039	FLOW	TS	AS FOR M36B4035	MT PLEASANT	M36/882355
M36B4040	FLOW	TS	AS FOR M36B4035	MT PLEASANT	M36/881355
M36B4041	FLOW	TS	GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/881354
M36B4042	FLOW	TS	GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/881355
M36B4043	FLOW	TS	1.50 M WIDE, GREY BROWN, WEATHERED VESICULAR, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/881358
M36B4044	FLOW	TS	GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, LAGIOCLASE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/882355
M36B4045	FLOW	TS	DARK GREY, WEATHERED, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE BASALT	MT PLEASANT	M36/885356
M36B4287	TUFF		RED, CRYSTAL TUFF	MT PLEASANT	M36/875350
M36B4292	FLOW		AS FOR M36B3263	MT PLEASANT	M36/876351
M36B4296	FLOW		DARK, FRESH, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/876351
M36B4297	TUFF		AS FOR M36B4287	MT PLEASANT	M36/876352
M36B4300	FLOW	TS	DARK, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE- PHYRIC BASALT	MT PLEASANT	M36/877350
M36B4301	FLOW	TS, XRF	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE- PYROXENE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/877351
M36B4303	FLOW	TS	AS FOR M36B4292	MT PLEASANT	M36/879350
M36B4315	FLOW		8-12 M THICK, COLUMNAR TABULAR JOINTED, DARK GREY YELLOW-BROWN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/878354

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1	2	3	4	5	6
M36B4318	FLOW		AS FOR M36B4315	MT PLEASANT	M36/877353
M36B4319	FLOW		AS FOR M36B4030	MT PLEASANT	M36/886353
M36B4320	DIKE		5 M WIDE, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT (AS FOR M36B4036)	MT PLEASANT	M36/885354
M36B4321	DOME	TS	10 M THICK, GREY GREEN, MODERATELY WEATHERED, FINE-GRAINED, TRACHYTE	MT PLEASANT	M36/887358
M36B4323	DIKE		1 M WIDE, DARK, WEATHERED, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/888358
M36B4325	LAHAR		AS FOR M36B5211	MT PLEASANT	M36/889359
M36B4333	FLOW		MASSIVE, 5-1 M THICK, MODERATELY COLUMNAR TO TABULAR JOINTED, DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/884352
M36B4334	DIKE		3 M WIDE, DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/884351
M36B4335	FLOW		10 M THICK, COLUMNAR TO TABULAR JOINTED, DARK PINK YELLOW-BROWN, WEATHERED, PLAGIOCLASE-PHYRIC LAVA FLOW (AS FOR M36B4003)	MT PLEASANT	M36/885350
M36B4336	FLOW		AS FOR M36B4433	MT PLEASANT	M36/885350
M36B4337	FLOW		3-5 M THICK, MODERATELY COLUMNAR TO TABULAR JOINTED, FRESH, MEDIUM-COARSE GRAINED PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/885351
M36B4338	FLOW		GREY, MODERATELY WEATHERED, FINE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/886352
M36B4339	FLOW	TS	DARK GREY, MODERATELY WEATHERED, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/886353
M36B4340	FLOW		DARK GREY, MODERATELY WEATHERED, MEDIUM-COARSE GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/886352
M36B4341	FLOW	TS	AS FOR M36B4333	MT PLEASANT	M36/888348
M36B4342	FLOW	TS	AS FOR M36B4335	MT PLEASANT	M36/888347
M36B4343	FLOW		AS FOR M36B4339	MT PLEASANT	M36/887349
M36B4344	FLOW		DARK, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/888350
M36B4349	FLOW		AS FOR M36B4340	MT PLEASANT	M36/884346
M36B4352	FLOW	TS, XRF	AS FOR M36B4301	MT PLEASANT	M36/885346
M36B4353	DIKE		3 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	MT PLEASANT	M36/884346
M36B4355	FLOW		AS FOR M36B4335	MT PLEASANT	M36/888348
M36B4356	FLOW	TS, XRF	DARK, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/886346
M36B4357	DIKE		4 M WIDE, DARK GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/885346
M36B4358	FLOW	XRF	DARK RED-BROWN, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/884346
M36B4359	FLOW		AS FOR M36B4340	MT PLEASANT	M36/884346
M36B4360	FLOW	TS	DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/887346
M36B4364	LAHAR		AS FOR M36B3211	MT PLEASANT	M36/887346

1	2	3	4	5	6
M36B4378	FLOW		DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/886344
M36B4402	FLOW		AS FOR M36B4339	MT PLEASANT	M36/888361
M36B4406	FLOW		AS FOR M36B4339	MT PLEASANT	M36/886360
M36B4407	FLOW		AS FOR M36B4360	MT PLEASANT	M36/885360
M36B4408	FLOW	TS	AS FOR M36B4360	MT PLEASANT	M36/887366
M36B4410	FLOW	TS, XRF	DARK GREY, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	MT PLEASANT	M36/886365
M36B4595	FLOW		AS FOR M36B4003	MT PLEASANT	M36/876357
M36B4596	FLOW	TS, XRF	DARK GREY YELLOW-BROWN, WEATHERED, VESICULAR, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/875357
M36B4613	FLOW	TS, XRF	MODERATELY TABULAR JOINTED, GREY YELLOW-GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	WINDSOR CASTLE	M36/895363
M36B4619	FLOW	TS, XRF	DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	WINDSOR CASTLE	M36/895365
M36B4634	FLOW	TS, XRF	DARK GRAY, PLAGIOCLASE-PHYRIC BASALT	NORTH OF MT PLEASANT	M36/895365
M36B4866	FLOW	TS	AS FOR M36B4619	MONCK'S BAY	M36/888378
M36B4891	FLOW	TS	AS FOR M36B4410	MT PLEASANT	M36/877368
M36B4902	FLOW	TS	AS FOR M36B4619	McCORMACKS BAY	M36/882388
M36B4905	FLOW	TS	DARK GREY, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	HEATHCOTE VALLEY	M36/865379
M36B4906	FLOW	XRF	AS FOR M36B4619	FERRYMEAD	M36/865385
M36B4907	FLOW		DARK GREY, WEATHERED, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	MT PLEASANT	M36/881365
M36B4908	FLOW	TS	AS FOR M36B4907	MT PLEASANT	M36/881362
M36B4909	FLOW	XRF	AS FOR M36B4907	MT PLEASANT	M36/881359
M36B4911	FLOW		AS FOR M36B4907	MT PLEASANT	M36/884356
M36B4912	FLOW		AS FOR M36B4907	MT PLEASANT	M36/885358
M36B4913	FLOW		AS FOR M36B4907	MT PLEASANT	M36/888354
M36B4914	FLOW	TS	AS FOR M36B4907	MT PLEASANT	M36/889356
M36B4915	FLOW	TS	AS FOR M36B4619	MT PLEASANT	M36/893353
M36B4916	FLOW	TS	AS FOR M36B4619	MT PLEASANT	M36/892349
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M36B5376	FLOW	TS	10 M THICK, MASSIVE MODERATELY COLUMNAR TO TABULAR JOINTED, DARK, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PHYRIC BASALT	N-E OF LYTTELTON HARBOUR	M36/889343
M36B5383	DIKE		3 M WIDE, GREY GREEN, WEATHERED, PLAGIOCLASE-PHYRIC TRACHYTE	N-E OF LYTTELTON	M36/895346
M36B5385A	DIKE		1 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	EVANS PASS	M36/897348
M36B5385B	LAHAR		AS FOR M36B3427	EVANS PASS	M36/897348



1	2	3	4	5	6
M3685396	DIKE		4 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED PLAGIOCLASE-PHYRIC TRACHYTE	N-E OF LYTTTELTON	M36/893347
M3685429	FLOW	TS	GREY YELLOW-BROWN, WEATHERED, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PHYRIC BASALT	WEST OF EVANS PASS	M36/894354
M3685431	LAHAR		3 M THICK, RED BROWN, STRUCTURELESS MATRIX SUPPORTED TO CLAST-SUPPORTED, POLYMICT BOULDER BRECCIA AND CONGLOMERATE	EVANS PASS	M36/899352
M3685440	FLOW	TS, XRF	DARK GRAY, PLAGIOCLASE-PHYRIC BASALT	W-OF EVANS PASS	M36/895353
M3685441	FLOW	TS	MODERATELY KNOBBLY TO COLUMNAR JOINTED, DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	WEST OF EVANS PASS	M36/895352
M3685443	FLOW	TS, XRF	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC-BASALT	EVANS PASS	M36/896350
N36A5478	FLOW	TS	5 M THICK, COLUMNAR TO TABULAR JOINTED, DARK GREY YELLOW-BROWN, WEATHERED, MEDIUM-COARSE-GRAINED, PLAGIOCLASE-PHYRIC BASALT	BREEZE BAY	N36/924348
N36A5482	FLOW	TS	AS FOR N36A5478	TAYLORS MISTAKE	N36/919354
N36A5508	FLOW	TS, XRF	AS FOR M3685478	LIVINGSTONE BAY	N36/915348
N36A5507	FLOW		AS FOR N36A5478	LIVINGSTONE BAY	N36/915347
N36A5509	FLOW	TS, XRF	COLUMNAR TO TABULAR JOINTED, DARK, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	LIVINGSTONE BAY	N36/914348
N36A5518	FLOW	TS	DARK GREY, FRESH, MEDIUM-COARSE GRAINED, PLAGIOCLASE-PHYRIC BASALT	SUMNER	N36/908358
N36A5520	FLOW	TS	DARK GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	TAYLORS MISTAKE	N36/921359
N36A5531	FLOW	TS	MODERATELY COLUMNAR TO TABULAR JOINTED, GREY YELLOW-BROWN, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	TAYLORS MISTAKE	N36/916359
M3685557	FLOW		AS FOR M3684902	SCARBOROUGH	M36/915373
M3685560	FLOW		AS FOR M3685443	LYTTTELTON	M36/882334
M3685563	SILL	TS, XRF	10-15 M THICK, MASSIVE TABULAR JOINTED, YELLOW-RED, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	EAST OF LYTTTELTON HARBOUR	M36/884334
M3685568	FLOW	TS	AS FOR M3685443	NORTH EAST OF LYTTTELTON	M36/887341
M3685732	DIKE		0.50 M WIDE, GREY, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	CORSAIR BAY	M36/855332
M3685751A	TUFF	TS	CRYSTAL TUFF	LYTTTELTON	M36/882334
M3685751B	DIKE		2 M WIDE, GREY, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	N-E OF LYTTTELTON	M36/882334
M3685752	TUFF		RED, WEATHERED CRYSTAL-TUFF	N-E OF LYTTTELTON	M36/882334
M3685756	DIKE		AS FOR M3685751B	N-E OF LYTTTELTON	M36/883334
M3685757	DIKE		3 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	N-E OF LYTTTELTON	M36/892337

1	2	3	4	5	6
M3685758	FLOW	TS	DARK GREY-BROWN, WEATHERED, FINE-MEDIUM GRAINED, PLAGIOCLASE-PHYRIC BASALT	N-E OF LYTTTELTON	M36/891341
M3685759	FLOW	TS	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	N-E OF LYTTTELTON	M36/892341
M3685766	FLOW	TS	PLAGIOCLASE-PHYRIC BASALT	N-E OF LYTTTELTON	M36/892341
M3685768	FLOW	TS, XRF	AS FOR M3685759	N-E OF LYTTTELTON	M36/894343
M3685772	FLOW	TS, XRF	AS FOR M3685768	LYTTTELTON HARBOUR	M36/896346
M3685781	FLOW	TS	AS FOR M3685759	SOUTH OF SUMNER	N36/902355
M3685791	FLOW	TS, XRF	DARK GREY-GREEN, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	N-E OF LYTTTELTON HARBOUR	N36/901351
M3685792	FLOW	TS, XRF	5-10 M THICK, COLUMNAR TO TABULAR JOINTED, DARK GREY-YELLOW-BROWN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT (AS FOR N36A5507)	N-E OF LYTTTELTON HARBOUR	M36/899349
M3685797	FB		AS FOR M3684349	EVANS PASS	M36/899349
M3685804	FLOW		AS FOR M3685768	EVANS PASS	M36/899352
M3685805	FLOW	XRF	DARK GREY, MODERATELY WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-OLIVINE-PHYRIC BASALT	EVANS PASS	M36/900354
N36A5811	FLOW	TS	AS FOR M3685805	SUMNER	N36/901356
N36A5822	FLOW	TS, XRF	AS FOR M3685768	LYTTTELTON	N36/904349
N36A5824	FLOW	TS, XRF	AS FOR M3685768	N-E OF LYTTTELTON	N36/903348
N36A5825	FLOW	TS	DARK GREY, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	N-E OF LYTTTELTON	N36/902348
N36A5826	FLOW	TS, XRF	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PYROXENE-OLIVINE-PHYRIC BASALT	N-E OF LYTTTELTON	N36/902347
M3685828	DIKE		5 M WIDE, GREY GREEN, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC TRACHYTE	N-E OF LYTTTELTON	N36/901348
M3685830	FLOW	TS	DARK, FRESH, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	N-E OF LYTTTELTON	M36/897346
M3685846	TUFF		RED, CRYSTAL TUFF	N-E OF LYTTTELTON	M36/890339
M3685849	FLOW		DARK-YELLOW, WEATHERED, MEDIUM-GRAINED, PLAGIOCLASE-PHYRIC BASALT	LYTTTELTON HARBOUR	M36/882333
M3685852	FLOW	TS	AS FOR M36A5826	LYTTTELTON HARBOUR	M36/879333
N36A5853	FLOW	TS	AS FOR M36A4907	CAVE ROCK	M36/906379
N36A5854	FLOW	TS	AS FOR M3685853	SUMNER	N36/904374
N36A5918	DIKE		AS FOR M3685757	LIVINGSTONE BAY	N36/909346
N36A5919	DIKE		PLAGIOCLASE-PHYRIC LAVA	LIVINGSTONE BAY	N36/915348



APPENDIX III PETROGRAPHIC AND MINERALOGICAL DESCRIPTIONS

This appendix contains general information concerning thin section studies. 183 thin sections are described : 153 of lava flows, 28 of dikes, sills, and other intrusive bodies and 2 from pyroclastic units. Detailed field descriptions and locations of thin sectioned samples are listed in appendix II.

The mineral abundances listed are visual estimates. Rock names are assigned according to *average plagioclase composition* as indicated in table below. Plagioclase compositions were estimated by measurement of the extinction angle by the Michel-Levy method to determine anorthite (An) content.

[ 1 ] PLAGIOCLASE COMPOSITION :-

An mol.%	0 - 10	10 - 30	30 - 50	50 - 70	70 - 90	90 - 100
Plag.	albite	oligoclase	andesine	labradorite	bytownite	anorthite

[ 2 ] ALKALINE BASALT ASSOCIATION :-

Rock name	Basalt	Hawaiite	Mugearite	Trachyte
Anorthite	> 50	50 - 30	10-30	< 10
Plagioclase	Labradorite	andesine	oligoclase	albite or anorthoclase

For *petrographic rock classification* purposes an *average plagioclase composition* of phenocrysts and groundmass was estimated.

Key for Table III-A:-

(i) Olivine:- (a) Includes fresh olivine

(b) olivine \* :- Indicates olivine + secondary mineral  
or mineraloid (iddingsite) considered to be  
pseudomorphic after olivine

(ii) Clinopyroxene:-Includes augite in basic rocks, and green clinopyroxene  
(ferroaugite to hedenbergite to aegirine-augite)  
in intermediate and felsic rocks.

(iii) Orthopyroxene:- Is represented by hypersthine

(iv) Brown hornblende:-Is represented by kaersutite

(v) Oxides:- Represents mainly Fe-Ti oxide (ilmenite) and rarely magnetite

*Trachytoid texture* is used for all trachytic and pilotaxitic texture

## APPENDIX III A

## PETROGRAPHIC AND MINERALOGICAL DESCRIPTIONS

SAMPLE	TEXTURE	PHENOCRYSTS	GROUNDMASS	ROCK NAME	CHEMICAL NAME
M36B2046A (M36B6a)	FRESH, APHANITIC, TRACHYTOID, HAYPOCRYSTALLINE	5% PLAGIOCLASE < 1% CLINOPYROXENE	65% PLAGIOCLASE 10% CLINOPYROXENE TRACE OLIVINE 5% OXIDE 15% GLASS	TRACHYTE	Ne-TRACHYTE
M36B2046B (M36B62b)	FRESH, APHANITIC, HYPOCRYSTALLINE	2% PLAGIOCLASE < 1% CLINOPYROXENE	65% PLAGIOCLASE, 18% CLINOPYROXENE 15% GLASS	TRACHYTE	N.A
(M36B23)	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	8% PLAGIOCLASE 2% CLINOPYROXENE < 1% OLIVINE < 1% OXIDE	50% PLAGIOCLASE 20% CLINOPYROXENE 10% OLIVINE 9% OXIDE	MUGEARITE	N.A
M36B2047	MODERATELY WEATHERED, VESICULAR, TRACHYTOID HYPOCRYSTALLINE	3% PLAGIOCLASE < 1% OLIVINE	67% PLAGIOCLASE 15% CLINOPYROXINE 15% GLASS	TRACHYTE	Ne-TRACHYTE
M36B2048	MODERATELY WEATHERED, INTERGRANULAR, APHANITIC HYPOCRYSTALLINE	5% PLAGIOCLASE 2% OLIVINE 1% CLINOPYROXENE	58% PLAGIOCLASE 14% CLINOPYROXENE 14% OLIVINE 6% OXIDE	HAWAIIITE	N.A
M36B2051	WEATHERED, VESICULAR, PORPHYRITIC, HYPOCRYSTALLINE	12% PLAGIOCLASE 1% CLINOPYROXENE 1% OLIVINE	52% PLAGIOCLASE 13% CLINOPYROXENE 12% OLIVINE 10% GLASS	HAWAIIITE	N.A
(M36B24)	FRESH, VESICULAR PORPHYRITIC HOLOCRYSTALLINE	15% OLIVINE 2% CLINOPYROXENE	40% PLAGIOCLASE 28% OLIVINE 10% CLINOPYROXENE 5% OXIDE	OLIVINE- BASALT	OL-HAWAIIITE
M36B2052	MODERATELY WEATHERED, HYPOCRYSTALLINE, APHANITIC	3% PLAGIOCLASE <1% CLINOPYROXENE	67% PLAGIOCLASE 15% CLINOPYROXENE 15% GLASS	TRACHYTE	N.A
M36B2054	FRESH, VESICULAR, SUB-TRACHYTOID, APHANITIC		65% PLAGIOCLASE 20% CLINOPYROXENE 15% GLASS	TRACHYTE	N.A
M36B2055	FRESH, PORPHYRITIC, INTERGRANULAR, HYPOCRYSTALLINE,	15% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	51% PLAGIOCLASE 20% CLINOPYROXENE 3% OXIDE 7% GLASS	HAWAIIITE	N.A
M36B2056	MODERATELY WEATHERED,	5% PLAGIOCLASE 1% CLINOPYROXENE TRACE OLIVINE	54% PLAGIOCLASE 15% CLINOPYROXENE 5% OXIDE 20% GLASS	MUGEARITE	N.A
M36B2059	MODERATELY WEATHERED APHANITIC, SUB TRACHYTOID HYPOCRYSTALLINE	1% PLAGIOCLASE	49% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 10% OXIDE	MUGEARITE	N.A
M36B2060	MODERATELY WEATHERED VESICULAR, HOLOCRYSTALLINE INTERGRANULAR	12% PLAGIOCLASE 4% OLIVINE 2% CLINOPYROXENE	50% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B2061	MODERATELY FRESH, VESICULAR, TRACHYTOID HYPOCRYSTALLINE	6% PLAGIOCLASE 1% CLINOPYROXENE	63% PLAGIOCLASE 10% CLINOPYROXENE 20% GLASS	TRACHYTE	N.A

M36B2063 (M36B37)	FRESH, VESICULAR, HOLOCRYSTALLINE PORPHYRITIC, SUB-TRACHYTOID	7% PLAGIOCLASE 2% OLIVINE * 2% CLINOPYROXENE	50% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 9% OXIDE	MUGEARITE	Ol-MUGEARITE
M36B2066	MODERATELY FRESH, PORPHYRITIC HOLOCRYSTALLINE	8% PLAGIOCLASE 2% OLIVINE	50% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 5% OXIDE 10% GLASS	MUGEARITE	N.A
M36B2067	MODERATELY FRESH, HYPOCRYSTALLINE TRACHYTOID	10% PLAGIOCLASE < 1% CLINOPYROXENE < 1% OLIVINE	53% PLAGIOCLASE 20% CLINOPYROXENE 7% OLIVINE 8% OXIDE	TRACHYTE	N.A
M36B2068	MODERATELY WEATHERED HYPOCRYSTALLINE	5% PLAGIOCLASE 1% CLINOPYROXENE 1% OLIVINE	63% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE TRACE APATITE 5% GLASS	HAWAIIITE	N.A
M36B2069	MODERATELY FRESH, VESICULAR, HYPOCRYSTALLINE SUB-TRACHYTOID, APHANITIC		60% PLAGIOCLASE 10% OLIVINE 10% CLINOPYROXENE 20% GLASS	MUGEARITE	N.A
M36B2071	FRESH, HYPOCRYSTALLINE APHANITIC, SUB-TRACHYTOID	5% PLAGIOCLASE 3% OLIVINE *	57% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B2072	MODERATELY WEATHERED HYPOCRYSTALLINE, APHANITIC SUB-TRACHYTOID	3% PLAGIOCLASE 1% OLIVINE	46% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 5% APATITE 10% OXIDE 5% GLASS	HAWAIIITE	Ol-MUGEARITE
(M36B33)	MODERATELY WEATHERED PORPHYRITIC HOLOCRYSTALLINE	10% PLAGIOCLASE 2% OLIVINE < 1% OXIDE	50% PLAGIOCLASE 20% OLIVINE 12% CLINOPYROXENE TRACE APATITE 5% OXIDE	HAWAIIITE	Ol-HAWAIIITE
M36B2073	MODERATELY WEATHERED, VESICULAR, HYPOCRYSTALLINE SUB-TRACHYTOID, APHANITIC		50% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 5% OXIDE 15% GLASS	MUGEARITE	N.A
M36B2074	MODERATELY FRESH, VESICULAR HYPOCRYSTALLINE, APHANITIC	3% PLAGIOCLASE 1% OLIVINE TRACE CLINOPYROXENE	56% PLAGIOCLASE 17% OLIVINE 10% CLINOPYROXENE 3% OXIDE 10% GLASS	MUGEARITE	N.A
M36B2076 (M36B56)	MODERATELY FRESH, HYPOCRYSTALLINE, APHANITIC SUB-TRACHYTOID	3% PLAGIOCLASE	57% PLAGIOCLASE 15% CLINOPYROXENE 5% OLIVINE 7% OXIDE 13% GLASS	TRACHYTE	Oz-TRACHYTE
M36B2078	MODERATELY FRESH, VESICULAR, HYPOCRYSTALLINE APHANITIC, SUB-TRACHYTOID	3% PLAGIOCLASE	67% PLAGIOCLASE 10% CLINOPYROXENE 20% GLASS	TRACHYTE	N.A
M36B2082	MODERATELY FRESH, VESICULAR, HYPOCRYSTALLINE APHANITIC, TRACHYTOID	5% PLAGIOCLASE 2% CLINOPYROXENE 1% KAERSUTITE	57% PLAGIOCLASE 15% CLINOPYROXENE 5% OXIDE 15% GLASS	TRACHYTE	N.A
M36B2083	MODERATELY WEATHERED HYPOCRYSTALLINE APHANITIC, SUB-TRACHYTOID	2% PLAGIOCLASE 1% OLIVINE	52% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE	MUGEARITE	N.A



			15% GLASS		
M36B2087	MODERATELY FRESH, PORPHYRITIC, HOLOCRYSTALLINE	15% PLAGIOCLASE < 1% CLINOPYROXENE < 1% OLIVINE	53% PLAGIOCLASE 14% CLINOPYROXENE 12% OLIVINE 6% OXIDE	HAWAIIITE	Hy-HAWAIIITE
(M36B31)	MODERATELY WEATHERED PORPHYRITIC HYPOCRYSTALLINE	12% PLAGIOCLASE < 1% OLIVINE < 1% CLINOPYROXENE	53% PLAGIOCLASE 17% CLINOPYROXENE 16% OLIVINE	HAWAIIITE	Hy-HAWAIIITE
M36B2088	MODERATELY FRESH, HOLOCRYSTALLINE PORPHYRITIC	20% PLAGIOCLASE 4% OLIVINE	51% PLAGIOCLASE 10% CLINOPYROXENE 10% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B2089	FRESH, APHANITIC HYPOCRYSTALLINE	3% PLAGIOCLASE 1% OLIVINE	60% PLAGIOCLASE 16% CLINOPYROXENE 15% OLIVINE 5% OXIDE	MUGEARITE	N.A
M36B2091	MODERATELY WEATHERED PORPHYRITIC, HOLOCRYSTALLINE	11% PLAGIOCLASE 3% OLIVINE < 1% CLINOPYROXENE	55% PLAGIOCLASE 13% CLINOPYROXENE 12% OLIVINE 5% OXIDE	HAWAIIITE	BASALT
M36B2094	AS FOR M36B2091	10% PLAGIOCLASE 3% OLIVINE	55% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 7% OXIDE	HAWAIIITE	N.A
M36B2096	FRESH, VESICULAR, TRACHYTOID, PORPHYRITIC HOLOCRYSTALLINE	6% PLAGIOCLASE 3% CLINOPYROXENE	61% PLAGIOCLASE 25% CLINOPYROXENE 5% OXIDE	TRACHYTE	N.A
M36B2100B	FRESH, HYPOCRYSTALLINE APHANITIC, SUB-TRACHYTOID		65% PLAGIOCLASE 5% OLIVINE 5% CLINOPYROXENE 5% OXIDE 20% GLASS	MUGEARITE	N.A
M36B2101	METROLITHIC TUFF BRECCIA:- CONSISTS OF LAVA LITHOLOGIC CLAST AND FRAGMENTAL MATRIX, INDIVIDUAL CLAST HAVE PHENOCRYSTS AND GROUNDMASSSES. SOME CLAST CONSIST OF PLAGIOCLASE, RARE OLIVINE AND CLINOPYROXENE PHENOCRYST, BUT THE ABUNDANCE OF PHENOCRYST MINERALS IS VARIABLE IN DIFFERENT CLASTS. MOST CLASTS ARE APHANATIC. THE FRAGMENTAL MATRIX IS DOMINANTLY GLASS AND LARGE CRYSTALS OF PLAGIOCLASE AND MINOR OLIVINE AND CLINOPYROXENE				
M36B2102	FRESH, HYPOCRYSTALLINE, SUB-TRACHYTOID HYPOCRYSTALLINE	6% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	50% PLAGIOCLASE 10% OLIVINE 10% CLINOPYROXENE 5% OXIDE 15% GLASS	MUGEARITE	N.A
M36B2103A	FRESH, HOLOCRYSTALLINE, PORPHYRITIC, INTERGRANULAR	13% PLAGIOCLASE 4% CLINOPYROXENE 4% OLIVINE	50% PLAGIOCLASE 14% CLINOPYROXENE 10% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B2103B	FRESH, HYPOCRYSTALLINE APHANITIC, SUB-TRACHYTOID	9% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	40% PLAGIOCLASE 12% CLINOPYROXENE 10% OLIVINE 5% OXIDE 20% GLASS	HAWAIIITE	N.A
M36B2105A	MODERATELY FRESH, HYPOCRYSTALLINE, SUB-TRACHYTOID APHANITIC		55% PLAGIOCLASE 15% CLINOPYROXENE 5% OLIVINE 5% OXIDE 20% GLASS	MUGEARITE	N.A
M36B2105B	FRESH, HYPOCRYSTALLINE		60% PLAGIOCLASE 15% CLINOPYROXENE 5% OXIDE 20% GLASS	MUGEARITE	N.A

M36B2117A	MODERATELY FRESH, VESICULAR, PORPHYRITIC HOLOCYSTALLINE	13% PLAGIOCLASE 4% OLIVINE	55% PLAGIOCLASE 12% CLINOPYROXENE 11% OLIVINE 5% OXIDE	HAWAIIITE	BASALTE
M36B2117B	FRESH, PORPHYRITIC HOLOCYSTALLINE	13% PLAGIOCLASE 4% OLIVINE	45% PLAGIOCLASE 20% ALTERED OLIVINE 10% CLINOPYROXENE TRACE APATITE 8% OXIDE	HAWAIIITE	N.A
M36B2139	FRESH, PORPHYRITIC HOLOCYSTALLINE	16% PLAGIOCLASE 4% OLIVINE	50% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B2151	FRESH, APHANITIC, TRACHYTOID, HYPOCRYSTALLINE		60% PLAGIOCLASE 25% CLINOPYROXENE 10% GLASS 5% OXIDE	TRACHYTE	Ne-TRACHYTE
M36B2155	FRESH, APHANITIC SUB-TRACHYTOID HYPOCRYSTALLINE	5% PLAGIOCLASE 2% OLIVINE <1% CLINOPYROXENE	50% PLAGIOCLASE 10% CLINOPYROXENE 10% OLIVINE TRACE APATITE 8% OXIDE 15% GLASS	HAWAIIITE	N.A
M36B2156A	MODERATELY WEATHERED VESICULAR, PORPHYRITIC HYPOCRYSTALLINE	8% PLAGIOCLASE 2% OLIVINE	60% PLAGIOCLASE 15% OLIVINE 5% CLINOPYROXENE 10% OXIDE	HAWAIIITE	N.A
M36B2156B	MODERATELY FRESH VESICULAR, SUB-TRACHYTOID HYPOCRYSTALLINE APHANITIC		58% PLAGIOCLASE 8% OLIVINE 7% CLINOPYROXENE 2% OXIDE 25% GLASS	HAWAIIITE	N.A
M36B2157	MODERATELY FRESH PORPHYRITIC HOLOCYSTALLINE	16% PLAGIOCLASE 2% OLIVINE	50% PLAGIOCLASE 15% OLIVINE * 12% CLINOPYROXENE TRACE APATITE 5% OXIDE	HAWAIIITE	N.A
M36B2158A	FRESH, VESICULAR, PORPHYRITIC HOLOCYSTALLINE	13% PLAGIOCLASE 2% OLIVINE * < 1% CLINOPYROXENE	60% PLAGIOCLASE 15% OLIVINE * 5% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B2158B	FRESH, PORPHYRITIC HOLOCYSTALLINE	17% PLAGIOCLASE 3% OLIVINE * 2% CLINOPYROXENE	50% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 3% OXIDE	HAWAIIITE	N.A
M36B2162	FRESH, PORPHYRITIC, HOLOCYSTALLINE	7% PLAGIOCLASE 2% CLINOPYROXENE 1% OLIVINE < 1% ORTHOPYROXENE	50% PLAGIOCLASE 16% OLIVINE 15% CLINOPYROXENE 8% OXIDE TRACE APATITE	HAWAIIITE	Oz-HAWAIIITE
M36B2163	MODERATELY FRESH VESICULAR, HOLOCYSTALLINE PORPHYRITIC, INTERGRANULAR	11% PLAGIOCLASE 3% OLIVINE * 2% CLINOPYROXENE	54% PLAGIOCLASE 15% ALTERD OLIVINE 15% CLINOPYROXENE	HAWAIIITE	BASALT
M36B2164A (M36B49)	FRESH, HYPOCRYSTALLINE PORPHYRITIC	8% PLAGIOCLASE 4% OLIVINE	50% PLAGIOCLASE 17% CLINOPYROXENE 15% OLIVINE 6% OXIDE	HAWAIIITE	Ol-HAWAIIITE
M36B2164B (M36B48)	FRESH, PORPHYRITIC HOLOCYSTALLINE SUB-TRACHYTOID	5% PLAGIOCLASE 2% OLIVINE 1% CLINOPYROXENE	50% PLAGIOCLASE 20% OLIVINE 17% CLINOPYROXENE 5% OXIDE	MUGEARITE	Ol-MUGEARITE

M36B2164C	MODERATELY FRESH, VESICULAR, HYPOCRYSTALLINE APHANITIC	3% PLAGIOCLASE	60% PLAGIOCLASE 9% ALTERED OLIVINE 8% CLINOPYROXENE 20% GLASS	HAWAIIITE	OL-HAWAIIITE
M36B2165A	MODERATELY WEATHERED HYPOCRYSTALLINE	5% PLAGIOCLASE 2% OLIVINE 2% CLINOPYROXENE	55% PLAGIOCLASE 13% CLINOPYROXENE 7% ALTERED OLIVINE 8% OXIDE 8% GLASS	HAWAIIITE	N.A
M36B2165B	MODERATELY WEATHERED HYPOCRYSTALLINE APHANITIC		59% PLAGIOCLASE 13% OLIVINE 12% CLINOPYROXENE 1% OXIDE 15% GLASS	MUGEARITE	N.A
M36B2165C	FRESH, HYPOCRYSTALLINE APHANITIC		45% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 5% OXIDE 20% GLASS	HAWAIIITE	N.A
M36B2166	MODERATELY FRESH, VESICULAR, HOLOCRYSTALLINE PORPHYRITIC	13% PLAGIOCLASE 3% OLIVINE	50% PLAGIOCLASE 15% OLIVINE 14% CLINOPYROXENE 5% GLASS	HAWAIIITE	N.A
M36B2652	MODERATELY WEATHERED, INTERGRANULAR PORPHYRITIC	8% PLAGIOCLASE 3% CLINOPYROXENE 1% OXIDE	55% PLAGIOCLASE 15% CLINOPYROXENE 14% OLIVINE TRACE APATITE 4% OXIDE	TRACHYTE	N.A
M36B2659	MODERATELY FRESH, VESICULAR, PORPHYRITIC INTERGRANULAR, HOLOCRYSTALLINE	8% PLAGIOCLASE 2% CLINOPYROXENE 1% OLIVINE	31% PLAGIOCLASE 10% CLINOPYROXENE 8% OLIVINE 30% Fe OXIDE 10% GLASS	HAWAIIITE	Fe-ALTERED ROC
M36B2714	MODERATELY FRESH HOLOCRYSTALLINE SUB-TRACHYTOID	10% PLAGIOCLASE	60% PLAGIOCLASE 10% OLIVINE 10% CLINOPYROXENE 10% GLASS	HAWAIIITE	N.A
M36B2732	FRESH, HYPOCRYSTALLINE APHANITIC	5% PLAGIOCLASE 1% ORTHOPYROXENE	60% PLAGIOCLASE 10% ORTHOPYROXENE 5% OXIDE 19% GLASS	ANDESITE	N.A
M36B2745	MODERATELY WEATHERED HOLOCRYSTALLINE PORPHYRITIC	10% PLAGIOCLASE 2% OLIVINE 2% CLINOPYROXENE 1% IDINGSITE	50% PLAGIOCLASE 15% OLIVINE * 10% CLINOPYROXENE 10% Fe OXIDE	HAWAIIITE	N.A
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M36B3192	FRESH, HOLOCRYSTALLINE INTERGRANULAR, PORPHYRITIC	9% OLIVINE 3% CLINOPYROXENE 3% PLAGIOCLASE	50% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
(M36B61a)	MODERATELY WEATHERED HYPOCRYSTALLINE TRACHYTOID	5% PLAGIOCLASE 1% CLINOPYROXENE < 1% OXIDE TRACE KAERSUTITE	63% PLAGIOCLASE 15% CLINOPYROXENE 15% GLASS	TRACHYTE	TRACHYTE
(M36B60)	MODERATELY WEATHERED TRACHYTOID	3% PLAGIOCLASE	54% PLAGIOCLASE 16% CLINOPYROXENE 15% OXIDE 12% GLASS	TRACHYTE	Qz-TRACHYTE
M36B3205	CRYSTAL TUFF:- TEXTURE = VESICULAR, VITROPHYRIC CRYSTALS = PLAGIOCLASE WITH SOME OLIVINE AND CLINOPYROXENE. CRYSTALS EMBEDDED GLASS MATRICES				



M36B3250	MODERATELY FRESH, HOLOCYSTALLINE, INTERGRANULAR, PORPHYRITIC	5% PLAGIOCLASE 5% CLINOPYROXENE < 1% OLIVINE	60% PLAGIOCLASE 15% CLINOPYROXENE 11% OLIVINE 4% OXIDE	MUGEARITE	Oz-BENMOREITE
M36B3271	MODERATELY FRESH VESICULAR, HOLOCYSTALLINE INTERGRANULAR PORPHYRITIC	9% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	50% PLAGIOCLASE 16% CLINOPYROXENE 16% OLIVINE TRACE ORTHOPYROXENE 5% OXIDE	HAWAIIITE	Ol-HAWAIIITE
M36B3272	MODERATELY FRESH, HYPOCRYSTALLINE, APHANITIC SUB-TRACHYTOID	5% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	50% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE TRACE APATIITE 10% OXIDE	HAWAIIITE	Ol-HAWAIIITE
M36B3280	MODERATELY WEATHERED VESICULAR, PORPHYRITIC HYPOCRYSTALLINE, INTERGRANULAR	10% PLAGIOCLASE	55% PLAGIOCLASE 10% OLIVINE 10% CLINOPYROXENE 8% OXIDE 7% GLASS	HAWAIIITE	N.A
M36B3286	MODERATELY WEATHERED HYPOCRYSTALLINE MICRO-PORPHYRITIC	9% PLAGIOCLASE 2% CLINOPYROXENE 1% OLIVINE	55% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 10% OXIDE	HAWAIIITE	Hy-HAWAIIITE
M36B3580	FRESH, HOLOCYSTALLINE SUB-TRACHYTOID	15% PLAGIOCLASE 2% CLINOPYROXENE < 1% OLIVINE	58% PLAGIOCLASE 20% CLINOPYROXENE 5% OXIDE	TRACHYTE	N.A
M36B3582	MODERATELY FRESH, HYPOCRYSTALLINE, APHANITIC	1% PLAGIOCLASE	54% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 10% OXIDE 10% GLASS	HAWAIIITE	N.A
M36B3677	MODERATELY FRESH HYPOCRYSTALLINE APHANITIC		60% PLAGIOCLASE 15% CLINOPYROXENE 5% OXIDE 20% GLASS	TRACHYTE	Qz-TRACHYTE
M36B3678	MODERATELY FRESH HOLOCYSTALLINE	16% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	50% PLAGIOCLASE 13% CLINOPYROXENE 12% OLIVINE 5% OXIDE	HAWAIIITE	Hy-HAWAIIITE
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M36B4001	MODERATELY FRESH HYPOCRYSTALLINE APHANITIC	5% PLAGIOCLASE < 1% OLIVINE < 1% CLINOPYROXENE	55% PLAGIOCLASE 13% OLIVINE 12% CLINOPYROXENE 5% OXIDE 10% GLASS	HAWAIIITE	N.A
M36B4002	FRESH, APHANITIC HYPOCRYSTALLINE INTERSERTAL		46% PLAGIOCLASE 12% OLIVINE 12% CLINOPYROXENE 30% GLASS	HAWAIIITE	N.A
M36B4003	MODERATELY WEATHERED VESICULAR, HOLOCYSTALLINE PORPHYRITIC	25% PLAGIOCLASE 1% ALTERED OLIVINE 1% ALTERED CLINOPYROXENE	50% PLAGIOCLASE 10% OLIVINE 10% CLINOPYROXENE 3% OXIDE	TRACHYTE	Qz-TRACHYTE
M36B4004	MODERATELY WEATHERED HOLOCYSTALLINE PORPHYRITIC	25% PLAGIOCLASE 2% OLTERED OLIVINE < 1% OLTERED CLINOPYROXENE	50% PLAGIOCLASE 10% OLIVINE 9% CLINOPYROXENE 3% OXIDE	TRACHYTE	T.A
M36B4005	FRESH, PORPHYRITIC HOLOCYSTALLINE	8% PLAGIOCLAASE 2% OLIVINE 1% CLINOPYROXENE	50% PLAGIOCLASE 24% OLIVINE 10% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A

M36B4006	FRESH, PORPHYRITIC INTERGRANULAR HOLOCYSTALLINE	8% PLAGIOCLASE 3% OLIVINE < 1% CLINOPYROXENE	50% PLAGIOCLASE 20% OLIVINE 13% CLINOPYROXENE TRACE APATITE TRACE ZEOLITE 7% OXIDE	HAWAIIITE	N.A
M36B4007	FRESH, PORPHYRITIC HOLOCYSTALLINE INTERGRANULAR	9% PLAGIOCLASE 2% OLIVINE 1% CLINOPYROXENE 1% IDINGSITE	50% PLAGIOCLASE 20% OLIVINE * 12% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B4008	FRESH, PORPHYRITIC HOLOCYSTALLINE INTERGRANULAR	15% PLAGIOCLASE 2% OLIVINE 1% CLINOPYROXENE 1% IDINGSITE	50% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 6% OXIDE	HAWAIIITE	N.A
M36B4009	FRESH, APHANITIC HYPOCRYSTALLINE VESICULAR	5% PLAGIOCLASE 3% OLIVINE 1% CLINOPYROXENE	50% PLAGIOCLASE 20% OLIVINE 16% CLINOPYROXENE TRACE APATITE 6% OXIDE	HAWAIIITE	OL-HAWAIIITE
M36B4012	FRESH, VESICULAR APHANITIC, HYPOCRYSTALLINE	2% PLAGIOCLASE 1% OLIVINE	55% PLAGIOCLASE 25% OLIVINE 12% CLINOPYROXENE TRACE KAERSUTITE 5% OXIDE	HAWAIIITE	OL-HAWAIIITE
M36B4013	FRESH, APHANITIC HYPOCRYSTALLINE	6% PLAGIOCLASE 1% OLIVINE 1% CLINOPYROXENE	52% PLAGIOCLASE 20% OLIVINE 15% CLINOPYROXENE TRACE KAERSUTITE 5% OXIDE	HAWAIIITE	N.A
M36B4014	FRESH, VESICULAR PORPHYRITIC, HOLOCYSTALLINE INTERGRANULAR	10% PLAGIOCLASE 1% CLINOPYROXENE 1% OLIVINE *	50% PLAGIOCLASE 17% CLINOPYROXENE 16% OLIVINE * 5% OXIDE	HAWAIIITE	N.A
M36B4015	FRESH, HYPOCRYSTALLINE SUB-TRACHYTOID, APHANITIC INTERGRANULAR	12% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	50% PLAGIOCLASE 13% CLINOPYROXENE 12% OLIVINE 9% OXIDE	HAWAIIITE	N.A
M36B4016	FRESH, PORPHYRITIC HOLOCYSTALLINE INTERGRANULAR	15% PLAGIOCLASE 2% CLINOPYROXENE	43% PLAGIOCLASE 20% OLIVINE 15% CLINOPYROXENE TRACE APATITE 5% OXIDE	BASALT	N.A
M36B4017	FRESH, APHANITIC HYPOCRYSTALLINE SUB-TRACHYTOID		53% PLAGIOCLASE 17% CLINOPYROXENE 12% OLIVINE 5% OXIDE 13% GLASS	HAWAIIITE	N.A
M36B4018	FRESH, PORPHYRITIC HOLOCYSTALLINE INTERGRANULAR	12% PLAGIOCLASE 3% OLIVINE 2% CLINOPYROXENE	50% PLAGIOCLASE 15% CLINOPYROXENE 13% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B4019	FRESH, PORPHYRITIC HOLOCYSTALLINE	11% PLAGIOCLASE 4% OLIVINE 2% CLINOPYROXENE <1% OXIDE	47% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B4020	FRESH, PORPHYRITIC HOLOCYSTALLINE INTERGRANULAR	8% PLAGIOCLASE 3% OLIVINE 3% CLINOPYROXENE	48% PLAGIOCLASE 20% OLIVINE 10% CLINOPYROXENE 4% CALCITE TRACE APATITE TRACE HYPERSTINE 4% OXIDE	HAWAIIITE	He-HAWAIIITE

M36B4021	FRESH, VESICULAR, HOLOCRYSTALLINE, PORPHYRITIC INTERGRANULAR	8% PLAGIOCLASE 3% OLIVINE 1% CLINOPYROXENE	52% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 7% OXIDE	HAWAIIITE	OL-HAWAIIITE
M36B4023	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	11% PLAGIOCLASE 3% OLIVINE 2% CLINOPYROXENE	48% PLAGIOCLASE 16% CLINOPYROXENE 15% OLIVINE TRACE APATITE 5% OXIDE	HAWAIIITE	N.A
M36B4024	FRESH, PORPHYRITIC HOLOCRYSTALLINE	8% PLAGIOCLASE 2% OLIVINE * 1% CLINOPYROXENE	48% PLAGIOCLASE 21% OLIVINE * 10% CLINOPYROXENE TRACE APATITE 10% OXIDE	HAWAIIITE	OL-HAWAIIITE
M36B4025	FRESH, PORPHYRITIC HOLOCRYSTALLINE	7% PLAGIOCLASE 3% OLIVINE 1% CLINOPYROXENE < 1% OXIDE	48% PLAGIOCLASE 19% OLIVINE 15% CLINOPYROXENE 7% OXIDE	HAWAIIITE	N.A
M36B4026	FRESH, HYPOCRYSTALLINE APHANITIC, SUB-TRACHYTOID	8% PLAGIOCLASE 3% OLIVINE 1% CLINOPYROXENE	52% PLAGIOCLASE 18% CLINOPYROXENE 12% OLIVINE 6% OXIDE	HAWAIIITE	N.A
M36B4027	FRESH, PORPHYRITIC HYPOCRYSTALLINE INTERGRANULAR	12% PLAGIOCLASE 4% OLIVINE 2% CLINOPYROXENE	50% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE TRACE APATITE 7% OXIDE	HAWAIIITE	N.A
M36B4028	MODERATELY WEATHERED VESICULAR, HOLOCRYSTALLINE	25% PLAGIOCLASE 2% ALTERED OLIVINE < 1% ALTERED CLINOPYROXENE	43% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 5% OXIDE	TRACHYTE	N.A
M36B4029	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	15% PLAGIOCLASE 5% OLIVINE 2% CLINOPYROXENE	45% PLAGIOCLASE 13% OLIVINE 12% CLINOPYROXENE 8% OXIDE	HAWAIIITE	N.A
M36B4030	FRESH, APHANITIC HYPOCRYSTALLINE	4% PLAGIOCLASE 1% OLIVINE <1% CLINOPYROXENE TRACE APATITE	60% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B4031	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	15% PLAGIOCLASE 3% OLIVINE * 1% CLINOPYROXENE	45% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 6% OXIDE	HAWAIIITE	N.A
M36B4032	FRESH, PORPHYRITIC HOLOCRYSTALLINE	13% PLAGIOCLASE 3% OLIVINE * 1% CLINOPYROXENE < 1% OXIDE	42% PLAGIOCLASE 20% CLINOPYROXENE 15% OLIVINE TRACE APATITE 6% OXIDE	HAWAIIITE	N.A
M36B4033	FRESH, HOLOCRYSTALLINE MICRO-PORPHYRITIC SUB-TRACHYTOID	8% PLAGIOCLASE 1% CLINOPYROXENE 1% OLIVINE	50% PLAGIOCLASE 18% OLIVINE 14% CLINOPYROXENE 8% OXIDE	TRACHYTE	N.A
M36B4034	FRESH, PORPHYRITIC MICRO-VESICULAR HOLOCRYSTALLINE INTERGRANULAR	15% OLIVINE 2% CLINOPYROXENE < 1% PLAGIOCLASE	48% PLAGIOCLASE 25% OLIVINE 15% CLINOPYROXENE TRACE APATITE 5% OXIDE	OLIVINE- BASALT	N.A
M36B4035	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	11% PLAGIOCLASE 2% OLIVINE 1% CLINOPYROXENE	50% PLAGIOCLASE 17% OLIVINE 10% CLINOPYROXENE 9% OXIDE	HAWAIIITE	N.A



M36B4036	FRESH, HYPOCRYSTALLINE MICRO-PORPHYRITIC	9% OLIVINE 2% PLAGIOCLASE 1% CLINOPYROXENE	45% PLAGIOCLASE 20% OLIVINE 14% CLINOPYROXENE 3% APATITE 7% OXIDE	OLIVINE- BASALT	N.A
M36B4037	FRESH, PORPHYRITIC HOLOCRYSTALLINE VESICULAR	11% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE *	51% PLAGIOCLASE 15% CLINOPYROXENE 14% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B4038	FRESH, PORPHYRITIC HOLOCRYSTALLINE	9% PLAGIOCLASE 3% OLIVINE *	47% PLAGIOCLASE 15% OLIVINE 12% CLINOPYROXENE 5% OXIDE 8% GLASS	HAWAIIITE	N.A
M36B4039	FRESH, PORPHYRITIC HOLOCRYSTALLINE	6% PLAGIOCLASE 2% OLIVINE * 1% CLINOPYROXENE	56% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 10% OXIDE	HAWAIIITE	N.A
M36B4040	FRESH, PORPHYRITIC HOLOCRYSTALLINE SUB-TRACHYTOID	9% PLAGIOCLASE 2% OLIVINE * 2% CLINOPYROXENE	50% PLAGIOCLASE 17% OLIVINE 15% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B4041	FRESH, PORPHYRITIC HOLOCRYSTALLINE	12% PLAGIOCLASE 3% OLIVINE 3% CLINOPYROXENE	46% PLAGIOCLASE 16% CLINOPYROXENE 15% OLIVINE 5% OXIDE	HAWAIIITE	N.A
M36B4042	FRESH, PORPHYRITIC HOLOCRYSTALLINE VESICULAR	6% PLAGIOCLASE 1% CLINOPYROXENE < 1% OLIVINE *	53% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 5% OXIDE 10% GLASS	HAWAIIITE	N.A
M36B4043	FRESH, VESICULAR PORPHYRITIC SUB-TRACHYTOID	7% PLAGIOCLASE 1% OLIVINE *	52% PLAGIOCLASE 10% CLINOPYROXENE 10% OLIVINE 5% OXIDE 15% GLASS	HAWAIIITE	N.A
M36B4044	FRESH, VESICULAR PORPHYRITIC HYPOCRYSTALLINE	7% PLAGIOCLASE 1% OLIVINE * 1% CLINOPYROXENE	44% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 7% OXIDE 10% GLASS	HAWAIIITE	N.A
M36B4045	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	13% PLAGIOCLASE 3% OLIVINE * 1% CLINOPYROXENE TRACE KAERSUTITE TRACE APATITE	48% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 10% OXIDE	HAWAIIITE	N.A
M36B4300	MODERATELY FRESH HOLOCRYSTALLINE PORPHYRITIC	12% PLAGIOCLASE 3% ALTERED OLIVINE	55% PLAGIOCLASE 20% OLIVINE 10% CLINOPYROXENE	HAWAIIITE	N.A
M36B4301	MODERATELY FRESH HOLOCRYSTALLINE PORPHYRITIC	10% PLAGIOCLASE 3% OLIVINE * 2% CLINOPYROXENE	50% PLAGIOCLASE 17% OLIVINE 13% CLINOPYROXENE 5% OXIDE	HAWAIIITE	OL-HAWAIIITE
M36B4303	MODERATELY FRESH HOLOCRYSTALLINE PORPHYRITIC	8% PLAGIOCLASE 4% OLIVINE *	53% PLAGIOCLASE 18% OLIVINE 12% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B4321	MODERATELY FRESH VESICULAR SUB-TRACHYTOID	3% PLAGIOCLASE	65% PLAGIOCLASE 20% CLINOPYROXENE 7% OLIVINE 5% OXIDE	TRACHYTE	N.A

M364339	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	10% PLAGIOCLASE 2% IDINGSITE 1% OLIVINE 1% CLINOPYROXENE	54% PLAGIOCLASE 14% OLIVINE 10% CLINOPYROXENE TRACE ORTHOPYROXENE TRACE APATITE 8% OXIDE	HAWAIIITE	N.A
M36B4341	FRESH, PORPHYRITIC HOLOCRYSTALLINE	9% PLAGIOCLASE 2% IDINGSITE 2% OLIVINE < 1% CLINOPYROXENE	52% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B4342	MODERATELY FRESH PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	12% PLAGIOCLASE 2% OLIVINE 2% CLINOPYROXENE	46% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE 8% OXIDE	HAWAIIITE	N.A
M36B4352	MODERATELY WEATHERED PORPHYRITIC HOLOCRYSTALLINE	12% PLAGIOCLASE 3% ALTERED OLIVINE 1% CLINOPYROXENE	49% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 5% CALCITE 5% OXIDE	HAWAIIITE	BASALT
M36B4356	MODERATELY WEATHERED HOLOCRYSTALLINE SUB-TRACHYTOID PORPHYRITIC	7% PLAGIOCLASE 2% OLIVINE 1% IDINGSITE < 1% CLINOPYROXENE	55% PLAGIOCLASE 17% OLIVINE 10% CLINOPYROXENE 5% OXIDE 4% CALCITE	HAWAIIITE	Hy-HAWAIIITE
M36B4360	FRESH, PORPHYRITIC HOLOCRYSTALLINE	16% PLAGIOCLASE 2% OLIVINE 2% CLINOPYROXENE	50% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B4408	FRESH, PORPHYRITIC HOLOCRYSTALLINE INTERGRANULAR	12% PLAGIOCLASE 4% OLIVINE * 1% CLINOPYROXENE	45% PLAGIOCLASE 16% CLINOPYROXENE 14% OLIVINE 8% OXIDE	HAWAIIITE	N.A
M36B4410	MODERATELY FRESH HYPOCRYSTALLINE	10% PLAGIOCLASE 1% CLINOPYROXENE < 1% OLIVINE	56% PLAGIOCLASE 20% CLINOPYROXENE 8% OLIVINE 5% OXIDE	TRACHYTE	Qz-TRACHYTE
M36B4596	FRESH, HOLOCRYSTALLINE PORPHYRITIC INTERGRANULAR	9% PLAGIOCLASE 3% OLIVINE 1% IDINGSITE	51% PLAGIOCLASE 20% OLIVINE 10% CLINOPYROXENE TRACE APATITE 6% OXIDE	HAWAIIITE	Hy-HAWAIIITE
M36B4613	FRESH, PORPHYRITIC HYPOCRYSTALLINE SUB-TRACHYTOID	12% PLAGIOCLASE 3% CLINOPYROXENE	51% PLAGIOCLASE 20% CLINOPYROXENE 8% OLIVINE TRACE ORTHOPYROXENE 6% OXIDE	TRACHYTE	Qz-BENMOREITE
M36B4619	MODERATELY FRESH HOLOCRYSTALLINE PORPHYRITIC	9% PLAGIOCLASE 3% OLIVINE	54% PLAGIOCLASE 15% OLIVINE 15% CLINOPYROXENE TRACE APATITE 4% OXIDE	HAWAIIITE	Ol-HAWAIIITE
M36B4634	FRESH, PORPHYRITIC SUB-TRACHYTOID	12% PLAGIOCLASE 2% CLINOPYROXENE	46% PLAGIOCLASE 22% CLINOPYROXENE 10% OLIVINE 8% OXIDE	TRACHYTE	Hy-BENMOREITE
M36B4866	FRESH, VESICULAR HYPOCRYSTALLINE SUB-TRACHYTOID	12% PLAGIOCLASE 3% OLIVINE * 1% CLINOPYROXENE	50% PLAGIOCLASE 15% CLINOPYROXENE 14% OLIVINE TRACE ORTHOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B4891	MODERATELY FRESH	11% PLAGIOCLASE	50% PLAGIOCLASE	HAWAIIITE	N.A

	HOLOCYSTALLINE PORPHYRITIC	3% OLIVINE 1% IDINGSITE 1% CLINOPYROXENE	15% CLINOPYROXENE 10% OLIVINE 9% OXIDE		
M36B4902	FRESH, PORPHYRITIC HOLOCYSTALLINE INTERGRANULAR	10% PLAGIOCLASE 4% OLIVINE 1% IDINGSITE 1% OXIDE	40% PLAGIOCLASE 20% OLIVINE 17% CLINOPYROXENE 7% OXIDE	HAWAIIITE	N.A
M36B4905	FRESH, PORPHYRITIC HOLOCYSTALLINE	8% PLAGIOCLASE 1% CLINOPYROXENE 1% IDINGSITE	45% PLAGIOCLASE 20% OLIVINE 15% CLINOPYROXENE 10% OXIDE	HAWAIIITE	N.A
M36B4908	FRESH, PORPHYRITIC HOLOCYSTALLINE INTERGRANULAR	10% PLAGIOCLASE 2% OLIVINE 1% IDINGSITE 3% CLINOPYROXENE 1% OXIDE	47% PLAGIOCLASE 13% OLIVINE 13% CLINOPYROXENE 10% OXIDE	HAWAIIITE	N.A
M36B4914	FRESH, PORPHYRITIC HYPOCRYSTALLINE	10% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE 1% OXIDE	50% PLAGIOCLASE 12% CLINOPYR 13% OLIVINE 10% OXIDE	HAWAIIITE	N.A
M36B4915	MODERATELY WEATHERED HYPOCRYSTALLINE PORPHYRITIC	10% PLAGIOCLASE 3% ALTERED OLIVINE	54% PLAGIOCLASE 13% CLINOPYROXENE 12% ALTERED OLIVINE 8% OXIDE	HAWAIIITE	N.A
M36B4916	MODERATELY WEATHERED HYPOCRYSTALLINE	8% PLAGIOCLASE 2% OLIVINE	50% PLAGIOCLASE 12% CLINOPYROXENE 12% OLIVINE 6% OXIDE 10% GLASS	HAWAIIITE	N.A
M36B5376	MODERATELY WEATHERED HOLOCYSTALLINE PORPHYRITIC	11% PLAGIOCLASE 5% OLIVINE < 1% CLINOPYROXENE	46% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 4% CALCITE 8% OXIDE	MUGEARITE	N.A
M36B5429	MODERATELY WEATHERED HYPOCRYSTALLINE PORPHYRITIC	10% PLAGIOCLASE 2% CLINOPYROXENE 1% OLIVINE	54% PLAGIOCLASE 18% CLINOPYROXENE 5% OXIDE 10% GLASS	TRACHYTE	N.A
M36B5440	MODERATELY WEATHERED PORPHYRITIC	8% PLAGIOCLASE 3% CLINOPYROXENE 1% OLIVINE	50% PLAGIOCLASE 18% CLINOPYROXENE TRACE APATITE TRACE QUARTZ 10% OXIDE 10% GLASS	TRACHYTE	Qz-BENMOREITE
M36B5441	MODERATELY FRESH HOLOCYSTALLINE PORPHYRITIC	11% PLAGIOCLASE 3% OLIVINE 1% CLINOPYROXENE	45% PLAGIOCLASE 20% OLIVINE 15% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B5443	MODERATELY FRESH HOLOCYSTALLINE PORPHYRITIC	14% PLAGIOCLASE 4% OLIVINE 2% ALTERED CLINOPYROXENE	45% PLAGIOCLASE 18% OLIVINE 12% CLINOPYROXENE TRACE APATITE 5% OXIDE	HAWAIIITE	OL-HAWAIIITE
M36A5478	MODERATELY WEATHERED PORPHYRITIC	15% PLAGIOCLASE 4% CLINOPYROXENE < 1% OLIVINE	44% PLAGIOCLASE 16% CLINOPYROXENE 10% OXIDE 10% GLASS	TRACHYTE	N.A
M36A5482	MODERATELY WEATHERED HOLOCYSTALLINE	15% PLAGIOCLASE 4% CLINOPYROXENE < 1% OLIVINE	44% PLAGIOCLASE 20% CLINOPYROXENE 7% OXIDE	TRACHYTE	N.A



			10% GLASS		
N36A5508	MODERATELY FRESH HOLOCRYSTALLINE PORPHYRITIC INTERGRANULAR	13% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE 1% IDdingsite 1% OXIDE	45% PLAGIOCLASE 12% OLIVINE 10% CLINOPYROXENE TRACE APATITE 8% OXIDE 6% GLASS	HAWAIIITE	Qz-HAWAIIITE
N36A5509	MODERATELY FRESH HOLOCRYSTALLINE PORPHYRITIC INTERGRANULAR	12% PLAGIOCLASE 4% OLIVINE 1% CLINOPYROXENE < 1% OXIDE	45% PLAGIOCLASE 20% OLIVINE 10% CLINOPYROXENE 7% OXIDE	HAWAIIITE	Qz-HAWAIIITE
N36A5518	FRESH, HOLOCRYSTALLINE PORPHYRITIC INTERGRANULAR	10% PLAGIOCLASE 5% OLIVINE 1% CLINOPYROXENE < 1% OXIDE	53% PLAGIOCLASE 14% CLINOPYROXENE 12% OLIVINE <1% ORTHOPYROXENE 5% OXIDE	HAWAIIITE	N.A
N36A5520	FRESH, HOLOCRYSTALLINE PORPHYRITIC INTERGRANULAR	12% PLAGIOCLASE 3% OLIVINE * 2% CLINOPYROXENE < 1% OXIDE	42% PLAGIOCLASE 18% OLIVINE 15% CLINOPYROXENE 7% OXIDE	HAWAIIITE	N.A
N36A5531	FRESH, HOLOCRYSTALLINE INTERGRANULAR	11% PLAGIOCLASE 2% OLIVINE * 2% CLINOPYROXENE	55% PLAGIOCLASE 15% OLIVINE 10% CLINOPYROXENE 1% ORTHOPYROXENE 5% OXIDE	HAWAIIITE	N.A
N36A5563	FRESH, HYPOCRYSTALLINE PORPHYRITIC	13% PLAGIOCLASE < 1% CLINOPYROXENE	55% PLAGIOCLASE 17% CLINOPYROXENE 15% GLASS	TRACHYTE	Qz-TRACHYTE
N36A5568	FRESH, HYPOCRYSTALLINE APHANITIC	< 1% PLAGIOCLASE < 1% CLINOPYROXENE	62% PLAGIOCLASE 15% CLINOPYROXENE 23% GLASS	TRACHYTE	N.A
M36B5751A	CRYSTAL TUFF AS FOR M36B3205				
M36B5758	MODERATELY FRESH HYPOCRYSTALLINE SUB-TRACHYTOID	8% PLAGIOCLASE 1% CLINOPYROXENE < 1% OLIVINE	63% PLAGIOCLASE 11% CLINOPYROXENE 8% OXIDE 10% GLASS	TRACHYTE	N.A
M36B5759	MODERATELY FRESH HOLOCRYSTALLINE PORPHYRITIC	10% PLAGIOCLASE 2% CLINOPYROXENE < 1% OLIVINE	60% PLAGIOCLASE 19% CLINOPYROXENE 8% OXIDE	TRACHYTE	N.A
M36B5766	FRESH, PORPHYRITIC HOLOCRYSTALLINE	15% PLAGIOCLASE 2% OLIVINE 1% CLINOPYROXENE	46% PLAGIOCLASE 14% CLINOPYROXENE 12% OLIVINE 10% OXIDE TRACE APATITE	HAWAIIITE	Qz-HAWAIIITE
M36B5768	FRESH, HOLOCRYSTALLINE PORPHYRITIC, INTERGRANULAR	13% PLAGIOCLASE 3% OLIVINE 2% CLINOPYROXENE	53% PLAGIOCLASE 13% OLIVINE 12% CLINOPYROXENE TRACE APATITE 5% OXIDE	HAWAIIITE	Ol-HAWAIIITE
M36B5772	FRESH, HOLOCRYSTALLINE PORPHYRITIC	15% PLAGIOCLASE 3% OLIVINE 1% CLINOPYROXENE	46% PLAGIOCLASE 20% OLIVINE 10% CLINOPYROXENE TRACE APATITE TRACE CALCITE 6% OXIDE	HAWAIIITE	Ol-HAWAIIITE
N36A5781	FRESH, HYPOCRYSTALLINE PORPHYRITIC, SUB-TRACHYTOID	12% PLAGIOCLASE 2% OLIVINE 1% CLINOPYROXENE	50% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE 5% OXIDE	HAWAIIITE	N.A
N36A5791	FRESH, HOLOCRYSTALLINE	12% PLAGIOCLASE	46% PLAGIOCLASE	MUGEARITE	Hy-BENMOREITE

	PORPHYRITIC SUB-TRACHYTOID	2% CLINOPYROXENE 2% OLIVINE 2% IDDINGSITE 1% KAERSUTITE	20% OLIVINE 10% CLINOPYROXENE 6% OXIDE		
M36B5792	MODERATELY WEATHERED PORPHYRITIC	14% PLAGIOCLASE 3% CLINOPYROXENE 1% OLIVINE	45% PLAGIOCLASE 15% CLINOPYROXENE 10% OLIVINE 2% ORTHOPYROXENE 10% OXIDE	MUGEARITE	Qz-BENMOREITE
N36A5811	FRESH, HOLOCYSTALLINE PORPHYRITIC	12% PLAGIOCLASE 2% CLINOPYROXENE 1% OLIVINE	50% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE 5% OXIDE	MUGEARITE	N.A
N36A5822	MODERATELY FRESH HOLOCYSTALLINE PORPHYRITIC INTERGRANULAR	12% PLAGIOCLASE 3% CLINOPYROXENE 2% OLIVINE	50% PLAGIOCLASE 14% OLIVINE 13% CLINOPYROXENE TRACE KAERSUTITE 6% OXIDE	MUGEARITE	Qz-BENMOREITE
N36A5824	FRESH, HYPOCRYSTALLINE SUB-TRACHYTOID	11% PLAGIOCLASE 2% CLINOPYROXENE 2% OLIVINE	53% PLAGIOCLASE 13% CLINOPYROXENE 12% OLIVINE 7% OXIDE	MUGEARITE	MUGEARITE
N36A5825	FRESH, HOLOCYSTALLINE PORPHYRITIC	15% PLAGIOCLASE 5% OLIVINE * 2% CLINOPYROXENE	50% PLAGIOCLASE 12% CLINOPYROXENE 11% OLIVINE TRACE APATITE 5% OXIDE	MUGEARITE	N.A
N36A5826	MODERATELY WEATHERED HOLOCYSTALLINE PORPHYRITIC	11% PLAGIOCLASE 4% OLIVINE 2% CLINOPYROXENE	50% PLAGIOCLASE 14% CLINOPYROXENE 14% OLIVINE 5% OXIDE	HAWAIIITE	Hy-HAWAIIITE
M36B5830	MODERATELY FRESH HOLOCYSTALLINE PORPHYRITIC	15% PLAGIOCLASE 4% OLIVINE 1% CLINOPYROXENE	45% PLAGIOCLASE 20% OLIVINE 10% CLINOPYROXENE 5% OXIDE	HAWAIIITE	N.A
M36B5852	MODERATELY WEATHERED HOLOCYSTALLINE PORPHYRITIC SUB-TRACHYTOID	12% PLAGIOCLASE 3% CLINOPYROXENE 3% OLIVINE	47% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE TRACE APATITE 5% OXIDE	HAWAIIITE	N.A
N36A5853	FRESH, HOLOCYSTALLINE PORPHYRITIC	15% PLAGIOCLASE 6% OLIVINE 3% CLINOPYROXENE	42% PLAGIOCLASE 12% CLINOPYROXENE 12% OLIVINE 10% OXIDE	HAWAIIITE	N.A
N36A5854	FRESH, HOLOCYSTALLINE PORPHYRITIC SUB-TRACHYTOID	12% PLAGIOCLASE 4% OLIVINE 2% CLINOPYROXENE	46% PLAGIOCLASE 15% CLINOPYROXENE 15% OLIVINE 5% OXIDE	HAWAIIITE	N.A

NOTE:-N.A = NOT ANALYZED

APPENDIX III B

SAMPLE DESCRIPTIONS

SAMPLE	ROCK TYPE	NAME	VOLCANIC PHASE	GROUP	FORMATION
M36B2046A	INT	TRACHYTE	LATE	LYTTELTON	MT PLEASANT
(M36B6a)	INT	Ne-TRACHYTE	LATE	LYTTELTON	MT PLEASANT
M36B2046B	INT	TRACHYTE	MAIN	LYTTELTON	
M36B2047	DIKE	HAWAIIITE	LATE	LYTTELTON	MT PLEASANT
(M36B24)	DIKE	01-HAWAIIITE	LATE	LYTTELTON	
M36B2048	FLOW	HAWAIIITE	MAIN	LYTTELTON	
(M36B29)	FLOW	01-HAWAIIITE	MAIN	LYTTELTON	
M36B2051	FLOW	HAWAIIITE	LATE	LYTTELTON	MT PLEASANT
M36B2052	DIKE	TRACHYTE	MAIN	LYTTELTON	
(M36B50d)	DIKE	TRACHYTE	MAIN	LYTTELTON	
M36B2054	DIKE	TRACHYTE	MAIN	LYTTELTON	
M36B2055	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2056	FLOW	MUGEARITE	MAIN	LYTTELTON	
M36B2059	FLOW	MUGEARITE	MAIN	LYTTELTON	
M36B2060	DIKE	HAWAIIITE	MAIN	LYTTELTON	
M36B2061	DIKE	TRACHYTE	MAIN	LYTTELTON	
M36B2063	DIKE	01-MUGEARITE	MAIN	LYTTELTON	
(M36B37)	DIKE	01-MUGEARITE	MAIN	LYTTELTON	
M36B2066	DIKE	MUGEARITE	LATE	LYTTELTON	MT PLEASANT
M36B2067	DIKE	TRACHYTE	MAIN	LYTTELTON	
M36B2068	FLOW	HAWAIIITE	LATE	LYTTELTON	MT PLEASANT
M36B2069	FLOW	MUGEARITE	LATE	LYTTELTON	MT PLEASANT
M36B2071	FLOW	HAWAIIITE	LATE	LYTTELTON	MT PLEASANT
M36B2072	FLOW	01-MUGEARITE	MAIN	LYTTELTON	
(M36B33)	FLOW	01-HAWAIIITE	MAIN	LYTTELTON	
M36B2073	FLOW	MUGEARITE	MAIN	LYTTELTON	
M36B2074	FLOW	MUGEARITE	MAIN	LYTTELTON	

M36B2076	SILL	TRACHYTE	MAIN	LYTTELTON	
(M36B56)	SILL	Qz-TRACHYTE	MAIN	LYTTELTON	
M36B2078	SILL	TRACHYTE	MAIN	LYTTELTON	
M36B2082	DIKE	TRACHYTE	MAIN	LYTTELTON	
(M36B53)	DIKE	TRACHYTE	MAIN	LYTTELTON	
M36B2083	FLOW	MUGEARITE	MAIN	LYTTELTON	
M36B2087	FLOW	Hy-HAWAIIITE	MAIN	LYTTELTON	
(M36B31)	FLOW	Hy-HAWAIIITE	MAIN	LYTTELTON	
M36B2088	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2089	FLOW	MUGEARITE	MAIN	LYTTELTON	
M36B2091	FLOW	BASALT	MAIN	LYTTELTON	
M36B2094	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2096	DIKE	HAWAIIITE	MAIN	LYTTELTON	
M6B62100B	FLOW	MUGEARITE	MAIN	LYTTELTON	
M36B2101	LAHAR	HTB	LATE	LYTTELTON	MT PLEASANT
M362102	FLOW	MUGEARITE	MAIN	LYTTELTON	
M36B2103A	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2103B	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2105A	FLOW	MUGEARITE	LATE	LYTTELTON	MT PLEASANT
M36B2105B	FLOW	MUGEARITE	LATE	LYTTELTON	MT PLEASANT
M36B2117A	FLOW	BASALT	MAIN	LYTTELTON	
M36B2117B	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2139	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2151	PLUG	Ne-TRACHYTE	MAIN	LYTTELTON	
M36B2155	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2156A	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2156B	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2157	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2158A	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2158B	FLOW	HAWAIIITE	MAIN	LYTTELTON	
M36B2162	FLOW	Qz-HAWAIIITE	MAIN	LYTTELTON	
M36B2163	FLOW	BASALT	MAIN	LYTTELTON	
M36B2164A	FLOW	01-HAWAIIITE	LATE	LYTTELTON	MT PLEASANT
(M36B49)	FLOW	01-HAWAIIITE	LATE	LYTTELTON	MT PLEASANT
M36B2164B	FLOW	01-MUGEARITE	LATE	LYTTELTON	MT PLEASANT
M36B2164C	FLOW	01-HAWAIIITE	LATE	LYTTELTON	MT PLEASANT
M36B2165A	FLOW	01-HAWAIIITE	LATE	LYTTELTON	MT PLEASANT



M36B2165B	FLOW	O1-MUGEARITE	LATE	LYTTELTON	MT PLEASANT
M36B2165C	FLOW	O1-MUGEARITE	LATE	LYTTELTON	MT PLEASANT
M36B2166	FLOW	HAWAIITE	MAIN	LYTTELTON	
M36B2652	FLOW	Qz-BENMOREITE	MAIN	LYTTELTON	
M36B2659	FLOW	Fe-ALTERED	MAIN	LYTTELTON	
M36B2714	FLOW	HAWAIITE	MAIN	LYTTELTON	
M36B2732	FLOW	ANDESITE	MAIN	LYTTELTON	
M36B2745	FLOW	HAWAIITE	MAIN	LYTTELTON	

M36B3192	FLOW	HAWAIITE	MAIN	LYTTELTON	
M36B3205	TUFF	CRYSTAL-TUFF	LATE	LYTTELTON	
M36B3250	FLOW	Qz-BENMOREITE	LATE	LYTTELTON	MT PLEASANT
M36B3271	FLOW	O1-HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B3272	FLOW	O1-HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B3280	FLOW	HAWAIITE	MAIN	LYTTELTON	MT PLEASANT
M36B3281	FLOW	Qz-TRACHYTE	MAIN	LYTTELTON	
M36B3286	FLOW	Hy-HAWAIITE	MAIN	LYTTELTON	
M36B3572	FLOW	Qz-TRACHYTE	MAIN	LYTTELTON	
(M36B60)	FLOW	Qz-TRACHYTE	MAIN	LYTTELTON	
M36B3580	FLOW	TRACHYTE	MAIN	LYTTELTON	
M36B3582	FLOW	HAWAIITE	MAIN	LYTTELTON	
M36B3677	FLOW	Qz-TRACHYTE	MAIN	LYTTELTON	
M36B3678	FLOW	Hy-HAWAIITE	MAIN	LYTTELTON	

M36B4001	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4002	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4003	FLOW	Qz-TRACHYTE	LATE	LYTTELTON	MT PLEASANT
M36B4004	FLOW	TRACHYTE	LATE	LYTTELTON	MT PLEASANT
M36B4005	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4006	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4007	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4008	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4009	FLOW	O1-HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4012	FLOW	O1-HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4013	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT

M36B4014	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4015	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4016	DIKE	OLIVINE-BASALT	LATE	LYTTELTON	MT PLEASANT
M36B4017	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4018	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4019	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4020	FLOW	Ne-HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4021	FLOW	O1-HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4023	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4024	FLOW	O1-HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4025	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4026	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4027	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4028	FLOW	TRACHYTE	LATE	LYTTELTON	MT PLEASANT
M36B4029	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4030	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4031	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4032	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4033	DIKE	TRACHYTE	LATE	LYTTELTON	MT PLEASANT
M36B4034	DIKE	OLIVINE-BASALT	LATE	LYTTELTON	MT PLEASANT
M36B4035	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4036	DIKE	OLIVINE-BASALT	LATE	LYTTELTON	MT PLEASANT
M36B4037	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4038	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4039	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4040	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4041	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4042	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4043	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4044	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4045	FLOW	HAWAIITE	LATE	LYTTELTON	MT PLEASANT
M36B4300	FLOW	HAWAIITE	MAIN	LYTTELTON	
M36B4301	FLOW	O1-HAWAIITE	MAIN	LYTTELTON	
M36B4303	FLOW	HAWAIITE	MAIN	LYTTELTON	
M36B4321	DIKE	TRACHYTE	MAIN	LYTTELTON	
M36B4339	FLOW	HAWAIITE	MAIN	LYTTELTON	

M36B4341	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4342	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4352	FLOW	BASALT	MAIN	LYTTELTON
M36B4356	FLOW	Hy-HAWAIIITE	MAIN	LYTTELTON
M36B4358	FLOW	Hy-HAWAIIITE	MAIN	LYTTELTON
M36B4360	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4408	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4410	FLOW	Qz-TRACHYTE	MAIN	LYTTELTON
M36B4596	FLOW	Hy-HAWAIIITE	MAIN	LYTTELTON
M36B4613	FLOW	Qz-BENMOREITE	MAIN	LYTTELTON
M36B4619	FLOW	O1-HAWAIIITE	MAIN	LYTTELTON
M36B4634	FLOW	Hy-BENMOREITE	MAIN	LYTTELTON
M36B4866	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4891	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4902	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4905	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4906	FLOW	O1-HAWAIIITE	MAIN	LYTTELTON
M36B4908	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4909	FLOW	Hy-BENMOREITE	MAIN	LYTTELTON
M36B4914	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4915	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B4916	FLOW	HAWAIIITE	MAIN	LYTTELTON

M36B5376	FLOW	MUGEARITE	MAIN	LYTTELTON
M36B5429	FLOW	TRACHYTE	MAIN	LYTTELTON
M36B5440	FLOW	Qz-BENMOREITE	MAIN	LYTTELTON
M36B5441	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B5443	FLOW	O1-HAWAIIITE	MAIN	LYTTELTON
N36A5478	FLOW	TRACHYTE	MAIN	LYTTELTON
N36A5482	FLOW	TRACHYTE	MAIN	LYTTELTON
N36A5508	FLOW	Qz-HAWAIIITE	MAIN	LYTTELTON
N36A5509	FLOW	Qz-HAWAIIITE	MAIN	LYTTELTON
N36A5518	FLOW	HAWAIIITE	MAIN	LYTTELTON
N36A5520	FLOW	HAWAIIITE	MAIN	LYTTELTON
N36A5531	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B5563	SILL	Qz-TRACHYTE	MAIN	LYTTELTON

M36B5568	FLOW	TRACHYTE	MAIN	LYTTELTON
M36B5751A	TUFF	CRYSTAL TUFF	MAIN	LYTTELTON
M36B5758	FLOW	TRACHYTE	MAIN	LYTTELTON
M36B5759	FLOW	TRACHYTE	MAIN	LYTTELTON
M36B5766	FLOW	Qz-HAWAIIITE	MAIN	LYTTELTON
M36B5768	FLOW	O1-HAWAIIITE	MAIN	LYTTELTON
M36B5772	FLOW	O1-HAWAIIITE	MAIN	LYTTELTON
N36A5781	FLOW	HAWAIIITE	MAIN	LYTTELTON
N36A5791	FLOW	Hy-BENMOREITE	MAIN	LYTTELTON
M36B5792	FLOW	Qz-BENMOREITE	MAIN	LYTTELTON
M36B5805	FLOW	O1-HAWAIIITE	MAIN	LYTTELTON
N36A5811	FLOW	MUGEARITE	MAIN	LYTTELTON
N36A5822	FLOW	Qz-BENMOREITE	MAIN	LYTTELTON
N36A5824	FLOW	MUGEARITE	MAIN	LYTTELTON
N36A5825	FLOW	MUGEARITE	MAIN	LYTTELTON
N36A5826	FLOW	Hy-HAWAIIITE	MAIN	LYTTELTON
M36B5830	FLOW	HAWAIIITE	MAIN	LYTTELTON
M36B5852	FLOW	HAWAIIITE	MAIN	LYTTELTON
N36A5853	FLOW	HAWAIIITE	MAIN	LYTTELTON
N36A5854	FLOW	HAWAIIITE	MAIN	LYTTELTON

NOTE HTB = HETEROLITHIC TUFF BRECCIA  
INT = INTRUSION

APPENDIX IV ANALYTICAL METHODSX-RAY FLUORESCENCE

All *major* element and *trace* element analyses were obtained using a Philips PW 1400 X-Ray Spectrometer coupled to a Hewlett-packard 300 computer using calibrations set up by S.A Brown and S.D Weaver in the Department of Geology University of Canterbury. Comparisons of results for international laboratory standards presented as a measure of accuracy of major and trace element determinations are presented in tables 5-A and 6-A respectively.

Samples were prepared for *major* element analyses using the method outlined by Norrish and Hutton (1969) with modifications after Harvey et al (1973) and Schroeder et al (1980). Glass beads were irradiated using a 3 kw Cr-tube operating at 50 kv and 50 ma. Loss on ignition was determined at 1000°C and may be positive (high H<sub>2</sub>O, CO<sub>2</sub> etc.) or negative (high FeO, low H<sub>2</sub>O etc.).

*Trace* element analyses were obtained on 50 mm pressed-powder pellets prepared from powdered rock bonded with 7% aqueous solution of polyvinyl alcohol. Pellets were analyzed for Zr, Nb, Ba, Ni, Cr, V, Nd, Ce, La, and Zn using a 3 kw Au tube, and for Y, Rb, Sr, Ga, Pb and Th using a 3 kw Mo tube. Both tubes operated at 90 kv and 30 ma. Mass absorption corrections were applied using Compton tube lines and coefficients calculated from major element analyses.



APPENDIX V MAIOR ELEMENT ANALYSIS AND C.I.P.W. NORMS[1] General

Total Fe was determined by XRF and expressed as total Fe<sub>2</sub>O<sub>3</sub>. For the purposes of CIPW norm calculations Fe<sub>2</sub>O<sub>3</sub> and FeO were calculated assuming Fe<sub>2</sub>O<sub>3</sub>/FeO=0.3. The CIPW Norm calculation was carried out using the GPP computer program. All major elements analyses and C.I.P.W Norms are in Wt.%. *ref. M'Barney*

[2] Normative minerals:-

Q = Quartz	Di = Diopside	Ol = Olivine
Or = Orthoclase	Wo = Wollastonite	Fo = Forsterite
Ab = Albite	Hy = Hypersthene	Fa = Fayalite
An = Anorthite	En = Enstatite	Mt = Magnetite
Ne = Nepheline	Fs = Ferrosilite	Il = Ilmenite
Lc = Leucite		Ap = Apatite
C = Corundum		

[3] Definitions for abbreviations

D.I = Differentiation Index = Q + Or + Ab + Ne + Ks + Lc

P.R = Plagioclase Ratio = (100 An) / (An + Ab)

Mafics = 100 (FeO + Fe<sub>2</sub>O<sub>3</sub>) / (Fe<sub>2</sub>O<sub>3</sub> + FeO + MgO)

Kunos = (100 MgO) / (MgO + FeO + Fe<sub>2</sub>O<sub>3</sub> + Na<sub>2</sub>O + K<sub>2</sub>O)

Fe as 2+ = (Fe<sub>2</sub>O<sub>3</sub> / 1.111) + Fe<sub>2</sub>O<sub>3</sub> + MnO

Alkali = Na<sub>2</sub>O + K<sub>2</sub>O

Fe<sub>2</sub> / Mg<sub>2</sub> = 100 Mg / (Mg + Fe<sub>2+</sub>)

Na / K Ratio = Na<sub>2</sub>O / K<sub>2</sub>O

Fe<sub>3+</sub> Fe<sub>2+</sub> Ratio = Fe<sub>2</sub>O<sub>3</sub> / FeO

FeIsic = 100 (Na + K) / (Na + K + Ca)

Plag = An + Ab

Colour = Ol + Di + Hy + Mt + Il + Hm

Ol = Fa + Fo

Di = Wo + En + Fs (Di)

Hy = En + Fs (Hy)

Pyx = Pyroxene

Plag = Plagioclase

This appendix contains two tables. Table 5A shows International standard results and table 5B gives major element analyses, C.I.P.W. normative mineralogy, selected ratios, and chemical data of samples from Lyttelton volcano.

	GH		NIM-G		GA		G-2		GSP-1		NIM-S		SY-2		ACV-1	
	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal
SiO <sub>2</sub>	75.85	75.24	75.72	75.94	69.96	70.01	69.19	69.35	67.31	68.10	63.65	64.24	60.09	59.70	59.72	59.57
TiO <sub>2</sub>	.08	.08	.09	.10	.38	.36	0.50	.48	.66	.66	.04	.05	.15	.14	1.05	1.05
Al <sub>2</sub> O <sub>3</sub>	12.51	12.49	12.09	12.18	14.51	14.69	15.35	15.28	15.19	15.22	17.37	17.36	12.15	12.02	17.22	17.08
Fe <sub>2</sub> O <sub>3</sub>	1.34	1.36	2.02	2.00	2.83	2.73	2.62	2.66	4.34	4.32	1.40	1.44	6.29	6.27	6.88	6.81
MnO	.05	.06	.02	.01	.09	.08	.04	.03	.04	.01	.01	.01	.32	.32	.10	.09
MgO	.03	.06	.04	.09	.95	.95	.77	.75	.96	.99	.46	.45	2.69	2.70	1.55	1.53
CaO	.69	.73	.78	.79	2.45	2.45	1.98	1.94	2.02	2.02	.66	.70	8.00	8.01	5.00	5.00
Na <sub>2</sub> O	3.85	3.86	3.30	3.34	3.55	3.52	4.06	4.10	2.80	2.85	.42	.37	4.35	4.25	4.31	4.12
K <sub>2</sub> O	4.76	4.75	5.00	5.06	4.03	4.06	4.52	4.49	5.53	5.58	15.38	15.15	4.51	4.44	2.93	2.90
P <sub>2</sub> O <sub>5</sub>	.01	.01	.02	.02	0.12	.13	0.14	.14	.28	.29	.12	.11	.44	.42	.50	.50
LOI	-	.47	-	.11	-	.82	-	.38	-	.63	-	.63	-	.77	-	.74
TOTAL	-	99.11	-	99.63	-	99.80	-	99.61	-	100.68	-	100.50	-	99.03	-	99.39

	W-1		NIM-N		NIM-L		PCC-1		DTS-1		MRG-1		NIM-D		BR	
	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal	Rec	Anal
SiO <sub>2</sub>	52.72	52.73	52.56	52.66	52.45	52.41	42.15	41.81	40.68	40.45	39.24	39.08	38.88	38.49	38.39	38.76
TiO <sub>2</sub>	1.07	1.07	.20	.20	.49	.49	.01	.02	.01	.01	3.75	3.72	.02	.03	2.61	2.65
Al <sub>2</sub> O <sub>3</sub>	14.87	15.13	16.54	16.63	13.59	13.54	.73	.72	.29	.29	8.56	8.44	.32	.39	10.25	10.13
Fe <sub>2</sub> O <sub>3</sub>	11.10	11.15	8.87	8.95	9.94	9.98	8.24	8.22	8.61	8.68	17.79	17.83	16.97	16.86	12.94	12.92
MnO	.17	.20	.18	.18	.76	.79	.12	.12	.11	.12	.17	.15	.22	.23	.20	.20
MgO	6.63	6.66	7.48	7.46	.28	.33	43.63	42.31	49.83	48.58	13.51	13.49	43.56	42.26	13.35	13.24
CaO	10.98	10.98	11.46	11.57	3.24	3.14	.53	.55	.15	.15	14.72	14.72	.28	.29	13.87	13.84
Na <sub>2</sub> O	2.15	2.15	2.46	2.47	8.30	8.45	.01	.03	.01	.03	.71	.58	.05	.05	3.07	2.90
K <sub>2</sub> O	.64	.63	.25	.24	5.46	5.43	.00	.00	.00	.00	.18	.18	.01	.00	1.41	1.37
P <sub>2</sub> O <sub>5</sub>	.14	.13	.03	.03	.06	.06	.00	.01	.00	.01	.07	.07	.02	.02	1.05	1.07
LOI	-	.38	-	.15	-	2.59	-	4.01	-	.22	-	.84	-	.78	-	2.40
TOTAL	-	100.46	-	100.24	-	97.19	-	97.73	-	98.05	-	99.10	-	97.83	-	99.49

Table 5.A Table of International laboratory standard results to demonstrate accuracy.

Rec = Recommended value (Abbey, 1983)

Anal = Analysed value, Department of Geology, University of Canterbury.

APPENDIX 5B MAJOR ELEMENT CHEMISTRY, SELECTED CHEMICAL PARAMETERS AND C.I.P.W. NORMATIVE MINERALOGY.

SAMPLE/DATA	M36B2072	M36B2091	M36B2117A	M36B2151	M36B2162	M36B2163	M36B2164A	M36B2164B	M36B2164C	M36B2652
SiO2	50.76	48.52	48.21	59.71	51.05	49.50	49.66	54.19	50.82	59.47
TiO2	2.20	2.97	2.38	0.88	2.76	2.62	3.08	1.62	2.55	1.20
Al2O3	16.16	18.90	19.69	18.29	16.15	18.66	16.06	18.13	15.86	18.24
tFe2O3	12.22	11.88	9.93	6.56	11.91	11.39	12.76	8.99	12.94	5.97
Fe2O3	2.60	2.52	2.11	1.74	2.53	2.42	2.71	1.91	2.75	1.58
FeO	8.66	8.42	7.04	4.34	8.44	8.07	9.04	6.37	9.17	3.95
MnO	0.20	0.13	0.12	0.16	0.12	0.10	0.20	0.15	0.28	0.12
MgO	2.98	2.76	2.38	0.93	4.08	3.10	3.50	2.19	2.79	0.45
CaO	6.80	8.61	9.61	2.83	8.16	10.02	8.40	5.37	7.06	3.27
Na2O	4.91	3.32	3.51	7.01	3.40	3.43	4.18	5.63	4.57	5.54
K2O	1.94	1.06	0.96	3.72	1.49	0.80	1.43	2.65	1.76	3.66
P2O5	0.86	0.47	0.43	0.25	0.53	0.35	0.71	0.56	0.91	0.33
LOI	-0.66	0.79	2.25	0.34	0.41	1.49	1.08	0.49	1.71	2.53
TOTAL	98.37	99.42	99.45	100.67	100.05	101.46	101.06	99.98	100.70	100.78
Alkali	6.85	4.38	4.47	10.73	4.89	4.23	5.61	8.28	6.33	9.20
Na/K	2.53	3.13	3.66	1.88	2.28	4.28	2.92	2.12	2.60	1.51
Felsic	50.18	33.72	32.80	79.13	37.47	29.68	38.19	60.66	47.27	73.78
Mafic	79.07	79.51	79.34	68.24	72.89	77.19	77.05	79.08	81.03	92.47
Kunos	14.13	14.94	14.88	4.76	20.77	17.40	16.79	11.68	13.26	2.96
Q	-	1.85	0.25	-	2.67	1.03	-	-	-	4.62
or	11.76	6.45	6.03	22.08	8.97	4.80	8.59	15.92	10.62	22.17
ab	41.66	28.92	30.93	55.02	29.31	29.45	35.96	46.00	39.51	48.08
an	16.75	34.53	36.53	7.49	24.87	33.65	21.19	16.65	17.95	14.43
ne	0.53	-	-	2.48	-	-	-	1.33	-	-
c	-	-	-	-	-	-	-	-	-	0.01
di	10.08	5.21	8.46	4.24	10.54	11.96	13.60	5.60	9.84	-
hy	-	12.25	8.79	-	13.22	9.59	4.24	-	7.55	5.63
ol	8.97	-	-	4.35	-	-	4.73	7.19	3.29	-
mt	4.00	3.90	3.32	2.10	3.87	3.69	4.14	2.92	4.22	1.95
il	4.30	5.82	4.72	1.68	5.35	5.06	5.96	3.14	4.96	2.36
ap	1.94	1.06	0.98	0.55	1.19	0.78	1.59	1.25	2.05	0.74
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
D.I	53.95	37.22	37.21	79.58	40.95	35.28	44.55	63.25	50.13	74.87
Colour	27.35	27.18	26.27	12.37	32.98	30.30	32.67	18.85	29.86	9.94
Pyx.	10.08	17.46	17.25	4.24	23.76	21.55	17.84	5.60	17.39	5.63
Plag.	58.41	63.45	67.46	62.51	54.18	63.10	57.15	62.65	57.46	62.51
P.R	28.68	54.42	54.14	11.98	45.90	53.33	37.08	26.58	31.24	23.08
Name	Ol-Mu	Ba	Ba	Ne-Tr	Qz-Ha	Ba	Ol-Ha	Ol-Mu	Ol-Ha	Qz-Be

KEY:- Ba = BASALT  
 Ha = HAWAIIITE  
 Be = BENMOREITE  
 Mu = MUGEARITE  
 TR = TRACHYTE



	M36B2659	M36B6a	M36B24	M36B29	M36B31	M36B33	M36B37	M36B46a	M36B48a	M36B49	M36B50d	M36B53	M36B56
SiO2	38.68	61.18	47.13	48.46	49.26	51.09	51.79	56.87	51.54	49.02	60.71	61.40	66.79
TiO2	1.99	0.28	2.11	3.18	3.03	2.13	2.38	1.61	2.29	3.14	0.56	1.14	0.46
Al2O3	15.35	18.06	13.49	16.54	17.41	16.10	15.94	15.85	15.44	15.71	18.09	18.19	15.70
tFe2O3	28.26	5.04	13.00	12.41	12.20	11.76	11.34	9.90	12.35	13.23	5.69	4.55	3.77
Fe2O3	6.00	1.33	2.76	2.64	2.59	2.50	2.41	2.62	2.63	2.81	1.59	1.20	1.00
FeO	20.02	3.34	9.21	8.80	8.65	8.33	8.34	6.55	8.75	9.38	3.77	3.01	2.50
MnO	0.33	0.13	0.18	0.19	0.17	0.20	0.30	0.14	0.19	0.19	0.08	0.08	0.02
MgO	1.18	0.35	9.89	4.16	2.94	2.98	3.26	1.12	2.29	4.27	0.46	0.77	0.29
CaO	5.78	1.13	8.80	8.94	9.50	6.72	7.11	4.04	6.50	8.71	1.52	4.02	1.19
Na2O	2.78	7.41	2.69	3.71	3.74	4.53	4.81	4.80	4.61	3.98	6.13	5.65	5.24
K2O	0.62	5.29	1.11	1.21	1.24	2.09	2.02	2.90	1.98	1.33	4.76	3.83	4.68
P2O5	0.40	0.06	0.42	0.59	0.55	0.83	0.91	0.55	0.99	0.64	0.15	0.32	0.08
LOI	4.97	0.66	0.80	1.03	1.16	1.10	-0.36	2.20	0.76	1.36	1.16	0.90	0.90
TOTAL	100.34	99.59	99.62	100.42	101.20	99.53	99.49	99.98	99.58	101.58	99.31	99.04	99.10
Alkali	3.40	12.70	3.80	4.92	4.98	6.62	6.83	7.70	6.59	5.31	10.89	9.48	9.92
Na/k	4.48	1.40	2.42	3.06	3.01	2.16	2.38	1.65	2.32	2.99	1.28	1.47	1.11
Felsic	37.04	91.83	30.16	35.50	34.39	49.63	49.00	65.59	50.34	37.87	87.75	70.22	89.29
Mafic	95.66	93.02	54.76	73.33	79.27	78.42	76.95	89.12	83.25	74.06	91.97	84.59	92.35
Kunos	3.86	1.98	38.54	20.23	15.34	14.57	15.64	6.24	11.30	19.61	2.77	5.32	2.12
Q	-	-	-	-	-	-	-	6.48	-	-	1.03	4.77	14.55
or	3.98	31.79	6.75	7.31	7.44	12.74	12.13	17.75	12.03	7.97	28.86	22.47	28.28
ab	25.58	52.04	23.43	32.09	32.13	39.55	41.37	42.07	40.12	34.10	53.23	48.11	45.35
an	28.34	0.40	22.09	25.46	27.47	17.98	16.20	13.61	16.04	21.44	6.73	13.04	5.50
ne	-	6.36	-	-	-	-	-	-	-	-	-	-	-
c	0.60	-	-	-	-	-	-	-	-	-	0.46	-	0.04
di	-	4.27	16.12	13.06	13.87	9.01	11.26	2.93	8.74	14.93	-	4.13	-
hy	9.23	-	7.26	5.90	6.79	6.18	2.09	9.45	11.14	2.79	6.39	2.82	3.97
ol	17.38	2.83	14.99	4.61	1.28	4.60	6.62	-	1.15	6.99	-	-	-
mt	9.81	1.64	4.27	4.05	3.95	3.87	3.68	3.27	4.05	4.29	1.86	1.46	1.23
il	4.12	0.54	4.14	6.19	5.86	4.18	4.61	3.18	4.48	6.07	1.09	2.18	0.90
ap	0.96	0.13	0.95	1.33	1.23	1.88	2.04	1.25	2.24	1.43	0.34	0.71	0.18
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
D.I	29.56	90.19	30.18	39.40	39.57	52.29	53.50	66.30	52.15	42.07	83.12	75.65	88.18
Colour	40.54	9.28	46.78	33.81	31.75	27.84	28.26	18.83	29.56	35.07	19.34	10.59	6.10
Pyx.	9.23	4.27	23.38	18.96	20.66	15.19	13.35	12.38	19.88	17.22	6.39	6.95	3.97
Plag.	53.92	52.44	45.52	57.55	59.60	57.53	57.57	55.68	56.16	55.54	59.96	61.15	50.85
P.R	52.56	0.76	48.53	44.24	46.09	31.25	28.14	24.44	28.56	38.60	11.22	21.32	10.81

Name	Fe-ALTERD	Ne-Tr	Ol-Ha	Ol-Ha	Hy-Ha	Ol-Ha	Ol-Mu	Qz-Be	Mu	Ol-Ha	Tr	Tr	Oz-Tr
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	M36B60	M36B61a	M36B3250	M36B3271	M36B3272	M36B3281	M36B3286	M36B3572	M36B3677	M36B3678	M36B4003
SiO2	66.54	62.66	59.78	48.33	49.55	64.31	51.17	67.02	62.50	50.39	65.80
TiO2	0.47	0.38	1.26	3.05	3.08	0.87	2.33	0.46	1.05	2.90	0.48
Al2O3	15.47	18.33	16.84	17.43	15.64	16.37	16.25	16.12	16.18	18.58	16.69
tFeO3	4.87	4.62	7.86	12.26	13.56	5.66	12.02	3.63	6.48	10.40	4.03
Fe2O3	1.29	1.22	2.08	2.61	2.88	1.50	2.56	0.96	1.72	2.21	1.07
FeO	3.22	3.06	5.20	8.69	9.61	3.75	8.52	2.39	4.29	7.31	2.67
MnO	0.09	0.05	0.05	0.18	0.17	0.05	0.18	0.03	0.03	0.16	0.03
MgO	0.18	0.22	0.85	3.43	3.63	0.39	3.03	0.22	0.43	2.56	0.11
CaO	1.13	0.83	3.72	9.01	8.09	2.77	7.37	0.87	2.58	9.00	1.66
Na2O	5.38	6.57	4.58	3.80	4.02	4.20	4.39	5.62	4.81	3.99	5.14
K2O	4.69	5.25	3.12	1.17	1.50	3.95	1.73	4.65	3.55	1.37	4.28
P2O5	0.08	0.08	0.45	0.52	0.73	0.22	0.95	0.08	0.31	0.61	0.12
LOI	1.16	0.33	1.06	0.46	0.45	1.51	0.59	1.79	1.13	0.28	0.57
TOTAL	100.07	99.33	99.58	99.64	100.43	100.30	100.00	100.50	99.06	100.25	98.90
Alkali	10.07	11.82	7.70	4.97	5.52	8.15	6.12	10.27	8.36	5.36	9.42
Na/K	1.14	1.25	1.46	3.24	2.68	1.06	2.53	1.20	1.35	2.91	1.20
Felsic	89.91	93.44	67.43	35.55	40.56	74.63	45.37	92.19	76.42	37.33	85.01
Mafic	96.84	95.11	89.54	76.71	77.48	93.08	78.53	93.84	93.32	78.81	97.14
Kunos	1.14	1.35	5.37	17.41	16.77	2.83	14.98	1.59	2.91	14.68	0.83
Q	13.26	0.56	10.73	-	-	17.17	-	13.44	13.78	0.31	14.92
or	28.18	31.51	18.90	7.08	9.02	23.79	10.44	27.95	21.59	8.21	25.84
ab	46.30	56.49	39.74	32.93	34.62	36.23	37.96	48.39	41.91	34.23	44.45
an	4.28	3.65	15.91	27.70	20.56	12.54	19.95	3.86	11.09	29.14	7.2
ne	-	-	-	-	-	-	-	-	-	-	-
c	-	0.53	0.25	-	-	0.69	-	0.46	0.49	-	0.89
di	0.78	-	-	12.04	12.77	-	9.20	-	-	9.98	-
hy	4.53	4.85	8.42	4.22	7.70	5.56	10.97	3.64	6.24	7.80	3.77
ol	-	-	-	4.90	3.31	-	0.88	-	-	-	-
mt	1.58	1.50	2.57	4.01	4.40	1.84	3.92	1.18	2.13	3.37	1.31
il	0.91	0.74	2.46	5.95	5.97	1.69	4.53	0.89	2.06	5.60	0.93
ap	0.18	0.18	1.02	1.17	1.63	0.49	2.14	0.18	0.70	1.36	0.27
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
D.I	87.74	88.56	69.37	40.01	43.64	77.19	48.40	89.78	77.28	42.75	85.21
Colour	7.80	7.09	13.45	31.12	34.15	9.09	29.50	5.71	10.43	26.75	6.01
Pyx.	5.31	4.85	8.42	16.24	20.47	5.56	20.17	3.64	6.24	17.78	3.77
P.lag.	50.58	60.14	55.65	60.63	55.18	48.77	57.91	52.25	53.00	63.37	52.07
P.R	8.46	6.07	28.59	45.69	37.26	25.71	34.45	7.39	20.92	45.98	14.63
Name	Qz-Tr	Tr	Qz-Be	Ol-Ha	Ol-Ha	Qz-Tr	Hy-Ha	Qz-Tr	Qz-Tr	Hy-Ha	Qz-Tr

	M364009	M364012	M36B4020	M36B4021	M36B4024	M36B4301	M36B4352	M36B4356	M36B4358	M36B4410
SiO2	50.64	50.42	52.02	49.69	53.17	47.95	48.32	52.55	50.85	64.45
TiO2	2.46	2.76	1.99	2.71	1.89	2.65	2.90	2.41	2.52	0.53
Al2O3	16.63	15.98	17.46	16.01	17.82	16.04	17.65	16.41	17.60	16.72
tFe2O3	11.89	13.13	10.30	13.01	9.75	12.05	11.74	11.89	12.95	5.73
Fe2O3	2.53	2.79	2.19	2.77	2.07	2.56	2.50	2.53	2.75	1.52
FeO	8.43	9.31	7.30	9.22	6.91	8.54	8.32	8.43	9.18	3.79
MnO	0.17	0.19	0.17	0.22	0.19	0.16	0.15	0.10	0.15	0.04
MgO	2.87	3.38	3.42	3.34	1.99	5.28	4.11	3.05	1.73	0.34
CaO	6.81	7.29	6.75	7.63	5.77	8.69	9.59	7.40	6.24	1.86
Na2O	4.72	4.24	5.19	4.41	5.18	3.42	3.34	4.00	3.84	5.14
K2O	1.94	1.71	2.29	1.65	2.26	1.22	1.06	1.94	1.98	4.16
P2O5	0.87	0.81	0.59	0.79	0.68	0.57	0.47	0.77	0.72	0.14
LOI	0.07	-0.23	0.38	0.44	0.88	1.53	0.24	0.01	1.19	0.06
TOTAL	99.07	99.69	100.55	99.91	99.59	99.57	99.57	100.53	99.75	99.17
Alkali	6.66	5.95	7.48	6.06	7.44	4.64	4.40	5.94	5.82	9.30
Na/K	2.43	2.47	6.63	2.67	2.29	2.80	3.15	2.06	1.93	1.23
Felsic	49.44	44.94	72.14	44.26	56.32	34.81	31.45	44.53	48.26	83.33
Mafic	79.25	78.17	73.43	78.21	81.78	67.77	72.47	78.23	87.34	93.98
Kunos	14.01	15.77	11.25	15.61	10.81	25.12	21.26	15.29	8.88	2.27
Q	-	-	-	-	-	-	-	2.10	3.10	12.43
or	11.76	10.28	13.69	9.97	13.70	7.47	6.40	11.58	12.07	24.97
ab	40.98	36.52	38.43	38.16	44.98	29.99	28.88	34.19	33.52	44.19
an	18.94	19.87	17.79	19.45	19.19	25.72	30.70	21.31	25.73	8.45
ne	-	-	3.25	-	-	-	-	-	-	-
c	-	-	-	-	-	-	-	-	-	0.73
di	8.23	9.59	10.04	11.61	4.72	12.30	12.10	8.88	1.15	-
hy	2.34	9.59	-	1.84	5.60	8.08	9.07	11.77	13.59	6.04
ol	7.09	2.71	8.34	7.68	3.39	5.92	2.32	-	-	-
mt	3.89	4.27	3.33	4.25	3.19	3.99	3.83	3.83	4.26	1.86
il	4.81	5.35	3.83	5.28	3.69	5.23	5.64	4.64	4.95	1.03
ap	1.96	1.81	1.31	1.78	1.54	1.30	1.06	1.71	1.63	0.31
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
D.I	52.74	46.80	55.37	48.13	58.68	37.46	35.28	47.87	48.69	81.59
Colour	26.36	31.51	25.54	30.66	20.59	35.52	32.96	29.12	23.95	8.93
Pyx	10.57	19.18	10.04	13.45	10.32	20.38	21.17	20.65	14.74	6.04
Plag.	59.92	56.39	56.22	57.61	64.17	55.71	59.58	55.50	59.25	52.64
P.R	31.61	35.23	31.64	33.76	30.00	46.17	51.53	38.40	43.43	16.05
Name	Ol-Ha	Ol-Ha	Ne-Ha	Ol-Ha	Ol-Ha	Ol-Ha	Ba	Hy-ha	Hy-Ha	Qz-Tr



	M36B4596	M36B4613	M36B4619	M36B4634	M36B4906	M36B4909	M36B5440	M36B5443	N36A5508	N36A5509
SiO2	52.09	61.17	49.65	56.05	51.12	57.52	60.41	48.40	58.44	59.89
TiO2	2.61	1.02	2.67	1.27	2.47	1.16	1.04	2.80	1.40	1.43
Al2O3	16.10	16.94	16.39	17.63	16.65	17.25	16.39	16.97	15.81	15.94
tFe2O3	13.59	6.32	12.42	8.56	12.14	8.11	6.30	11.93	8.58	8.56
Fe2O3	2.89	1.67	2.64	1.82	2.58	2.15	1.67	2.54	2.27	2.27
FeO	9.63	4.18	8.80	6.07	8.60	5.38	4.17	8.45	5.68	5.67
MnO	0.14	0.12	0.21	0.12	0.17	0.14	0.05	0.19	0.07	0.08
MgO	2.91	1.33	3.27	0.94	2.86	1.32	1.17	4.23	2.01	2.68
CaO	6.99	3.49	7.9	3.30	6.89	3.83	3.75	9.04	4.44	4.90
Na2O	4.20	5.38	4.17	5.98	4.80	5.90	3.59	3.66	3.78	3.92
K2O	2.02	3.78	1.70	3.21	1.99	3.33	3.65	1.19	2.95	3.01
P2O5	0.87	0.25	0.87	0.42	0.86	0.38	0.32	0.57	0.38	0.43
LOI	0.38	0.34	0.31	2.64	-0.04	2.87	1.34	1.89	0.69	1.15
TOTAL	101.88	100.14	100.05	100.13	99.91	101.80	98.00	100.88	98.55	101.98
Alkali	6.22	9.16	5.87	9.19	6.79	9.23	7.24	4.85	6.73	6.93
Na/K	2.07	1.42	2.45	1.86	2.41	1.77	0.98	3.07	1.28	1.30
Felsic	47.08	72.41	42.51	73.58	49.63	70.67	65.88	34.92	60.25	58.58
Mafic	81.04	81.48	75.46	89.35	76.63	85.01	83.31	72.21	79.82	74.76
Kunos	13.44	8.14	17.70	5.22	13.73	7.30	8.21	21.07	12.04	15.27
Q	0.68	5.45	-	-	-	-	15.11	-	11.53	10.29
or	11.96	22.55	10.23	19.67	11.95	20.09	22.49	7.21	18.01	17.82
ab	35.62	45.98	35.96	52.49	41.28	50.99	31.68	31.78	33.05	32.25
an	19.16	11.02	21.38	12.22	18.31	10.98	17.22	27.05	18.04	17.05
ne	-	-	-	-	-	-	-	-	-	-
c	-	-	-	-	-	-	0.50	-	-	-
di	8.28	4.04	10.70	1.64	8.93	4.99	-	12.41	1.80	3.72
hy	13.06	6.40	3.61	4.29	1.05	5.85	8.10	5.40	11.13	11.45
ol	-	-	6.95	3.38	7.83	1.53	-	5.49	-	-
mt	4.35	2.05	4.04	2.83	3.94	2.64	2.10	3.91	2.83	2.74
il	4.98	1.96	5.18	2.51	4.78	2.26	2.07	5.47	2.75	2.73
ap	1.92	0.55	1.95	0.96	1.92	0.85	0.73	1.29	0.86	0.95
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
D.I	48.26	73.98	46.19	72.16	53.23	71.08	69.28	38.99	62.59	61.36
Colour	30.67	14.45	30.48	14.65	26.53	17.27	12.17	32.68	18.51	20.64
Pyroxene	21.34	10.44	14.31	5.93	9.98	10.84	8.10	17.81	12.93	15.17
Plag.	54.78	57.00	57.34	64.71	59.59	61.98	48.90	58.83	51.09	50.30
P.R	34.98	19.33	37.29	18.18	30.73	17.72	35.21	45.98	35.31	33.90
Name	Hy-Ha	Qz-Be	Ol-Ha	Hy-Be	Ol-Ha	Hy-Be	Qz-Be	Ol-Ha	Qz-Ha	Qz-Ha

	M36B5563	M36B5766	M36B5768	M36B5772	M36B5791	M36B5792	M36B5805	N36A5822	N36A5824	N36A5826
SiO2	66.99	56.87	50.31	48.69	56.35	63.80	48.84	61.65	53.60	49.58
TiO2	0.38	1.17	2.76	2.71	1.24	0.85	2.89	1.02	1.94	2.75
Al2O3	14.89	16.38	15.78	16.70	17.97	16.29	17.23	15.89	16.01	18.01
tFe2O3	5.12	9.42	12.21	11.86	7.69	5.84	12.04	6.74	10.75	11.22
Fe2O3	1.36	2.49	2.60	2.52	2.04	1.55	2.56	1.78	2.29	2.39
FeO	3.39	6.23	8.65	8.40	5.09	3.86	8.53	4.46	7.62	7.95
MnO	0.05	0.13	0.17	0.17	0.12	0.06	0.15	0.14	0.15	0.18
MgO	<0.05	2.53	3.40	4.47	1.75	0.83	3.79	1.37	2.53	3.57
CaO	1.07	5.77	7.68	9.36	4.51	3.14	9.17	3.83	6.05	9.37
Na2O	4.75	3.99	4.37	3.78	5.39	4.49	3.67	4.35	4.67	3.69
K2O	4.71	2.56	1.72	1.22	3.21	3.74	1.13	3.39	2.43	1.18
P2O5	0.10	0.48	0.62	0.57	0.45	0.27	0.53	0.34	0.79	0.56
LOI	1.64	0.37	0.79	0.43	1.65	1.40	1.10	0.73	0.29	0.00
TOTAL	99.69	100.23	99.81	99.96	100.35	100.70	100.55	99.45	99.22	100.09
Alkali	9.46	6.55	6.09	5.00	8.60	8.23	4.80	8.74	7.10	4.87
Na/K	1.00	1.55	2.54	3.09	1.67	1.20	3.24	1.28	1.92	3.12
Felsic	89.84	53.17	44.23	34.82	65.60	77.57	34.36	69.53	54.00	34.20
Mafic	98.96	77.51	76.79	70.96	80.29	86.70	74.58	82.00	79.66	74.34
Kunos	0.35	14.21	16.43	21.92	10.01	5.74	19.26	8.38	12.95	19.01
Q	17.50	7.31	-	-	-	14.36	-	12.49	0.96	-
or	28.56	15.33	10.43	7.35	19.41	22.41	6.82	20.46	14.72	7.06
ab	41.25	34.22	37.94	32.63	46.69	38.54	31.71	37.61	40.52	31.64
an	4.78	19.49	18.84	25.51	15.67	13.44	27.78	14.12	15.94	29.48
ne	-	-	-	-	-	-	-	-	-	-
c	0.28	-	-	-	-	-	-	-	-	-
di	-	5.27	13.30	14.78	3.54	0.49	12.44	2.54	7.96	11.43
hy	4.99	10.96	3.37	1.27	8.25	6.63	7.63	7.83	10.81	8.55
ol	-	-	5.33	8.05	0.50	-	2.88	-	-	1.65
mt	1.68	3.05	4.00	3.86	2.51	1.89	3.92	2.20	3.52	3.63
il	0.74	3.30	5.39	5.26	2.42	1.64	5.62	1.98	3.79	5.31
ap	0.23	1.07	1.40	1.28	1.01	0.60	1.19	0.76	1.78	1.25
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
D.I	87.31	56.86	48.37	39.98	66.10	74.31	38.53	70.56	56.20	38.70
Colour	7.41	22.58	31.39	33.32	17.21	10.65	32.49	14.55	26.08	30.57
Pyx	4.99	16.23	16.67	16.05	11.79	7.12	20.07	10.37	18.77	19.98
Plag.	46.03	53.71	56.78	58.14	62.69	51.98	59.49	51.73	56.46	61.12
P.R	10.38	36.29	33.18	43.88	25.00	25.86	46.70	27.30	28.23	48.23
Name	Qz-Tr	Qz-Ha	Ol-Ha	Ol-Ha	Hy-Be	Qz-Be	Ol-Ha	Qz-Be	Mu	Hy-Ha

APPENDIX VI TRACE ELEMENT ANALYSES AND RATIOS

All trace elements analyses are in ppm. The following chemical parameters are calculated :-

$$\text{Ca/Al} = \text{CaO/Al}_2\text{O}_3$$

$\text{Ce}_n/\text{Y}_n$  = Chondrite normalized Ce/Y ratio using values of Thompson et al, 1984.

$$\text{Ce} = .868 \text{ ppm, Y} = 2 \text{ ppm}$$

Co-ordinates for tectonic discrimination diagrams of:-

Pearce and Cann (1973) using  $\text{Ti}/100$ ,  $3*Y$  and  $Zr$  and Meshede (1986) using  $2Nb$ ,  $Y$  and  $Zr/4$  are calculated for *basic rocks*.

Table 6A Trace element data for international laboratory standard.

	AGV		G2		W1	
	Rec	Anal	Rec	Anal	Rec	Anal
V	123	116	36	34	260	277
Cr	12	11	9	11	120	125
Ni	17	16	5	3	75	72
Zn	88	84	85	87	84	90
Zr	230	246	313	322	105	93
Nb	14	15	12	14	9	9
Ba	1221	1205	1880	1926	162	116
La	38	40	86	103	11	<5
Ce	66	65	159	177	23	23
Nd	34	34	53	54	15	26
GA	21	18	23	22	16	18
Pb	33	40	30	33	7.8	11
Rb	67	68	170	170	21	21
Sr	660	663	480	481	190	191
Th	6.4	6	25	30	2.4	3
Y	19	21	11	14	25	21



APPENDIX 6B TRACE ELEMENT ANALYSES AND CALCULATED PARAMETERS.

	M36B2072	M36B2091	M36B2117A	M36B2151	M36B2162	M36B2163	M36B2164A	M36B2164B	M36B2164C	M36B2652
V	32	180	149	< 3	208	236	155	23	69	51
Cr	13	43	13	3	64	50	38	7	10	26
Ni	8	27	18	4	40	42	25	12	8	7
Zn	122	94	103	81	123	98	126	92	135	89
Ga	22	23	21	30	20	22	22	29	22	31
Rb	41	21	16	87	48	18	31	62	40	109
Sr	610	613	679	296	503	551	557	763	512	453
Y	53	34	27	36	33	28	46	36	53	40
Zr	328	214	179	516	218	156	270	434	326	494
Nb	67	42	34	101	38	32	54	87	62	73
Ba	449	116	111	1411	200	88	179	641	303	701
Pb	4	3	5	11	6	5	5	6	5	13
La	61	27	28	76	37	22	46	82	54	73
Ce	110	60	48	131	73	41	88	134	107	124
Nd	45	32	36	46	37	28	33	46	40	52
Th	10	5	4	15	7	5	4	14	8	21
Zr/Nb	4.896	5.095	5.265	5.109	5.737	4.875	5.000	4.989	5.258	6.761
Zr/Y	6.187	6.294	6.630	14.333	6.606	5.574	5.870	12.056	6.151	12.350
Zr/Rb	8.000	10.190	11.188	5.931	4.542	8.667	8.710	7.000	8.150	4.532
Zr/Ti	0.245	0.012	0.013	0.098	0.013	0.010	0.015	0.045	0.021	0.069
Nb/Y	1.264	1.235	1.259	2.806	1.152	1.143	1.174	2.417	1.170	1.825
Ti/Y	248.852	523.688	528.456	146.546	501.407	560.967	401.410	269.779	288.443	179.853
K/Ba	35.869	75.860	71.780	21.890	61.847	75.469	46.386	34.320	48.221	43.344
K/Rb	392.808	419.034	498.097	354.965	257.696	368.961	267.840	354.827	365.271	278.751
Rb/Sr	0.067	0.342	0.024	0.294	0.095	0.033	0.057	0.081	0.078	0.241
Nb/Th	6.700	8.400	8.500	6.733	5.429	6.400	13.500	6.214	7.750	3.476
Cen/Yn	4.798	4.082	4.110	8.412	5.115	3.386	4.423	8.606	4.668	7.168
*Ca/Al	0.421	0.456	0.488	0.155	0.505	0.537	0.523	0.296	0.445	0.179
Ti/100	131.892	178.054	142.683		165.464	157.072	184.645		152.875	
3*Y	159.000	102.000	81.000		99.000	84.000	138.000		159.000	
Zr	328.000	214.000	179.000		218.000	156.000	270.000		326.000	
Ti/100	21.311	36.039	35.433		34.296	39.557	31.157		23.966	
3*Y	25.691	20.645	20.115		20.512	21.155	23.285		24.927	
Zr	52.997	43.315	44.452		45.185	39.288	45.558		51.107	
2NB	49.8	48.9	48.6		46.4	48.8	48.7		47.9	
Zr/4	30.4	31.1	32.0		33.3	29.7	30.4		31.5	
Y	19.7	19.8	19.3		20.1	21.3	20.7		20.5	

	M36B2659	M36B6a	M36B24	M36B29	M36B31	M36B33	M36B37	M36B46a	M36B48a	M36B49	M36B50d	M36B53	M36B56
V	181	2	190	165	187	33	41	7	35	155	-1	34	-1
Cr	69	9	267	21	10	15	35	8	7	57	9	28	11
Ni	60	10	242	20	26	12	19	5	3	26	20	16	10
Zn	201	144	123	112	114	123	148	174	142	123	118	86	137
Ga	21	35	20	24	24	25	26	30	26	24	31	27	29
Rb	6	157	22	28	30	49	36	82	45	28	107	116	153
Sr	501	36	522	522	561	601	603	414	517	558	113	440	148
Y	42	51	36	34	35	44	49	50	51	38	33	32	35
Zr	180	1032	184	222	209	307	330	427	332	241	711	500	730
Nb	30	197	42	51	46	74	76	82	70	59	149	78	95
Ba	129	121	297	203	235	533	493	723	392	253	718	683	761
Pb	4	18	9	7	7	9	7	10	8	7	13	12	21
La	28	128	47	31	37	62	71	87	65	44	98	69	89
Ce	68	212	83	71	82	115	130	164	127	98	151	132	121
Nd	22	94	45	34	37	64	74	84	65	41	74	66	84
Th	4	30	5	5	7	9	11	14	8	7	19	19	22

Zr/Nb	6.000	5.239	4.381	4.353	4.543	4.147	4.342	5.207	4.743	4.085	4.772	6.412	7.601
Zr/Y	4.286	20.235	5.111	6.529	5.971	6.977	6.735	8.540	6.510	6.342	21.545	15.625	20.857
Zr/Rb	30.000	6.573	8.364	7.929	6.967	6.265	9.167	5.207	7.377	8.607	6.645	4.310	4.771
Zr/Ti	0.015		0.015	0.012	0.012	0.024	0.023	0.044	0.024	0.013	0.212	0.073	0.265
Nb/Y	0.714	3.863	1.167	1.500	1.314	1.682	1.551	1.640	1.373	1.553	4.515	2.436	2.714
Ti/Y	284.053	32.914	351.380	560.717	519.003	290.217	219.190	193.042	269.191	495.383	101.735	213.575	78.792
K/Ba	39.900	362.938	31.026	49.483	43.804	32.552	34.015	33.298	41.932	43.640	55.036	46.552	51.053
K/Rb	857.833	297.718	418.854	358.748	343.133	354.089	465.813	293.594	365.271	394.327	369.305	274.096	253.932
Rb/Sr	0.012	4.361	0.041	0.054	0.053	0.082	0.060	0.198	0.087	0.050	0.947	0.264	1.034
Nb/Th	7.500	6.567	8.400	10.200	6.574	8.222	6.909	5.857	8.750	8.429	7.842	4.105	4.318
Cen/Yn	3.743	9.611	5.331	7.168	5.417	6.043	6.132	7.676	5.758	5.963	10.580	9.536	7.993
*Ca/Al	0.377	0.063	0.652	0.541	0.546	0.417	0.446	0.255	0.421	0.544	0.484	0.221	0.076

Ti/100	119.302		126.496	190.644	181.651	127.695				188.247			
3*Y	126.000		108.000	102.000	105.000	132.000				144.000			
Zr	180.000		184.000	222.000	209.000	307.000				241.000			

Ti/100	26.380		30.226	37.044	36.649	22.533				34.652			
3*Y	29.626		25.807	19.820	21.184	23.293				20.985			
Zr	42.323		43.967	43.137	42.167	54.174				44.356			

2NB	40.8		50.6	53.2	51.3	55.0				54.5			
Zr/4	30.6		27.7	28.9	29.1	28.5				27.8			
Y	28.5		21.6	17.7	19.5	16.3				17.5			

	M36B60	M36B61a	M36b3250	M36B3271	M36B3272	M36B3281	M36B3286	M36B3572	M36B3677	M36B3678	M36B4003
V	2	0	22	186	150	37	87	< 3	< 3	185	5
Cr	10	10	6	16	26	3	7	< 3	< 3	42	3
Ni	10	11	3	20	17	4	8	< 3	3	26	< 3
Zn	112	104	101	106	124	80	118	109	131	132	83
Ga	28	31	31	23	26	26	24	32	29	22	31
Rb	155	157	106	26	71	142	40	147	123	30	134
Sr	150	38	384	637	563	308	529	141	338	613	252
Y	55	26	57	38	46	26	50	52	42	35	56
Zr	692	867	418	218	280	424	302	713	476	239	575
Nb	96	127	53	44	58	40	53	92	62	48	62
Ba	757	384	635	174	283	757	310	808	662	173	790
Pb	15	19	14	5	4	35	7	27	15	5	19
La	87	104	112	34	50	55	53	100	76	45	90
Ce	162	149	144	69	91	99	105	163	118	72	141
Nd	83	61	80	32	39	52	42	70	54	41	66
Th	23	32	16	5	6	20	6	23	17	6	21
Zr/Nb	7.208	6.827	7.887	4.955	4.828	10.600	5.698	7.750	7.677	4.979	9.274
Zr/Y	12.582	33.346	7.333	5.737	6.087	16.308	6.040	13.712	11.333	6.826	10.268
Zr/Rb	4.465	5.522	3.943	8.385	3.943	2.986	7.550	4.850	3.870	7.967	4.291
Zr/Ti	0.246	0.381	0.055	0.012	0.015	0.081	0.022	0.259	0.076	0.014	0.200
Nb/Y	1.745	4.884	0.930	1.158	1.261	1.538	1.060	1.769	1.476	1.371	1.107
Ti/Y	51.231	87.620	132.523	481.184	401.410	200.605	279.371	53.034	149.877	496.736	513.864
K/Ba	51.433	113.498	40.789	55.821	44.001	43.318	46.328	47.775	44.518	65.741	44.976
K/Rb	251.191	277.602	244.349	373.573	175.386	230.925	359.044	262.602	239.599	379.107	265.156
Rb/Sr	1.033	4.132	0.276	0.041	0.126	0.461	0.076	1.043	0.364	0.049	0.532
Nb/Th	4.174	3.969	3.313	8.800	9.667	2.000	8.833	4.000	3.647	8.000	2.952
Cen/Yn	6.810	13.250	5.841	4.198	4.574	8.804	4.855	7.248	6.496	4.756	5.821
*Ca/Al	0.073	0.045	0.221	0.517	0.417	0.169	0.454	0.054	0.159	0.485	0.099
Ti/100				182.850	184.650		139.685			173.857	
3*Y				144.000	138.000		150.000			105.000	
Zr				218.000	280.000		302.000			239.000	
Ti/100				35.515	30.640		23.608			33.572	
3*Y				22.142	22.900		25.351			20.276	
Zr				42.342	46.462		51.041			46.152	
2NB				48.7	50.0		45.7			50.3	
Zr/4				30.1	30.1		32.6			31.3	
Y				21.0	19.8		21.5			18.3	



	M36B4009	M36B4012	M36B4020	M36B4021	M36B4024	M36B4301	M36B4352	M36B4356	M36B4358	M36B4410
V	70	105	73	113	35	148	190	113	100	11
Cr	11	12	51	16	7	99	37	5	6	< 3
Ni	14	18	34	18	8	75	30	9	12	< 3
Zn	118	126	96	126	106	103	85	116	122	68
Ga	25	24	26	26	30	20	28	24	32	26
Rb	40	36	59	38	54	27	26	48	48	133
Sr	626	579	738	597	591	524	564	506	486	276
Y	55	60	39	63	50	39	31	44	40	35
Zr	345	302	372	304	389	237	203	296	313	556
Nb	69	62	68	62	74	45	40	52	57	59
Ba	395	325	569	322	522	159	114	337	353	757
Pb	9	4	9	4	4	3	2	6	9	23
La	79	61	69	69	80	36	27	51	54	73
Ce	102	94	121	102	127	77	59	99	104	133
Nd	57	46	47	53	57	38	28	50	44	56
Th	13	10	13	7	13	5	6	8	8	19
Zr/Nb	5.000	4.871	5.471	4.903	5.257	5.267	5.075	5.962	5.491	9.424
Zr/Y	6.273	5.033	9.538	4.825	7.780	6.077	6.548	6.727	7.825	15.886
Zr/Rb	8.625	8.389	6.305	8.000	7.204	8.778	7.808	6.167	6.521	4.180
Zr/Ti	0.023	0.018	0.031	0.019	0.034	0.015	0.012	0.020	0.021	0.175
Nb/Y	1.255	1.033	1.744	0.984	1.480	1.154	1.290	1.182	1.425	1.684
Ti/Y	268.144	275.774	305.903	257.884	226.614	407.358	560.830	328.367	377.690	90.783
K/Ba	40.772	43.679	33.411	42.539	35.945	63.698	77.190	47.790	46.564	45.624
K/Rb	402.628	394.327	322.215	360.465	347.439	375.110	338.450	335.523	513.662	259.659
Rb/Sr	0.064	0.062	0.080	0.064	0.091	0.052	0.926	0.095	0.098	0.482
Nb/Th	5.308	6.200	5.231	8.857	5.692	9.000	6.667	6.500	7.125	3.105
Cen/Yn	4.288	3.622	7.174	3.743	5.873	4.565	4.401	5.202	6.012	8.786
*Ca/Al	0.410	0.456	0.387	0.477	0.324	0.542	0.543	0.451	0.355	0.111
Ti/100	147.480	165.464	119.302	162.467	113.307	158.870	173.857	144.482	151.076	
3*Y	165.000	180.000	117.000	189.000	150.000	117.000	93.000	132.000	120.000	
Zr	345.000	302.000	372.000	304.000	389.000	237.000	203.000	296.000	313.000	
Ti/100	22.431	25.556	19.612	24.786	17.370	30.977	37.002	25.238	25.866	
3*Y	25.096	27.801	19.234	28.834	22.995	22.813	19.793	23.058	20.545	
Zr	52.473	46.643	61.154	46.380	59.634	46.211	43.205	51.705	53.590	
2NB	49.4	47.7	50.7	47.1	50.1	47.8	49.4	46.8	49.0	
Zr/4	30.8	29.0	34.7	28.8	32.9	31.4	31.3	33.3	33.6	
Y	19.6	23.0	14.5	23.9	16.9	20.7	19.1	19.8	17.2	

	M36B4596	M36B4613	M36B4619	M36B4634	M36B4906	M36B4909	M36B5440	M36B5443	N36A5508	N36A5509
V	111	39	98	21	63	12	64	166	87	92
Cr	32	26	20	6	8	6	8	50	65	37
Ni	25	23	21	7	13	7	9	39	25	27
Zn	146	75	117	112	113	99	85	106	89	89
Ga	25	28	19	29	24	33	27	24	34	27
Rb	54	118	35	85	41	92	113	25	103	103
Sr	508	377	659	452	619	423	358	577	412	385
Y	59	42	51	33	52	37	39	35	39	33
Zr	338	495	298	493	354	509	403	237	311	316
Nb	58	68	66	81	71	88	42	44	35	35
Ba	670	674	386	682	374	679	749	149	627	596
Pb	6	22	5	13	5	16	20	5	14	18
La	76	67	56	75	62	69	66	39	62	51
Ce	106	116	105	136	111	121	115	66	87	95
Nd	58	54	51	51	50	47	56	40	54	48
Th	8	21	7	15	10	20	18	5	16	16
Zr/Nb	5.828	7.279	4.515	6.086	4.986	5.784	9.595	5.386	8.886	9.023
Zr/Y	5.729	11.786	5.843	14.939	6.808	13.757	10.333	6.771	7.974	9.576
Zr/Rb	6.259	4.195	8.514	5.800	8.634	5.533	3.566	9.480	3.019	3.068
Zr/Ti	0.022	0.081	0.019	0.065	0.024	0.073	0.065	0.041	0.037	0.037
Nb/Y	0.983	1.619	1.294	2.455	1.365	2.378	1.077	1.257	0.897	1.061
Ti/Y	265.206	145.595	313.860	230.720	284.766	187.954	159.869	479.607	215.208	259.787
K/Ba	25.029	46.558	36.562	39.075	44.172	40.713	40.455	66.301	39.057	41.926
K/Rb	310.542	265.933	403.221	313.508	402.932	300.482	268.149	395.157	237.765	242.600
Rb/Sr	0.106	0.313	0.053	0.188	0.662	0.217	0.316	0.043	0.250	0.268
Nb/Th	7.250	3.238	9.429	5.400	7.100	4.400	2.333	8.800	2.186	2.186
Cen/Yn	4.154	6.386	4.760	9.529	4.936	7.561	6.818	4.360	5.158	6.656
*Ca/Al	0.434	0.206	0.482	0.187	0.414	0.222	0.229	0.533	0.281	0.307
Ti/100	156.472		160.069		148.079	69.543		167.862		
3*Y	177.000		153.000		156.000	111.000		105.000		
Zr	333.000		298.000		354.000	509.000		237.000		
Ti/100	23.303		26.195		22.502	10.085		32.923		
3*Y	26.360		25.038		23.705	16.100		20.600		
Zr	50.337		48.767		53.800	73.820		46.483		
2NB	44.7		51.2		50.2	51.7		48.2		
Zr/4	32.5		28.9		31.3	37.3		32.5		
Y	22.7		19.8		18.4	10.8		19.2		

	M36B5563	M36B5766	M36B5768	M36B5772	M36B5791	M36B5792	M36B5805	N36A5822	N36A5824	N36A5826
V	4	117	138	158	31	31	177	39	38	143
Cr	<3	17	20	67	5	6	1	10	< 3	24
Ni	4	15	21	47	11	5	44	8	4	28
Zn	82	105	128	110	89	81	106	77	128	82
Ga	29	29	22	24	26	23	23	28	33	26
Rb	160	84	48	25	115	132	24	121	58	24
Sr	138	451	488	584	695	316	585	344	451	643
Y	53	36	45	36	22	38	34	39	58	34
Zr	461	301	328	236	557	420	227	384	388	225
Nb	54	40	63	49	89	40	44	38	67	45
Ba	728	498	254	163	589	712	136	658	490	189
Pb	22	19	5	2	10	14	1	15	10	2
La	77	46	55	37	71	60	31	55	73	44
Ce	133	89	98	75	125	111	67	114	128	76
Nd	56	41	48	33	49	47	33	47	55	36
Th	25	12	7	4	17	20	5	15	12	6
Zr/Nb	8.533	7.525	5.206	6.258	6.258	10.500	5.159	10.105	5.791	5.000
Zr/Y	8.689	8.361	7.289	6.556	25.318	11.053	6.676	9.846	6.690	6.620
Zr/Rb	2.888	3.583	6.833	9.440	4.843	3.182	9.458	3.174	6.690	9.380
Zr/Ti	0.202	0.043	0.031	0.015	0.075	0.082	0.013	0.062	0.033	0.014
Nb/Y	1.019	1.111	1.400	1.361	4.045	1.052	1.294	0.974	1.155	1.324
Ti/Y	42.984	194.840	234.365	451.300	337.905	143.101	509.582	156.800	200.525	484.900
K/Ba	53.710	42.675	56.216	62.135	45.243	43.608	68.977	42.770	41.170	51.830
K/Rb	244.379	253.001	297.474	405.119	231.723	235.213	390.866	232.582	347.809	408.163
Rb/Sr	1.159	0.186	0.098	0.043	0.165	0.428	0.041	0.352	0.127	0.037
Nb/Th	2.160	3.333	9.000	12.250	5.235	2.000	8.800	2.533	5.583	7.500
Ce/Yn	5.802	5.716	5.035	4.817	13.137	6.754	4.556	6.759	5.103	5.168
*Ca/Al	0.072	0.352	0.487	0.560	0.251	0.193	0.532	0.241	0.378	0.520
Ti/100				162.468			173.258			164.865
3*Y				108.000			102.000			102.000
Zr				236.000			227.000			225.000
Ti/100				32.078			34.496			33.518
3*Y				21.324			20.308			20.737
Zr				46.597			45.196			45.744
2NB				50.7			49.2			49.9
Zr/4				30.5			31.7			31.2
Y				18.6			19.0			18.8



APPENDIX VII

SELECTED ROCK AND MINERAL ANALYSES

- Total Fe was determined by XRF, and the abundance of Fe2O3 and FeO were calculated using the following relationships.

- (1)  $Fe_2O_3 / FeO = 0.3$
- (2) Total Fe2O3 (XRF analysis) = 1.111 FeO + Fe2O3

- (1) FeO\* is calculated from rock analysis using GPP program.
- (2) For mineral analysis :- FeO\* is calculated using [total Fe2O3 (MP analysis) X 0.9] + FeO = FeO\*
- Mineral analyses are in Wt. %.

APPENDIX VII A SELECTED ROCK ANALYSES

	4021 M	2164B M	53 M	4003 M	4301 M	5626 N	5824 N	5822 N
S102	49.69	54.19	61.40	65.80	47.95	49.58	53.60	61.65
T102	2.71	1.62	1.14	0.48	2.65	2.75	1.94	1.02
AL2O3	16.01	18.13	18.19	16.69	16.04	18.01	16.01	15.89
+ FE2O3	13.01	8.99	4.55	4.03	12.05	11.22	10.75	6.74
FeO								
MNO	0.22	0.15	0.08	0.03	0.16	0.18	0.15	0.14
MGO	3.34	2.19	0.77	0.11	5.28	3.57	2.53	1.37
CaO	7.63	5.37	4.02	1.66	8.69	9.37	6.05	3.83
Na2O	4.41	5.63	5.65	5.14	3.42	3.69	4.67	4.35
K2O	1.65	2.65	3.83	4.28	1.22	1.18	2.43	3.39
H2O+	0.44	0.49	0.90	0.57	1.53		0.29	0.73
H2O-								
P2O5	0.79	0.56	0.32	0.12	0.57	0.56	0.79	0.34
TOTAL	99.90	99.97	100.85	98.91	99.56	100.11	99.21	99.45
FeO*	11.71	8.09	4.09	3.63	10.84	10.10	9.67	6.06

- 4021 - M36B4021 LATE PHASE HAWAIIITE LAVA FLOW
- 2164B - M36B2164B LATE PHASE MUGEARITE LAVA FLOW
- 53 - M36B53 TRACHYTE DIKE
- 4003 - LATE PHASE SILICA RICH TRACHYTE LAVA FLOW
- 4301 - MAIN PHASE MG RICH HAWAIIITE LAVA FLOW
- 5626 - MAIN PHASE MG LOW HAWAIIITE LAVA FLOW
- 5824 - N36A5824 MAIN PHASE MUGEARITE LAVA FLOW
- 5822 - N36B5822 MAIN PHASE SILICA RICH BENMOREITE LAVA FLOW

M - Samples prefixed by M36B  
N - Samples prefixed by N36A

APPENDIX VII B SOME REPRESENTATIVE MINERAL ANALYSES

	CPX.1	CPX.2	CPX.3	CPX.4	01.1	01.2	01.3	01.4	P1.1	P1.2	P1.3	P1.4	11.1	11.2
S102	49.16	51.56	49.91	46.61	38.95	37.02	36.50	34.04	48.59	63.02	52.97	58.10	0.10	0.51
T102	1.75	1.29	1.09	1.18	0.02	0.04	0.07	0.43	0.09	0.05	0.11		26.26	50.02
AL2O3	4.18	3.17	2.90	3.47	0.06	0.06	0.25	0.91	29.42	22.81	27.62	26.44	1.50	nd
FE2O3				0.90				1.46				0.04		4.19
FeO *	7.66	6.04	9.89	20.18 <sup>x</sup>	14.74	28.70	31.44	40.37 <sup>x</sup>	0.47	0.27	0.53	0.15 <sup>x</sup>	68.13	42.18 <sup>x</sup>
MNO	0.10	0.19	0.46	1.11	0.19	0.48	0.87	0.68					0.75	1.44
MGO	14.66	15.59	12.27	7.27	45.02	33.02	29.68	20.32	0.11	0.01	0.03	0.03	2.56	0.46
CaO	22.62	22.81	22.25	17.24	0.23	0.23	0.39	0.81	14.28	5.14	11.61	7.83	0.05	0.71
Na2O	0.44	0.33	0.79	1.04	0.02	0.04			4.06	8.45	4.81	6.48	0.11	
K2O		0.01		0.27	0.01		0.10		0.15	0.87	0.28	1.10		
H2O+				0.42				0.91				0.03		0.30
H2O-				0.04								0.06		
P2O5														
TOTAL	100.57	100.99	99.56	99.73	99.22	99.57	99.34	99.93	97.17	100.62	97.96	100.26	99.46	99.81
FeO *				20.99				41.68				18000		45.95
Cr2O3	.06000	.58000	.01000		.07000	.03000			.60000	.01000	.07000			

X = FeO

- CPX.1 - + CLINOPYROXENE (.31) PHEN-CORE-M36B1038
- CPX.2 - + CLINOPYROXENE (.51) PHEN-CORE-M36D2147
- CPX.3 - + CLINOPYROXENE (.81) PHEN-CORE-M36D2187
- CPX.4 - • FERROAUGITE (TABLE 13, 7)
- 01.1 - + OLIVINE (.11) PHEN-CORE-M36B1174
- 01.2 - + OLIVINE (.11) PHEN-CORE-M36D2187
- 01.3 - + OLIVINE (.11) PHEN-CORE-M36B1067
- 01.4 - • OLIVINE (TABLE 1, 3) HORTONOLITE (50-70 Fa)
- P1.1 - + PLAGIOCLASE (.51) PHEN-CORE-M36B1174
- P1.2 - + PLAGIOCLASE (.81) PHEN-CORE-M36D2110
- P1.3 - + PLAGIOCLASE (.31) PHEN-CORE-M36D2194
- P1.4 - • PLAGIOCLASE (TABLE 31, 4) ANDESINE
- 11.1 - + ILMENITE PHEN-CORE-M36B1067
- 11.2 - • ILMENITE (TABLE 14, 1)

- Analyses taken from Deer et al. (1986), numbers in parenthesis refer to their tables and analysis numbers.
- + Analyses taken from Sewell, 1985. Parentheses refer to mineral analysis number and the prefix M36 refers to rock sample number.

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