THE PETROLOGY OF SOME YOUNG SUBVOLCANIC AND VOLCANIC ROCKS FROM WEST KALIMANTAN, INDONESIA

by

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science.

University of Tasmania

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and to the best of my knowledge and belief, contains no copy or paraphrase of material previously published or written by another person, except where due reference in made in the text of this thesis.

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ABSTRACT

The northern part of West Kalimantan, which is the northern part of Sundaland, has been a continental margin since the Cretaceous time. The southern part of West Kalimantan is occupied by a belt of Cretaceous granitoids (West Borneo Basement), while the western part is composed of Jurassic-Cretaceous sediments, and Late Palaeozoic granitic and metamorphic rocks. The northern and central parts are now a sedimentary basin and a melange belt. There is a distinct unconformity between the Cretaceous and the Tertiary. Three episodes of volcanic activity (Cretaceous, Tertiary and Quaternary) have been recognized in western and central West Kalimantan.

The Cretaceous volcanics are mainly basalts and dacites and minor andesites. The basalts are characterized by the presence of quartz xenocrysts and biotite in the groundmass. They have higher SiO_2 and lower TiO_2, P_2O_5, La and Zr contents than the Tertiary volcanic rocks. These volcanics have been metamorphosed to greenschist facies. They are mainly distributed in the western part of West Kalimantan. These volcanics have an island-arc tholeiite character, which may be a response to the southward subduction recorded in the Lupar Line and the Boyan Melange.

The Tertiary volcanics are largely dacites with less common rhyolites, and minor basalts and andesites. They are mainly distributed in the central West Kalimantan (CWK). The basalts are tholeiitic, and the dacites, andesites and rhyolites are calcalkaline. A few rhyolites from the southern province of the CWK are alkaline and in the central province trondhjemite occurs. The basalts from the northern province have a different source from those of the southern province. The Tertiary volcanics contaminated by lower crustal material have a substantially different chemical signature from north to south. In the southern province, the Tertiary volcanics intrude into the belt of Cretaceous granitoids. These volcanics have the most siliceous character and the highest enrichment in K-type elements. In the northern province the Tertiary volcanics intrude the Boyan Melange belt and the Tertiary sediments of the Kentungau Basin. The andesites and dacites have a high TiO_2 content and the spidergram patterns are similar to those of ocean-island basalt which is contaminated by sediments. In the central province the Tertiary volcanics intrude the thick sedimentary succession of the Melawi Basin and the Cretaceous turbidite sediments. The volcanics found here are dacites and rhyolites. The Tertiary volcanics from CWK may be

related to the southeast subduction beneath the Sarawak accretionary prism. Mineral evidence indicates magma mixing has taken place in th dacites.

The Quaternary lavas from Mt Niut are trachybasalts and basaltic andesites. The lavas display the geochemical features of continental tholeiites which are similar to transitional mid-oceanic ridge basalt (MORB).

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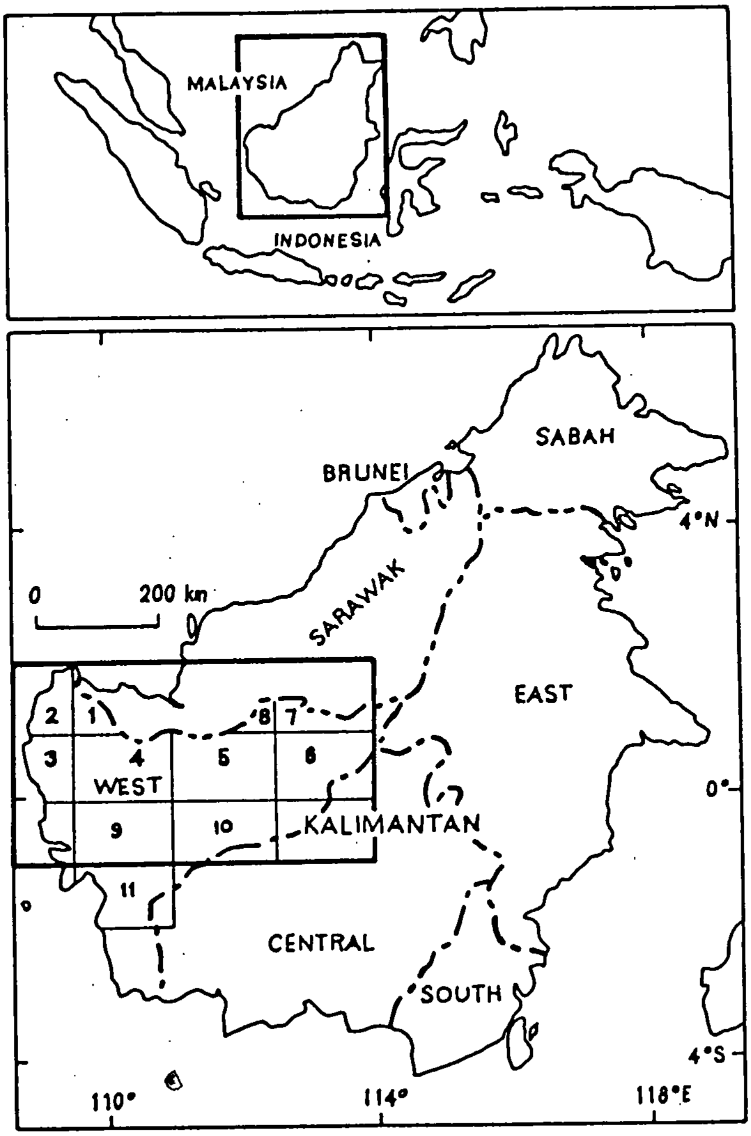
1. INTRODUCTION

1.1 STUDY ORIENTATION

The presence of Tertiary intrusives in West Kalimantan was first reported by Molengraaf (1900), but no systematic study of their field relationship was carried out until recently. No substantial modern geochemical studies have been attempted. Considering that Kalimantan is the second largest island of the Indonesian archipelago and is far larger than Jawa and Bali combined, a detailed study of the young volcanics is important to the understanding of the tectonic evolution of the Sunda Orogen. West Kalimantan occupies a key structural position in the Sunda Orogen (Haile, 1973), and the systematic petrological and geochemical study in this work provides important new information on the evolution of the Sunda Orogen.

There are four reasons to concentrate on the Tertiary igneous rocks in West Kalimantan. Firstly, the field relationships are clear and the rocks are fresh and widely distributed. Secondly, no previous study has provided the detailed information needed for tectonic interpretation. Thirdly, the study became logistically possible as a result of the mapping projects of the Indonesia-Australia Geological Mapping Project (IAGMP). Finally, the younger rocks can be linked to the tectonic activity in the area, known from other geological data.

The primary aim of this work is to investigate the petrology and geochemistry of the intrusions, and interpret them according to their tectonic setting. Most of the intrusions studied occur in the 1:250 000 sheet areas of Sintang and Nangapinoh, and only a few intrusive centres were included from Ketapang, Nangataman, Sanggau, Singkawang, and Siluas (Fig. 1.1). These samples were collected during six seasons of field mapping in the years 1983, 1984 and 1985, by the IAGMP geologists including the author. Most of the rock samples are of plugs. Dykes, sills and rarely tuff and lava were also sampled. In addition to these samples, seven rock samples from the western part of South Sulawesi (Western Sulawesi Province, Sukamto & Simanjuntak, 1982) are included in this thesis (Appendix 4), they are Mio-Pliocene dyke swarms and plugs, and have a similar intrusive environment to the West Kalimantan suite.



1:250 000 sheet areas

1 Siluas
2 Sambas
3 Singkawang
4 Sanggau
5 Sintang
6 Putussibau
7 Pegunungan Kapuas
8 Nangaobat
9 Nangataman
10 Nangapinoh
11 Ketapang

Fig. 1.1 Study area.

1.2 PREVIOUS WORK

1.2.1 Geology and Field Relationships

Large inselbergs rise up to 1000 m from the tropical peneplain associated with the Kapuas, Melawi and Ketungau River valleys in Central West Kalimantan (Molengraaf, 1900) (Fig. 1.4). They are composed of intermediate to acid igneous rocks (Emmichoven, 1939; Williams & Herianto, 1985). Hamilton (1979), in his compilation of the tectonic history of Indonesia, postulated that these rocks and their correlatives in Sarawak represent the last phase of igneous activity associated with southeastward subduction beneath the Sarawak accretionary prism, a conclusion also reached by Holloway (1982). Kirk (1968) described the rocks as belonging to a post-tectonic intrusive event or post-Upper Cretaceous Boyan Melange (Williams et al., 1985). Younger alkaline "plateau basalts" have been reported by Rutten (1927) and Bemmelen (1949) at Mt Niut (Fig. 4.1).

Recent mapping in West Kalimantan by IAGMP has shown large volumes of mid-Tertiary igneous rocks emplaced in all the major rock units in West Kalimantan. These units are a belt of Early Cretaceous granitoids or West Borneo Basement (Haile, 1973), marine to fluviatile sedimentary basin sequences (Melawi Basin), Cretaceous marine deposits, the Boyan Melange, and fluviatile to marginal marine sedimentary basin sequences (Ketungau Basin) (Fig. 1.2). More than a hundred small intrusions and over fifty large intrusions are shown by Williams & Herianto (1985) on the 1:250 000 scale, preliminary geological map of the Sintang quadrangle. Although minor intrusions are widespread, the larger intrusions, which range in size up to 17 x 7.5 km, appear to be restricted to the sedimentary basins and the Cretaceous marine deposits. These rocks have many of the petrological characteristics of the andesite-rhyolite-basalt volcanic association found among the rocks of the circum-Pacific belt (Turner & Verhoogen, 1951). Rhyolite is not, however, a significant component of the volcanic association in the West Kalimantan. A similar association has been reported by Kirk (1968) for Tertiary and Quaternary volcanics in Sabah and Sarawak. It is therefore more appropriate to use the name andesite-dacite-basalt association for the West Kalimantan, Sarawak, and Sabah sub-volcanic and volcanic rocks.

Around the Kayan River (Fig. 1.4) the concentration of intrusions indicates that there may be a major feeder zone or pluton at depth. In the upper Melawi area, magma intruded as thick sills in the shallowly dipping Melawi Group sedimentary rocks. In the Ketungau Basin to the north, the intrusions are very large stocks with a linear distribution, close to the deepest central part of the basin. Lower Tertiary intrusions into the

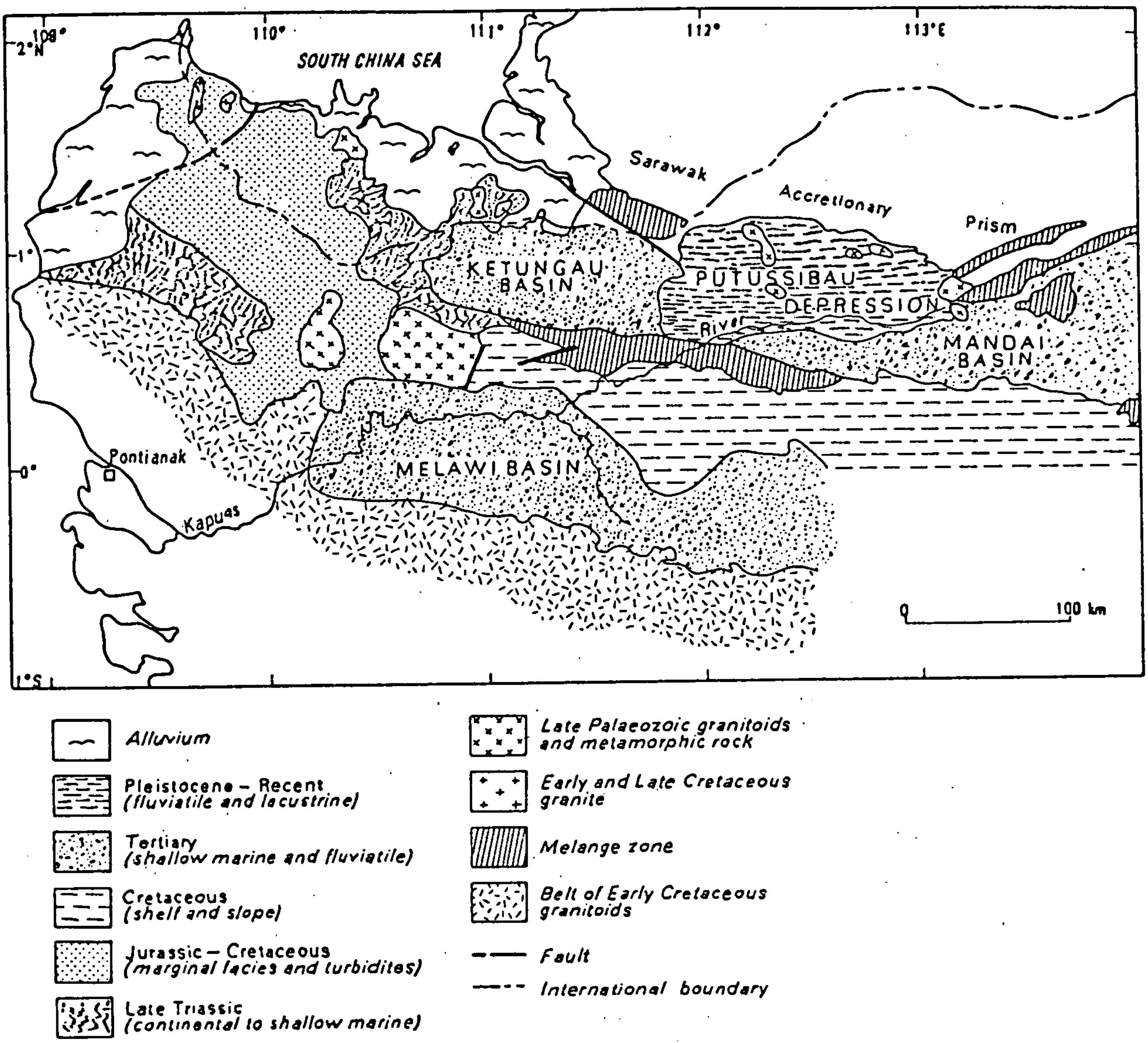


Fig. 1.2 The main tectonic elements in West Kalimantan.

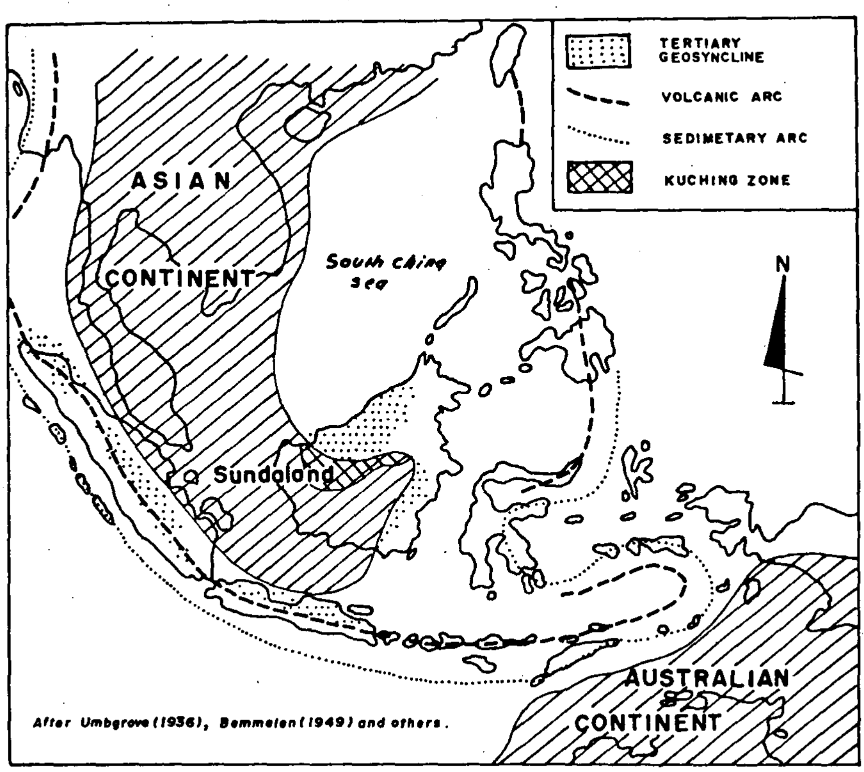


Fig. 1.3 Map of Sundaland.

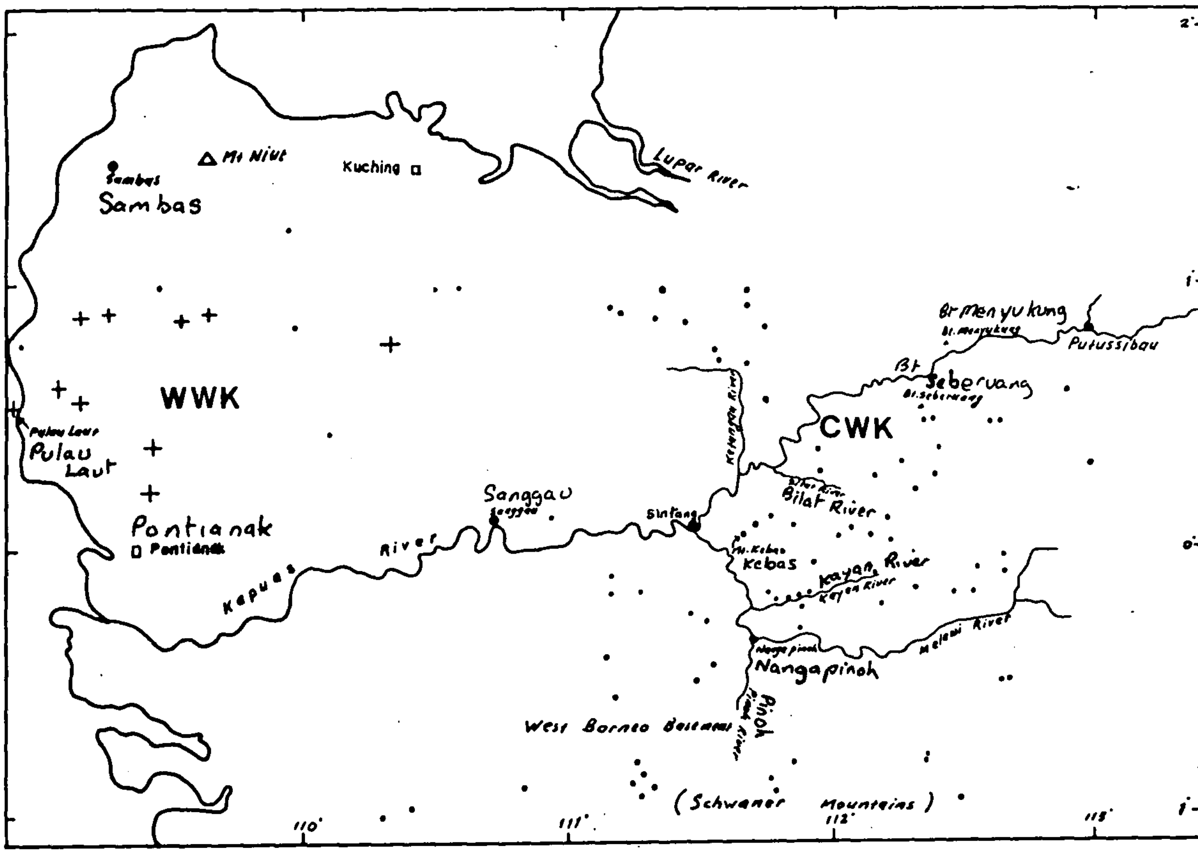


Fig. 1.4 Distribution of subvolcanic and volcanic rocks in West Kalimantan. Small dots are Tertiary subvolcanic and volcanic rocks. Pluses are Cretaceous subvolcanic and volcanic rocks. CWK = central West Kalimantan, WWK = western part of West Kalimantan. This map also shows geographic names used in this thesis.

Cretaceous I-type granitoid basement are typically narrow dykes. Cretaceous intrusions occur in the western part of this basement, as dykes and plugs. Tuff and agglomerate are rare.

1.2.2 Geochronology

K/Ar mineral and whole rock ages were determined on twelve samples, collected mainly from the intrusions close to Sintang (Fig. 1.4). The results are shown in Appendix 1. Apart from sample 69306, the K/Ar ages range from 23.0 to 30.4 m.y. for intrusions in the southern part of the region, in the Melawi Basin. Samples taken from the northern plugs have K/Ar ages of 16.4 ± 0.1 to 17.9 ± 0.2 m.y. The K/Ar ages of similar Tertiary intrusives from Sarawak, just north of this region are 16 ± 4 m.y. and 19 ± 3 m.y. (Kirk, 1968).

1.2.3 Mineral Resources

Gold, cinnabar, stibnite and uranium are being mined in this region. Williams & Herianto (1985) reported that there is a striking correspondence between the distribution of the Oligo-Miocene Sintang Intrusives, and anomalous values of Cu, Au, Mn, As and Sb. A second major association of anomalies is with the Boyan Melange belt. A number of chromium occurrences are known to be associated with ultramafic rocks. Gold anomalies are common in the melange, associated with vein quartz. The third association is with the granite in the Kapuas Lake district. Anomalous tin in the region was surprising, as tin mineralization has not previously been reported in Kalimantan.

1.2.4 Tectonic Setting

Kalimantan lies on the continental side of the Sunda Island arc of Sumatera and Jawa in a position difficult to reconcile with any simple geotectonic pattern, either in terms of geosynclinal or plate tectonic theory (Haile et al., 1977). The western part of the island is situated in the northern margin of Sundaland, which forms the southeast end of the Asian continent (Fig. 1.3). Sundaland includes the Malay Peninsula, part of Sumatera's east coast, West Kalimantan, and the Sunda shelf, and is tectonically stable compared with the adjacent circum-Sunda islands of Jawa, Sulawesi and the Philippines (Leichti, 1960; Tjia, 1980). The region became tectonically stable in the Early Tertiary (Tjia, 1980). Its tectonic history may be explained as follows:

Cretaceous

The Cretaceous granitoid belt intruded low grade regional metamorphic rocks of unknown age. They are accompanied by intrusions ranging in composition from basaltic to dacitic, with K/Ar ages of 121 m.y., discussed in Chapter 3. They form the continental basement in the south (Fig. 1.2).

K/Ar dating of this granitoid basement shows that the rocks become younger from north to south (74 to 124 m.y.) (Haile et al. 1977).

The inception of southward subduction activity was recorded in the Upper Cretaceous along the Lupar Line of Western Sarawak (Haile, 1974; Hutchison, 1975; Hamilton, 1979; Holloway, 1982), and along the Boyan Melange belt (Williams & Harahap, 1985). Hamilton (1979) suggested that the increase in potassium contents of the granitic rocks in West Kalimantan from north to south implies that the bulk of these rocks formed in response to subduction from the north. This predated the initiation of southward crustal movement in the South China Sea Basin (Fig. 1.3) and is therefore attributed to the counter-clockwise rotation of the West Borneo Basement (Haile, 1974; Holloway, 1982). The marine deposits (Williams & Herianto, 1985; Haile, 1974) are a broken formation and suggest a structural continuity with the Melange. The Melawi basin represents a fore-arc basin associated with the early phase of development of the subduction complex, and was then actively subsiding (Williams et al., 1986).

Palaeocene-Eocene

The accretionary wedge of the Sarawak Subduction system built outward to the north. Consequently, the position of the subduction trench also migrated northward, and formed the Lubok Antu Melange (Tan, 1982) and the associated accretionary terrain in Sarawak (Holloway, 1982; Hamilton, 1979). The convergence and migration of this subduction trench was a result of the rotation of Borneo and the southward movement of oceanic crust ahead of the advancing South China Continental Margin (Holloway, 1982). The Kerabai volcanics (Trail & Amirudin, 1986) of basalt-andesite-dacite-rhyolite composition (discussed in Chapter 2), are 65 m.y. old (based on K/Ar dating). They are possibly a response to this subduction.

Wood (1985) proposed an Early Tertiary crustal shortening by folding about an east to northeast oriented fold axis for the Borneo region. The Ketungau Basin was formed at this stage (Eocene) in the fore-arc position (Williams & Herianto, 1985). The Melawi Basin continued to receive sediment. The Melawi sediments were folded before the Late Eocene (Wood, 1985).

Oligocene-Miocene

Mid-Oligocene time is regarded as the time of cessation of continental crust attenuation and the commencement of sea-floor spreading (Holloway, 1982). By Oligocene time, Borneo is believed to have completed its counter-clockwise rotation (Holloway, 1982).

While the subduction continued to migrate northward, all the West Kalimantan rocks were unconformably overlain by flat-lying to gently-dipping fluviatile sandstone. A few later geologic events including a Late Miocene uplift of the Schwaner Mountains (Rose et al., 1978), the folding of Boyan Melange (Williams et al., 1984; Wood, 1985) and intrusions of calc-alkaline rocks (Hamilton, 1979; Williams & Harahap, 1985), discussed in Chapter 2, have been recorded in West Kalimantan.

Quaternary

Volcanism was limited to sparse volcanic centres in the Quaternary. One example, the basic lava flows of Mt Niut, is discussed in Chapter 4.

1.3 LOGISTICS

1.3.1 Geography and Physiography

The area dealt with by this thesis mainly comprises the central part of western Kalimantan (Borneo) Island (Fig. 1.1), known as "Propinsi Kalimantan Barat", with its capital city of Pontianak situated at the mouth of the Kapuas River.

This remote inland basin is located in the drainage area of the Kapuas River and its main tributary, the Melawi River. The Kapuas River is the largest river in Indonesia and drains 100 000 sq.km of equatorial rainforest. The river is navigable far inland (except during periods of extreme low water). It debouches into the South China Sea at a sprawling delta near Pontianak. The southern part of the area consists of the Schwaner Mountains, which rise to 2000 m. To the north of these mountains is the long and broad Melawi valley, a large area of low, rolling hills with numerous inselbergs formed of Tertiary intrusions. One of the most impressive of these mountains is Bukit Kelam, which rises almost vertically out of swamp to a height of 900 m (Plate 1.1). Another characteristic topographical feature is associated with the Plateau Sandstone (Emmichoven, 1939) or Dangkan Sandstone (Williams & Herianto, 1985). Where their dips are low, these sandstones form a characteristic dipslope escarpment. To the northwest of the Kapuas River, the country is low, rolling country. The large swampy area in the middle of the Kapuas valley is divided into two parts by the granite mountains of Bukit Menyukung and Seberuang (Fig. 1.4). The western part consists of large shallow lakes which frequently dry up during the dry season. The climate is generally hot and humid, with the wettest months from October to March. The average annual rainfall at Sintang is 3528 mm.

Plate 1.1 Bukit Kelam, view facing northeast.

1.3.2 Access

Air strips are available in most towns in West Kalimantan. There is a weekly service to Pontianak from these towns, while a daily air service links Pontianak with the Indonesian capital, Jakarta.

Surface transport is mainly by rivers. A road follows the Kapuas River from Pontianak to Sintang through Ngabang and Sanggau, and another runs along the west coast from Pontianak to Singkawang and Sambas. Another road is under construction from Putusibau to Sintang.

1.4 ANALYTICAL METHODS

Sixty-four rock samples have been selected for major element analysis by Xray fluorescence spectrometry based on the methods of Norrish & Hutton (1969), and Norrish & Chappell (1967), at the Department of Geology, University of Tasmania. The in-house standard Tasdol (Tasmanian dolerite) was used to check calibrations. All major element analyses have been recalculated to 100% total on a "volatile-free" basis. Trace element analyses have not been adjusted. Fe is reported as total FeO which signifies total Fe calculated as FeO. Twenty rock samples have also been analysed for rare earth elements (REE) by ion-exchange and thin film XRF techniques (Robinson et al., 1986). The standard sample used is Tasbas (Tasmanian basalt). Analyses of minerals reported in this thesis were all carried out by EDS analysis on the JEOL JXA50A microprobe instrument in the Central Science Laboratory at the University of Tasmania. The CIPW norms were calculated assuming molecular $Fe^{2+}/(Fe^{2+}+Fe^{3+}) = 0.9$. The rock samples included in this investigation are housed at the Department of Geology, University of Tasmania.

1.5 NOMENCLATURE

The basis of the nomenclature used here follows the current IUGS subcommission on the chemical classification of volcanic rocks, utilizing the total alkali-silica diagram (TAS diagram) of Lebas et al. (1986) (Fig. 1.5). This is more appropriate to use than a classification based on modal mineralogy because these rocks range from hypabyssal to volcanic in texture, and most could not be classified according to their modal composition due to their very fine grained matrix.

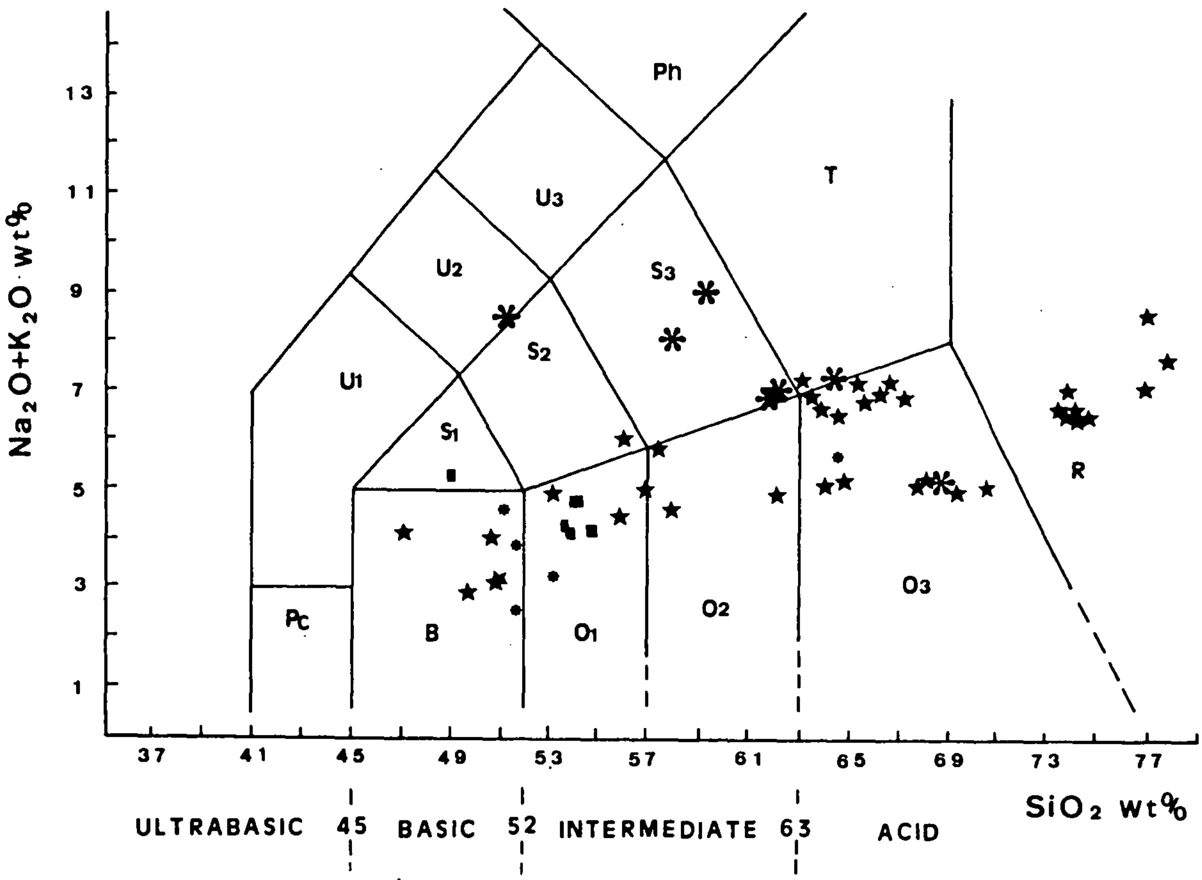


Fig. 1.5 TAS (total alkali versus silica) diagram. (Lebas et.al., 1986)
★ - Tertiary subvolcanic and volcanic rocks from central West Kalimantan
● - Cretaceous subvolcanic and volcanic rocks from the western part of West Kalimantan,
■ - Quaternary lava from Mt Niut
✱ - Neogene subvolcanic rocks from the western part of South Sulawesi.
Field symbols: P_c = picrobasalt, B = basalt, O_1 = basaltic andesite, O_2 = andesite, O_3 = dacite, R = rhyolite, T = trachydacite, U_1 = tephrite basanite, U_2 = phonotephrite, U_3 = tephriphonolite, S_1 = trachybasalt, S_2 = basaltic trachyandesite, S_3 = trachyandesite.

2. PETROLOGY OF TERTIARY SUBVOLCANIC AND VOLCANIC ROCKS FROM CENTRAL WEST KALIMANTAN

2.1 INTRODUCTION

The Tertiary subvolcanic and volcanic rocks of Central West Kalimantan (CWK) form a suite ranging from basalt (or dolerite), through andesite (or microdiorite), and dacite (or microgranodiorite), to rhyolite (microgranite). These rocks may be divided into three provinces based on the geological setting and on the igneous rock types found. The southern part of this region (Fig. 1.2), is called the southern province, while the central and northern parts are called central and southern province respectively.

A schematic section (Fig. 2.1) shows these three provinces. The southern province includes the belt of Cretaceous granitoids. It is bounded to its north by the Melawi Basin. The central province includes the Melawi Basin and the Cretaceous sediments. It is bounded to its north by the Cretaceous Boyan Melange. The northern province includes the Boyan Melange and the Ketungan Basin.

The relative abundance of the~~se~~ [igneous subvolcanic and volcanic] rock types varies between the three provinces. The southern province is dominated by rhyolites, basalts and andesites. The central province is dominated by dacites with basalt absent. The northern province is dominated by andesites and dacites.

The dacites and rhyolites occur mainly as plugs and dykes, with rare columnar jointing, while andesites and basalts are plugs and dykes respectively. Minor occurrences of rhyolitic and dacitic tuff, and agglomerate have been found in the southern province and the central province.

The mineral chemistry and general description of the rocks are presented in Appendices 2 and 3. The following discussion concentrates on the petrography of samples selected for detailed mineralogical analysis. The effects on the rocks of mild alteration or metamorphism are not considered in detail.

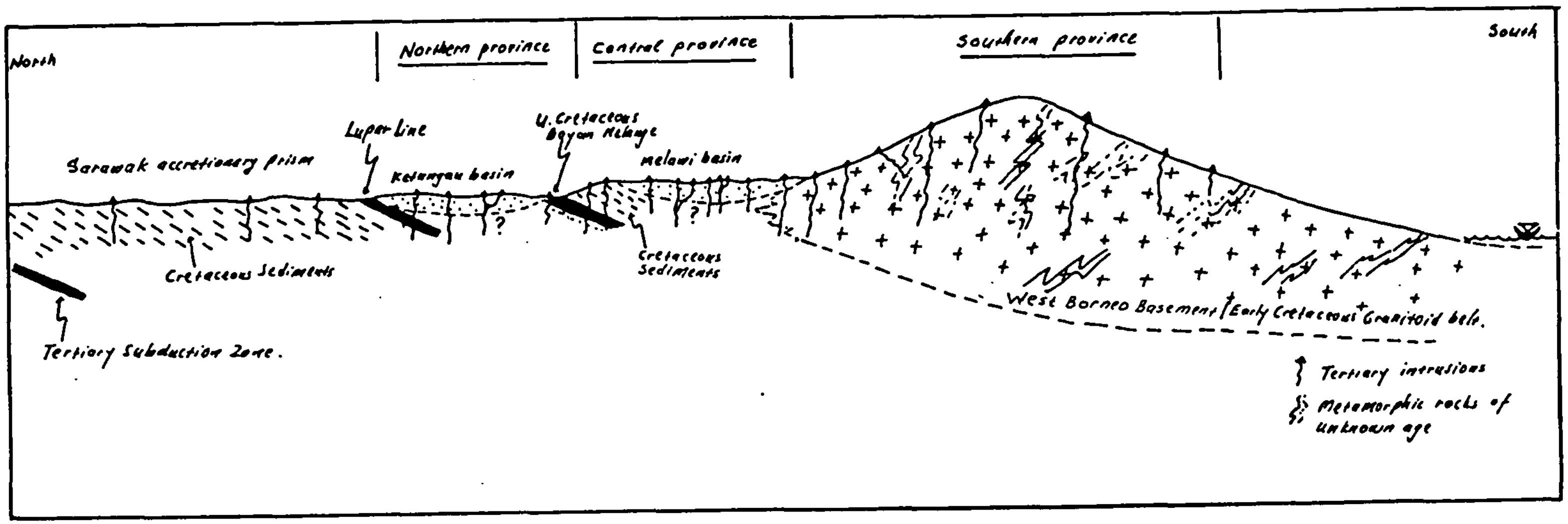


Fig. 2.1 Diagramatic cross-section of the Central West Kalimantan, to show the relation of the Tertiary intrusions with the country rocks. This section is taken from Fig. 1.2 from north to south at 111°E longitude

2.2 PETROGRAPHY AND MINERALOGY

The petrographic characteristics of the rocks of each province are summarized in Table 2.1 and the modal analyses shown in Table 2.2. Most rocks are holocrystalline. Detailed descriptions of each rock type follows.

2.2.1 Basalt

The basalts are dark-coloured porphyritic rocks, with fine grained groundmass. Some rocks have a doleritic texture. Rare oikocrysts, up to 1.30 cm across, occur.

The basalts from the northern province differ from those of the southern province. The northern province basalts contain two pyroxenes, with more ilmenite than magnetite, and minor amphibole. They have poikilitic and seriate textures. The southern basalts do not contain orthopyroxene and magnetite is more abundant than ilmenite. They have porphyritic and ophitic texture. The phenocrysts are plagioclase (maximum 3 x 130 mm), clinopyroxene (maximum 15 mm), orthopyroxene (maximum 0.8 mm), Fe-Ti oxides (maximum 0.4 mm). Chlorite of sample 69293 contains chrome spinel and appears to have pseudomorphed olivine. The groundmass consists of plagioclase, clinopyroxene, orthopyroxene, ilmenite, magnetite and apatite. Sample 69292 contains biotite in the groundmass.

Plagioclase grains are subhedral to euhedral and tabular. They contain inclusions of orthopyroxene, clinopyroxene and rare magnetite, ilmenite and apatite. A fine grained intergrowth of orthopyroxene and clinopyroxene occurs on the outer rim of many plagioclase grains. The plagioclase compositions are mostly An_{50} to An_{70}, although some are more calcic, up to An_{85} (Fig. 2.2, Appendix 2). Most of the phenocrysts are normally zoned. One phenocryst is reversely zoned. The reverse zonation may represent a xenocrystic plagioclase core (Larsen et al., 1937; Pe, G.G., 1974).

Total iron in plagioclase increases with decreasing An contents (Fig. 2.3) and probably reflects increasing Fe^{3+} activity in the melt during crystallization. The quartz normative basalt (69297) has lower Fe^{3+} in the plagioclase. It may be more reduced.

Clinopyroxene phenocrysts are equant, and anhedral to subhedral in form. They are augite and minor salite. In some grains the core is salitic in composition, whereas the rims are calcium augite (Fig. 2.4, Appendix 2), similar to most clinopyroxene from orogenic basic lavas (Ewart, 1976). Unlike trends typical of tholeiitic differentiate series, the CWK rocks do not show Fe enrichment of the clinopyroxene.

TABLE 2.1 SUMMARY OF PETROGRAPHY

PROVINCE	ROCK TYPE	Phenocryst										Groundmass									
		pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol	pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol
South	Basalt	+	-	-	+	-	-	-	-	-	±	+	-	-	+	-	-	±	+	-	-
	Andesite	+E	-	-	+	+	±	-	-	-	-	+	+	+	±	±	±	-	+	+	-
	Dacite	+E	-	+E	+	+	+E	+	-	-	-	+	+	+	+	+	+	+	+	+	-
	Rhyolite	+E	-	+E	-	-	+	±	-	-	-	+	+	+	-	-	-	-	+	±	-
Central	Andesite	+	-	+E	-	-	+	-	-	-	-	+	-	+	-	-	+	-	+	-	-
	Dacite	+E	-	+E	+	+	+E	+	-	-	-	+	+	+	+	+	+	+	+	+	-
	Rhyolite	+	-	+	-	-	-	-	-	-	-	+	+	+	-	-	-	+	+	-	-
North	Basalt	+	-	-	+	+	+	-	-	-	-	+	-	-	+	+	-	-	+	+	-
	Andesite	+E	-	-	+	+	±	±	-	-	-	+	-	+	+	+	+	+	+	+	-
	Dacite	+	-	-	±	±	±	±	+	-	-	+	+	+	+	+	+	+	+	±	-

TABLE 2.2 MODAL COMPOSITION

ock type	Sample no.	pl	cpx	opx	hbl	biot	Fe-Ti oxides	gr	qtz	act	chl	ap
Basalt	69297	50.21	8.73	31.48	tr	-	7.70	-	-	-	1.90	tr
,,	69292	55.93	13.55	-	-	-	10.83	-	-	tr	19.69	tr
,,	69293	41.05	2.38	-	-	-	4.51	47.77	-	-	4.29	tr
Andesite	69301	65.51	6.03	tr	-	-	5.27	32.18	-	-	-	tr
,,	69307	30.23	-	-	14.93	-	0.45	54.39	-	-	tr	tr
,,	69308	45.89	0.96	tr	-	2.94	tr	50.15	-	-	tr	tr
,,	69310	39.95	tr	5.51	-	-	6.0	48.34	-	-	tr	tr
,,	69306	68.36	12.50	7.10	0.30	9.02	1.55	-	-	-	-	1.1
Dacite	69334	46.50	-	-	4.68	8.39	1.45	19.51	19.47	-	-	tr

Explanation for Table 2.1 and 2.2 :
+ = present, - = absent, $\pm$ = not always present, E = indicate resorption
pl = plagioclase, san = sanidine, qtz = quartz, hbl = hornblende, biot = biotite, mg = magnetite, il = ilmenite, ol = olivine, act = actinolite, chl = chlorite, ap = apatite, cpx = clinopyroxene, opx = orthopyroxene, gr = groundmass.

Accessory minerals include apatite which is ubiquitous, and rare sphene, zircon, and rutile. Many rocks, particularly the dacites, contain metamorphic minerals such as chlorite, sericite, epidote, and carbonate. Prehnite and actinolite are present in a few samples. Sulphide minerals are mainly pyrite and chalcopyrite, and scarce pyrrhotite.

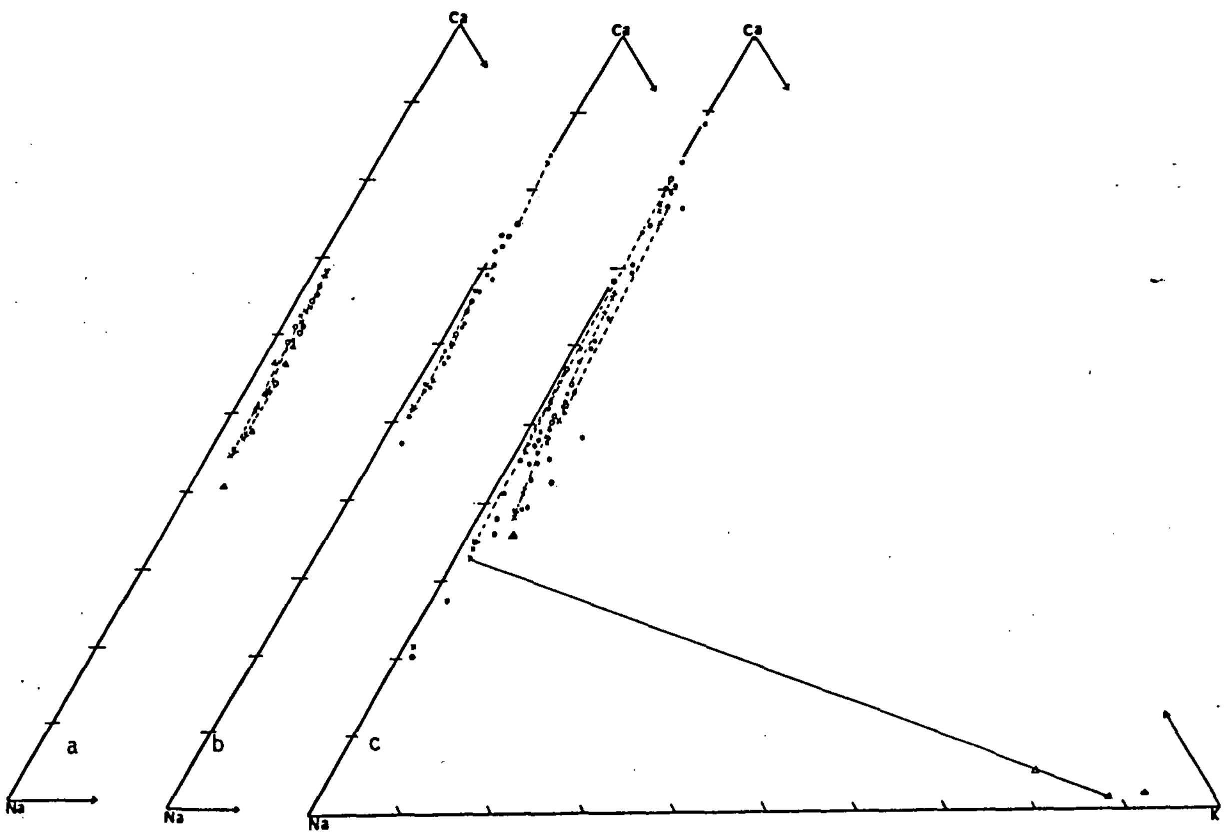


Fig. 2.2 Feldspar compositional variation from basalt (a), andesite type 1 (b), and andesite type 2 (c). Phenocryst (•) phenocryst core (o), rim (×), groundmass (△). Dashed lines connect core with rim of the same phenocryst. Tie line connects coexisting phases.

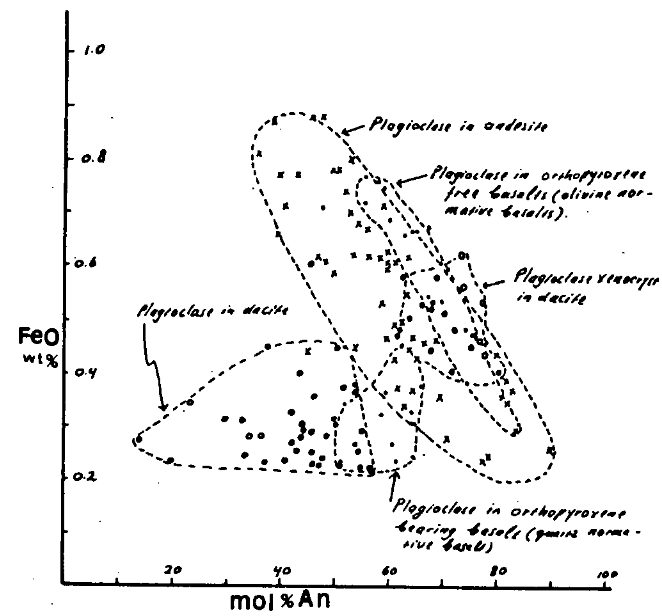


Fig. 2.3 Total iron versus mol% anorthite of the plagioclase from basalts (•), andesite (×) and dacites (∘).

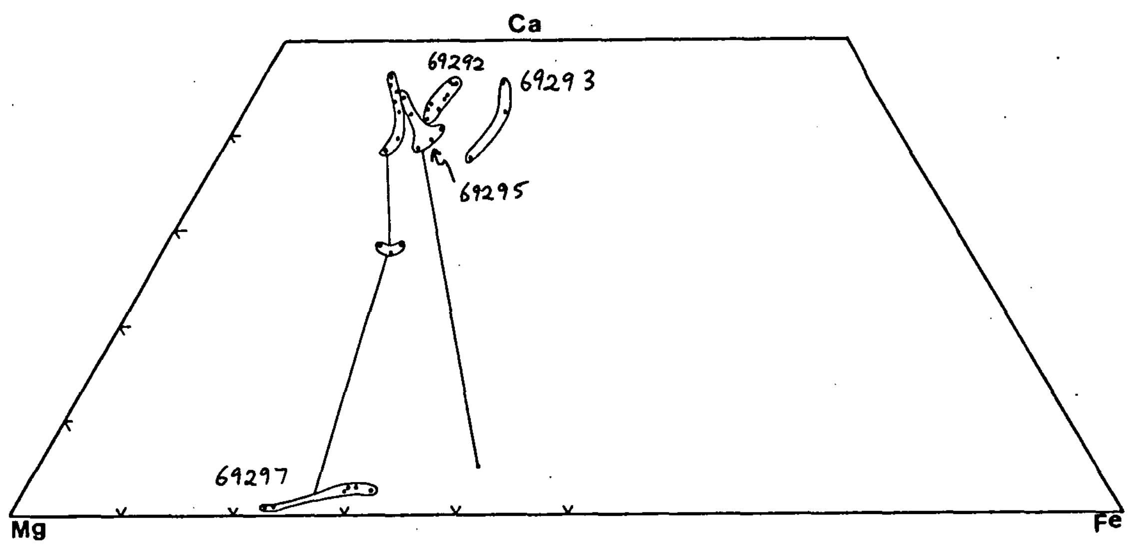


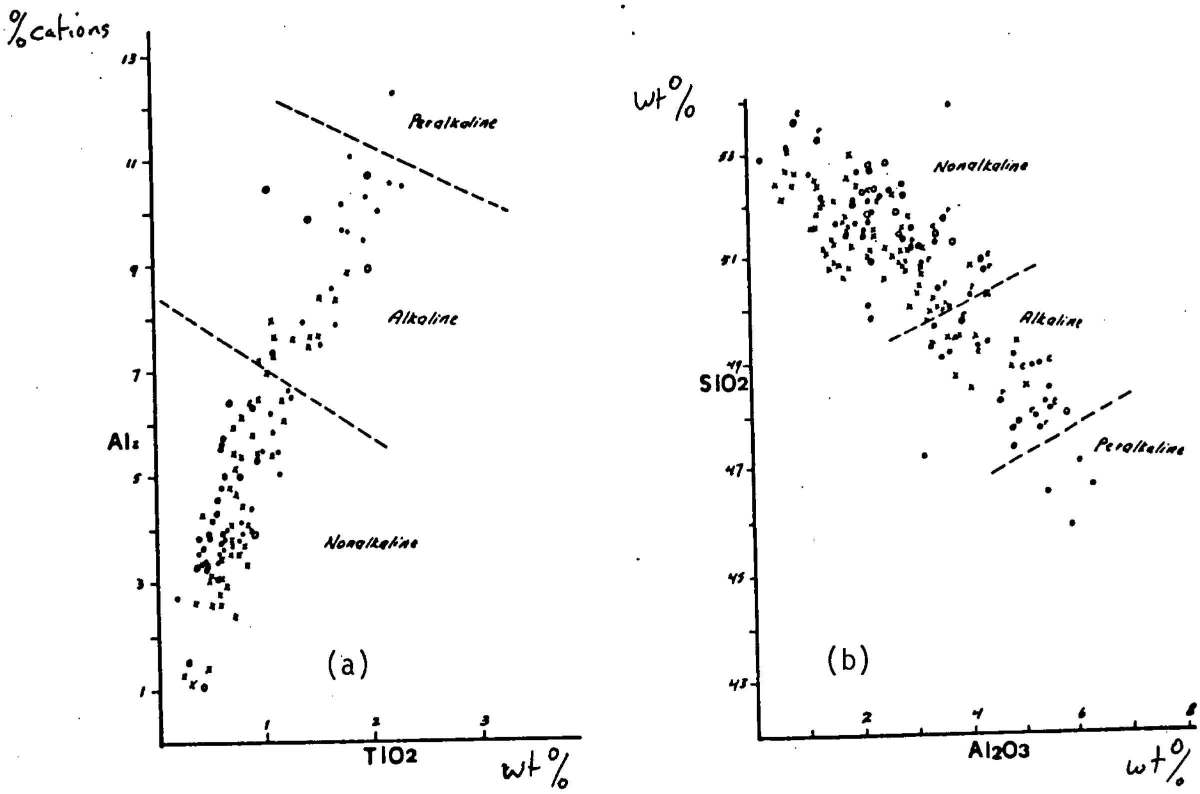
Fig. 2.4 Compositional variation of clinopyroxene, orthopyroxene and hornblende from basalts. Each field denotes a different sample. The tie lines connect coexisting phases.

Clinopyroxene phenocrysts with reverse and normal zoning co-exist in a single rock (specimen 69292). The cores of reversely zoned grains have 100Mg/(Mg+Fe) (to be written as Mg*) = 68 whereas the rims have Mg* = 72. Normally zoned grains have Mg* = 68 cores and Mg* = 67 rims. Reverse zonation is one of the three lines of evidence for magma mixing suggested by Kuno (1950). This reversal of zoning might also be due to contamination. Bowen (1928, p.206) noted that the addition of silica to a basic magma tends to decrease the amount of olivine, and to increase the magnesian content of the pyroxene. The most magnesian-rich clinopyroxenes are Mg* = 79 in the orthopyroxene-bearing northern province basalts and the least magnesian are Mg* = 64 in the orthopyroxene-free southern province basalts. The latter also contain much higher TiO_2 and Al_2O_3 contents (maximum 2.3 and 6.3 wt%, respectively) than the former, and appear more alkaline. The Al_2O_3 and TiO_2 contents of clinopyroxene in sample 69292 decrease from core to rim and exhibit alkaline-type cores, but non-alkaline rims (Fig. 2.5a,b). It is the reverse of normal clinopyroxene zoning in alkaline basalt (Takazawa & Hirano, 1977).

There is good correlation of Ti and Al with respect to Mg* within individual samples (Fig. 2.6a,b). In general the Ti and Al contents of clinopyroxene in basalts decrease with increasing Mg*. The Al content decreases with increasing SiO_2 (Fig. 2.5b). This is in agreement with Kushiro (1960) and Lebas (1962). They suggest that there is an inverse relation between the Al content of pyroxene and silica activity of the magma from which they crystallized.

Orthopyroxene grains (En_{68}-En_{78}) (Fig. 2.4, Appendix 2) are anhedral to subhedral. They are Mg-rich: even those from andesites and dacites have Mg* greater than 50. The Mg-rich nature of the ferromagnesian minerals reflects the high oxygen fugacities of the CWK magmas (Cameron et al., 1977). The equilibration temperatures (Wells, 1977) are $950^{o}C$-$1100^{o}C$ (Table 2.3). In the pyroxene quadrilateral of Lindsley & Anderson (1983) (Fig. 2.7), the clinopyroxene composition indicates crystallization temperatures of 800-$1100^{o}C$, while the orthopyroxene composition indicates crystallization temperatures of 850-$1400^{o}C$.

Magnesian hornblende (Leake, 1977) (Fig. 2.4, Appendix 2) occurs intergrown with clinopyroxene, and as groundmass and microphenocrysts. The Mg* = < 73 is comparable with that of coexisting clinopyroxene and orthopyroxene, supporting the view that most of the hornblendes are an early crystallizing phase. The Al_2O_3 is ~~high~~ low (8.0 wt%), and TiO_2 is variable within the range 1-3 wt%.



$Al_z = \frac{100 * \text{tetrahedral Al}}{2}$

based on 6 $O^=$

Fig. 2.5 TiO_2/Al_z (a) and Al_2O_3/SiO_2 (b) relation in clinopyroxene from basalts (•), andesites (×) and dacites (o). c = core composition, r = rim composition. After Lebas (1962).

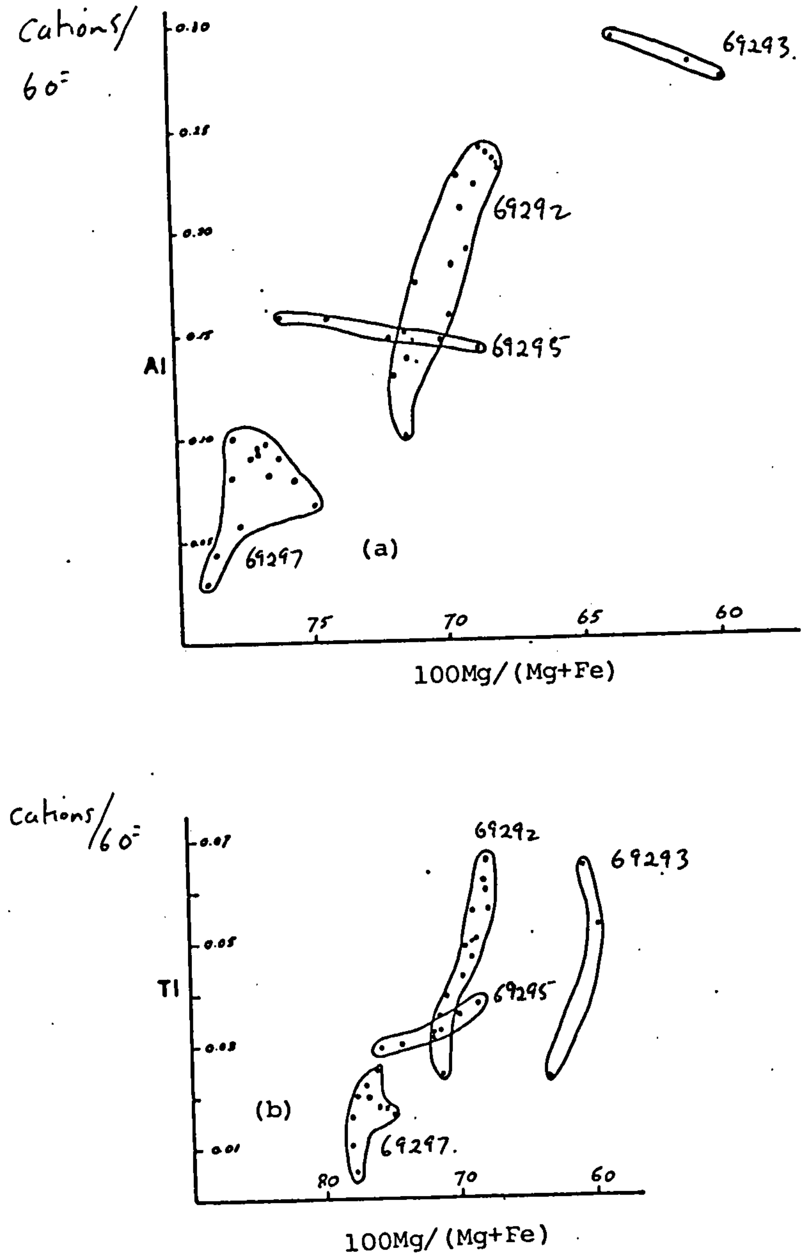


Fig. 2.6 Relation of Al-100Mg/(Mg+Fe) (a) and Ti-100Mg/(Mg+Fe) (b) of clinopyroxene in basalts. Each field denotes a different sample.

Table 2.3 **Temperature (°C) indicated by compositions of coexisting clinopyroxene (cpx) -orthopyroxene (opx) and magnetite - ilmenite pairs**

Rock type	sample no	cpx-opx	magnetite-ilmenite	log-fo2
		1034	625	-18
		948	765	-13.5
		1111	755	-13.8
Basalt	69297	994		
		986		
		988		
		952		
	69310	1142		
		1126		
	69308	989		
		955		
Andesite	69306	1046		
		1170		
		1036		
		1070		
	69301	1092		
		1094		
			985	-10.8
	69342		800	-13
			825	-13
			880	-12
Dacite				
	69328		860	-14
			880	-12
		1003		
	69344	1091		
		995		
		972		
			690	-16.30
Rhyolite	69379		665	-17.30
			640	-18.25

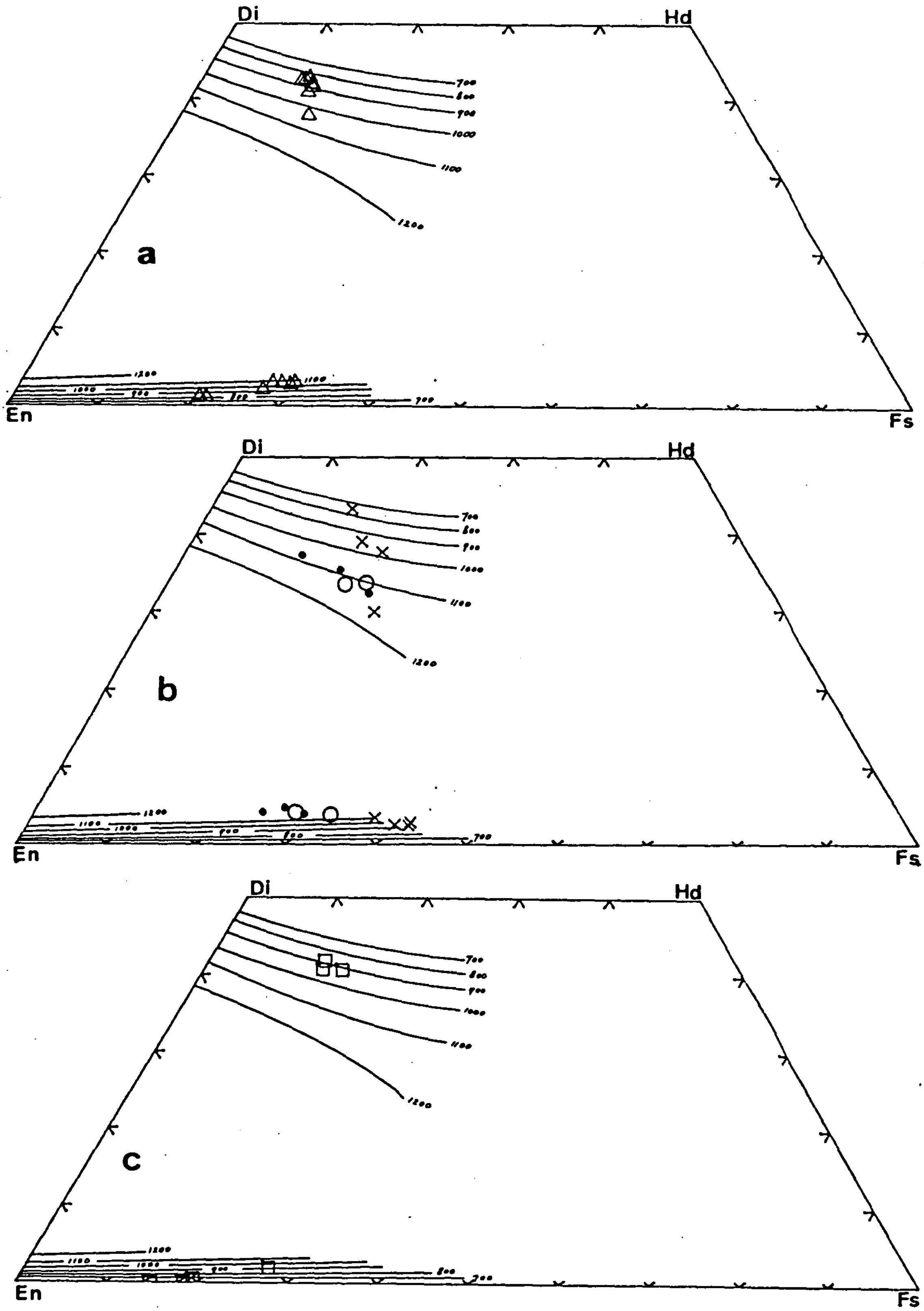


Fig. 2.7 Pyroxene quadrilateral (after Lindsley & Anderson, 1983) showing composition of phenocrysts in basalt (a), andesites (b) and dacites (c).

Fe-Ti oxides form anhedral to subhedral, embayed grains with exsolution lamellae, and inclusions of orthopyroxene, clinopyroxene and plagioclase. Some are interstitial. Ilmenite has evidently formed by an exsolution oxidation reaction, as proposed by Buddington & Lindsley (1964). The composition of titanomagnetite and ilmenite occurring as inclusions in clinopyroxene phases are the same of those of microphenocrysts and groundmass phases (Appendix 2). On the basis of Fe-Ti oxide geothermometry (Spencer & Lindsley, 1981; Lindsley & Spencer, 1982), the temperature of crystallization of ilmenite and magnetite is 625-755^{o}C with oxygen fugacities (log fO_2) in the range -13.5 to -18.0 (Table 2.3).

Chromium spinels occur as very small grains, with Mg* = 71-74 and 100Cr/(Cr+Al) = 23-28 (Appendix 2). They are more primitive than the chromium spinel from the Quaternary lavas, discussed in Chapter 4, and resemble chrome spinel from ultramafic nodules (Irvine, 1967; Irvine & Findlay, 1972).

2.2.2 Andesite (including basaltic andesite)

The andesites are characterized by strongly zoned plagioclase (Fig. 2.2b,c). Two types of andesites have been observed. Type 1 andesites (69310 and 69308) have a highly glomeroporphyritic texture with flow structures. They have a narrow range of plagioclase compositions (An_{40}-An_{60}) (Fig. 2.2b, Appendix 2). The phenocrysts consist of plagioclase, orthopyroxene, clinopyroxene and titaniferous magnetite. The groundmass is composed of the same minerals as the phenocrysts plus quartz and K-feldspar. Type 2 andesites (69306, 69301, 69299, 69303, 69307) have subporphyritic texture. Plagioclase compositions range from An_{20} to An_{100} (Fig. 2.2c). They contain the assemblage plagioclase-clinopyroxene-orthopyroxene-hornblende-biotite-ilmenite with minor magnetite, quartz and K-feldspar. From whole-rock chemical analysis (discussed later) the type 2 andesites have higher Al_2O_3 and lower TiO_2 contents than the type 1 andesites.

Plagioclase grains (maximum 3.2 x 7.4 mm) are subhedral to euhedral, and long prismatic. Common inclusions are orthopyroxene, clinopyroxene, magnetite, ilmenite and apatite. Most of the plagioclase is normally zoned, but some show reversed or complex zoning (Fig. 2.2b,c). Smith (1974) ascribed the zoning and compositional jumps of plagioclase in volcanic rocks to sudden change of the water vapour pressures or to a sudden escape of volatiles from the magma, probably during the eruption event. FeO content of the plagioclase (Fig. 2.3) decreases with increasing An content.

K-feldspars have been analysed from sample 69306 and have a compositional range of Or_{77} to Or_{90}. They are interstitial, suggesting late crystallization.

Clinopyroxene phenocrysts are anhedral to subhedral, and contain inclusions of ilmenite, apatite and biotite. In composition, they range from augite to minor endiopside, with Mg* = 77 and $Ca_{31}Mg_{44}Fe_{25}$ to $Ca_{40-45}Mg_{40-46}Fe_{14}$ (Fig. 2.8, Appendix 2). The clinopyroxene phenocrysts display normal and reverse compositional zoning. The reversely zoned grains have Mg* = 74 cores and Mg* = 76 rims. Most of the clinopyroxene analyses display low TiO_2 and Al_2O_3 contents, and a few high TiO_2 and Al_2O_3, falling in the non-alkaline and alkaline fields respectively (Fig. 2.5a,b). Unlike the clinopyroxene in basalt, the Al and Ti contents of the andesitic clinopyroxenes are not correlated with Mg*. Chromium contents of the clinopyroxene are up to 0.62 wt%: these increase with increasing Mg*. Cr^{3+} has a strong tendency to enter the early formed pyroxene, because of its high crystal field stabilization energy in the octahedral sites, resulting in its depletion in the melt with fractionation.

Orthopyroxene phenocrysts are anhedral to subhedral, showing compositional variation from $Ca_3Mg_{60}Fe_{37}$ to $Ca_4Mg_{74}Fe_{22}$ and Mg* = 55-78 (Fig. 2.8, Appendix 2), reflecting less iron enrichment of the andesites.

Orthopyroxene-clinopyroxene thermometry using Wells (1977), indicates equilibration temperatures of 955-1170°C (Table 2.3). On the pyroxene quadrilateral (Fig. 2.7) (Lindsley & Anderson, 1982), the orthopyroxene compositions indicate crystallization temperatures of 950-1150°C, while the clinopyroxene compositions indicate crystallization temperatures of 750-1175°C.

Amphibole grains (maximum 3.4 x 1.6 mm) are anhedral with minor reaction rims of biotite. They are calcic amphiboles (Leake, 1978): magnesio-hastingsite, magnesio-hornblende, and tschermakite (Figs 2.10 and 2.11a,b; Appendix 2). The hornblende phenocrysts in sample 69307 are reversely zoned (Fig. 2.10) suggesting magma mixing.

Biotite grains are anhedral and contain ilmenite and apatite inclusion. They have Mg* > 50 and high Ti contents (Fig. 2.10, Appendix 2) and most of them fall in the compositional range for biotites for orogenic volcanic rocks (Fig. 2.12) (Ewart, 1982).

Magnetite and ilmenite crystals are up to 0.2 x 0.3 mm in size. The titaniferous magnetites contain chromium up to 2.21 wt% (Appendix 2).

2.2.3 Dacite

The rocks are commonly highly porphyritic, some are glomeroporphyritic, and a few are aphyric. The most abundant phenocrysts

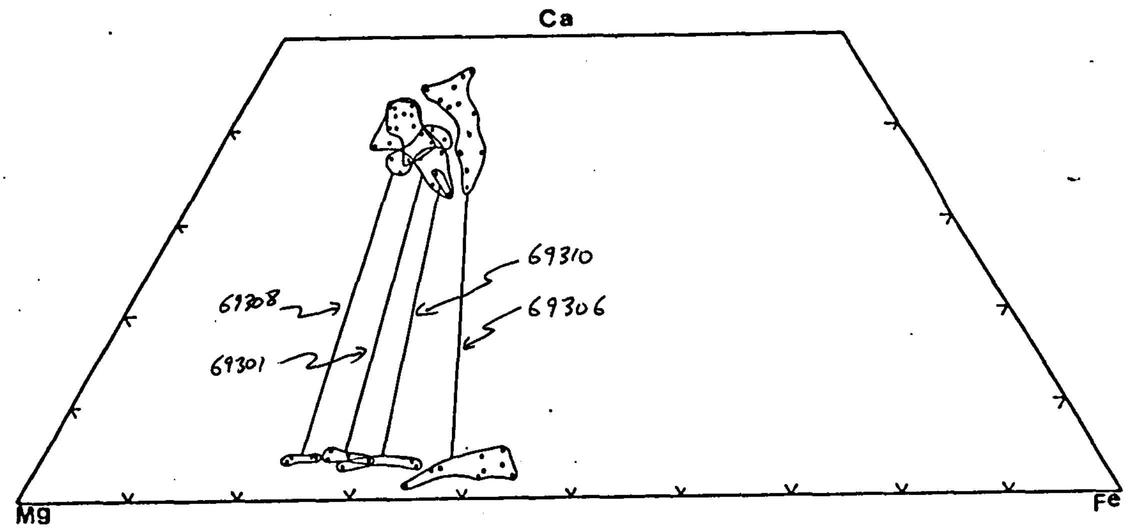


Fig. 2.8 Compositional variation of clinopyroxene and orthopyroxene in andesite. Each field denotes a different sample. Tie lines connect coexisting phases.

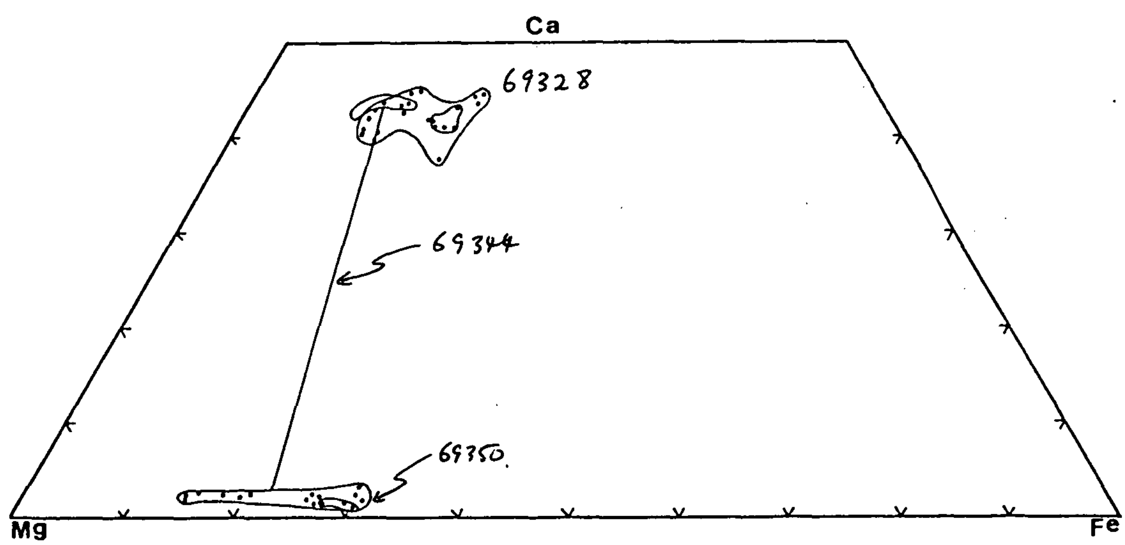


Fig. 2.9 Compositional variation of clinopyroxene and orthopyroxene in dacites. Each field denotes a different sample. Tie line connects coexisting phases.

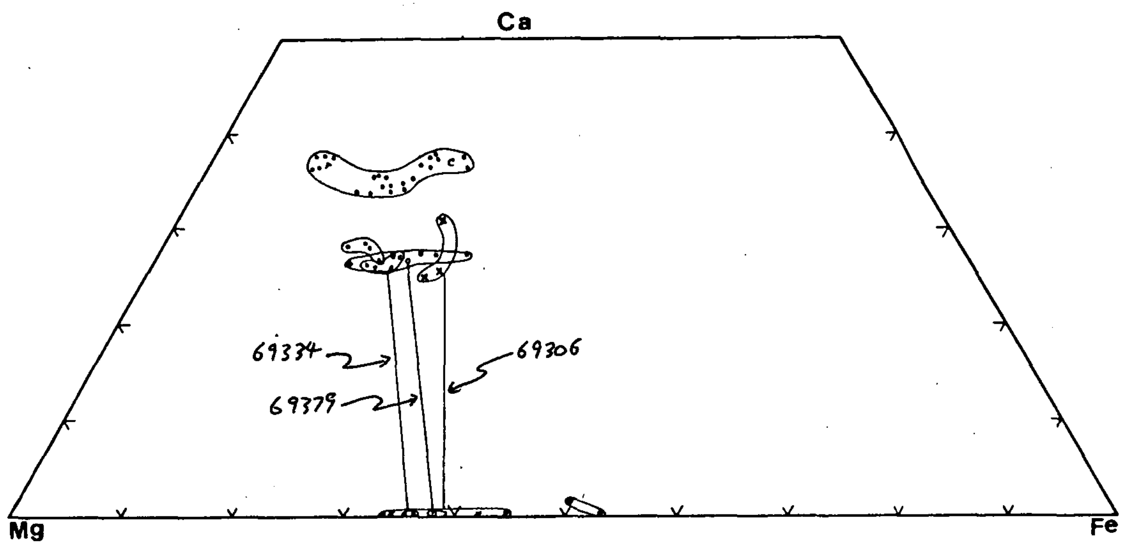


Fig. 2.10 Compositional variations of hornblende and biotite from andesites (x), dacites (•) and rhyolites (o). Tie lines connect coexisting phases. c = core composition, r = rim composition.

are of plagioclase. Other phenocrystic minerals are hornblende, biotite, quartz, clinopyroxene, orthopyroxene and magnetite. The groundmass is of microcrystalline or granular texture and is composed of all the phases listed above plus K-feldspar and a trace of ilmenite. Xenoliths present in sample 69350 consist of plagioclase and orthopyroxene with interstitial glass. The plagioclase phenocrysts (maximum 8.8 mm long) are subhedral to anhedral and contain magnetite, ilmenite, hornblende, orthopyroxene and apatite as inclusions. A few plagioclase phenocrysts are rounded , other plagioclase phenocrysts show extensive resorption of cores (An_{50}) followed by overgrowth of An_{70}. Plagioclase compositions range from An_{90} to An_{20}, and rarely An_{12} (Fig. 2.13, Appendix 2). Plagioclases with a compositional range of An_{50} to An_{90} in sample 69350 are possibly of xenocrystic origin. Some plagioclase phenocrysts have reversed and normal zoning (Fig.2.13). Similar zoning, together with reversed zonation of clinopyroxene, has been attributed to mixing of part-crystallized magmas (e.g. Sakuyama, 1979). The plagioclases with high An contents have higher FeO contents (Fig. 2.3), in agreement with the relationship described by Ribbe & Smith (1966).

In some dacites, the plagioclase is albitic (An_{1-3}) and may have been re-equilibrated during low-grade metamorphism of these rocks. Rarely, hornbelnde grains (maximum a x 0.3 mm) are subhedral to anhedral and contain magnetite and plagioclase as inclusions. A few crystals are rimmed by magnetite suggesting magmatic resorption. The hornblendes are magnesio-hornblende, anthophyllite, magnesio-hastingsitic hornblende, edenitic-hornblende and actinolitic hornblende (Figs 2.10 and 2.11a,b, Appendix 2). The phenocrysts have normal and reverse zoning.

Orthopyroxene phenocrysts are anhedral to subhedral and contain magnetite and plagioclase as inclusions. Orthopyroxene compositional variation, $Ca_2Mg_{70-80}Fe_{18-28}$ and Mg* = 69-85 (Fig. 2.9, Appendix 2) reflect less iron enrichment of the dacites .

Clinopyroxene phenocrysts are anhedral and colourless to greenish-grey. Hourglass structures occur in sample 69339, as quenched products originating from a rapid, disequilibrium crystallization at high temperature and relatively low pressure (Leung, 1974). The clinopyroxene phenocrysts are reverse, normal, and complexly zoned (Appendix 2) and clinopyroxene ranges compositionally from $Ca_{37-44}Mg_{35-43}Fe_{10-20}$ and Mg* = 64-83, and are slightly more magnesian than in the andesite. A few analyses suggest an alkaline character (Fig. 2.5a,b). The chromium contents are variable, with maximum 0.75 wt%. Clinopyroxene-orthopyroxene thermometry (Table 2.3) gives a range of 970-1000^{o}C for the temperature of equilibration of these minerals. The temperature calibration of the

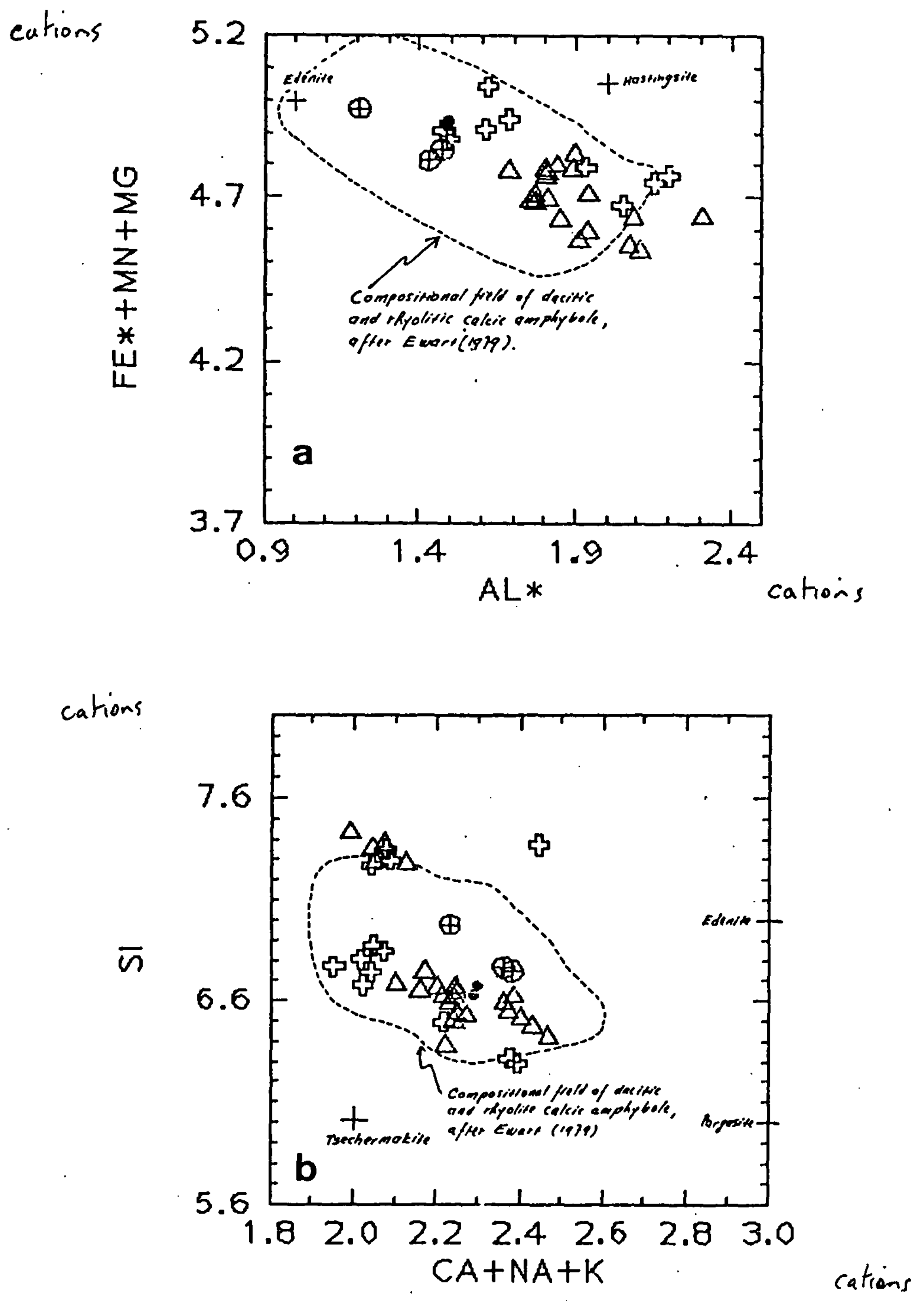


Fig. 2.11 Amphibole analyses from basalts (⊕), andesites (✣), dacites (△), and rhyolites (•) plotted in terms of cations per structural formula unit (O - 23). The generalized compositional fields of dacitic and rhyolitic hornblendes of Ewart (1979) are also shown.

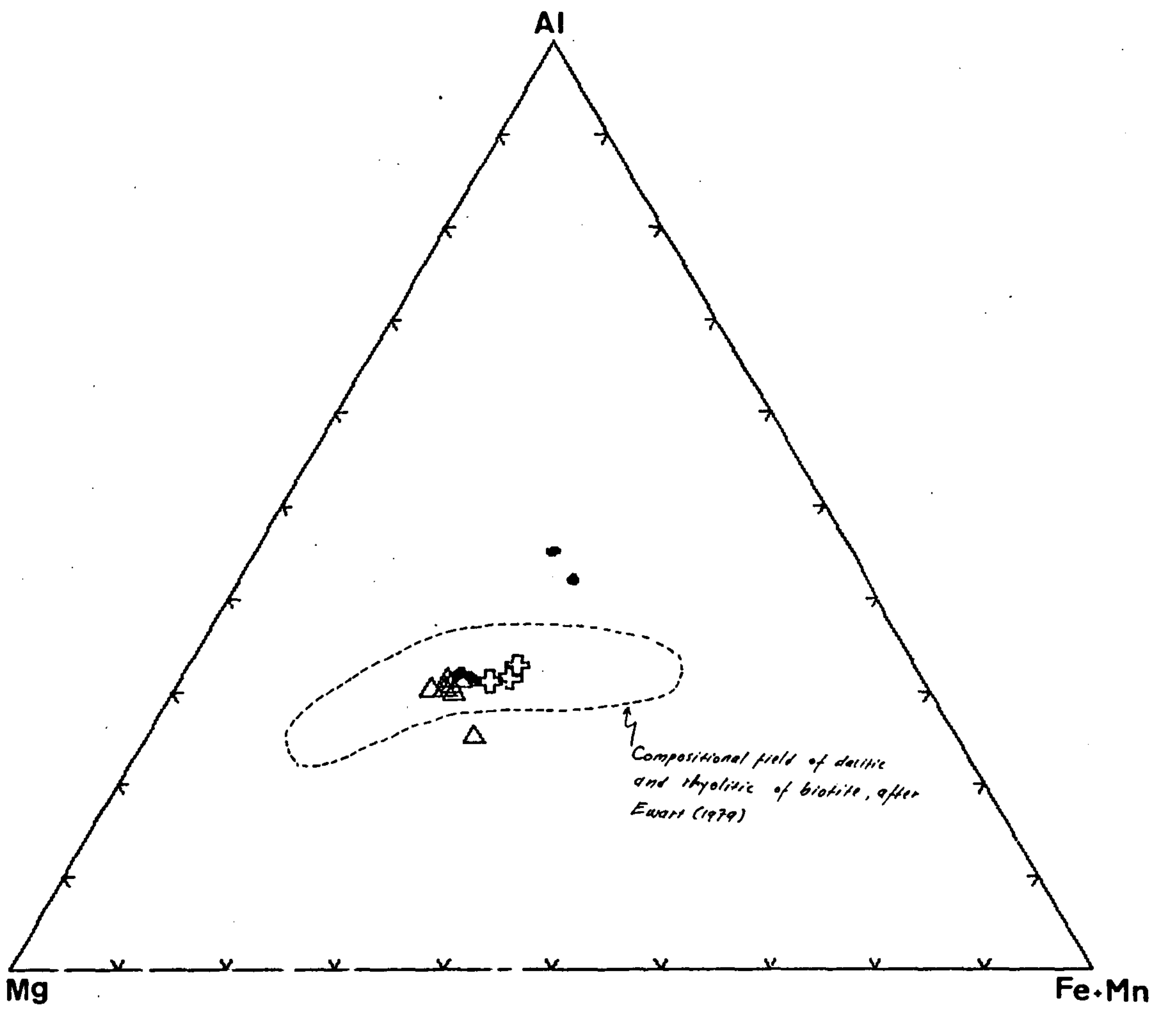


Fig. 2.12 Biotite analyses from andesites (✚), dacites (△) and rhyolites (•) plotted in terms of Mg, Fe+Mn and Al. The generalized compositional fields of dacitic and rhyolitic biotite of Ewart (1979) are also shown.

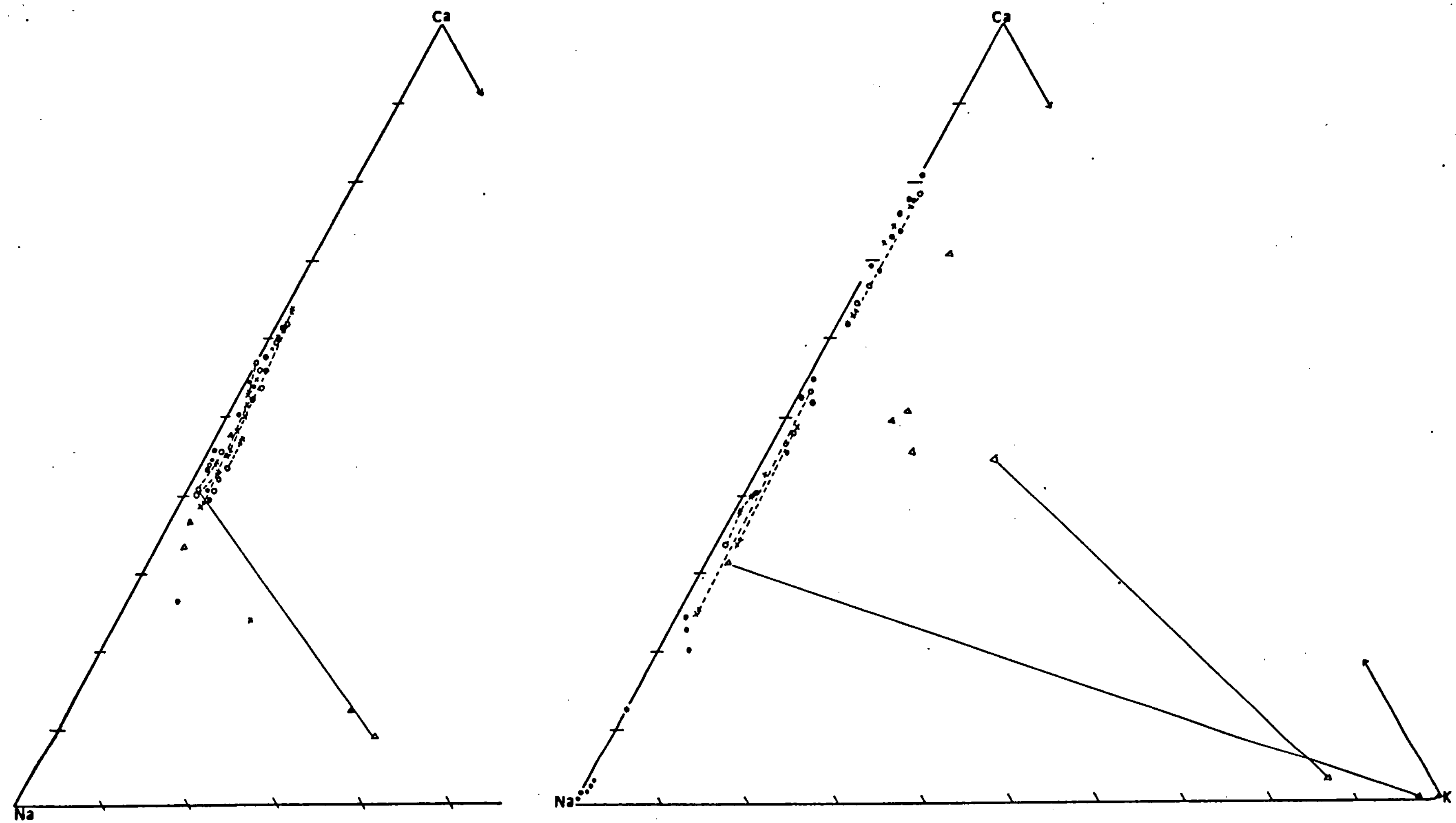


Fig. 2.13 Feldspar compositional variation of dacites.
Symbols as in Fig. 2.2.

pyroxene quadrilateral of Lindsley & Anderson (1982) (Fig. 2.7), suggests crystallization temperatures for orthopyroxene of 900-700°C and for clinopyroxene of 950-875°C.

Biotite (maximum size 0.5 mm) is anhedral to subhedral. The biotite has a small range in Mg in dacite (Fig. 2.10). The Mg* > 60 is slightly more magnesian than the biotite in the andesites (Fig. 2.10, Appendix 2).

Quartz grains (maximum size 0.4 x 0.8 mm) are anhedral, embayed and contain plagioclase as inclusions. The embayed texture is interpreted as partial resorption in the crystallization history. They may have crystallized at depth and later come out of equilibrium when carried up in the magma to a low pressure environment (Green & Ringwood, 1968). Resorbed phenocrysts of quartz or plagioclase (so-called xenocrysts) are widely reported from calcalkalic andesites. Three interpretations have been proposed for the origin of these phenocrysts: (i) a fragment of crustal material captured by magmas (e.g. Kuno, 1950; Sato, 1975), (ii) a sudden change of H_2O during crystallization of plagioclase or quartz (e.g. Yoder, 1969; Ringwood, 1975), and (iii) a relict phenocryst from rhyolitic or dacitic magmas, due to magma mixing (e.g. Larsen et al., 1937; Eichelberger, 1975, 1978).

Magnetite (maximum size 0.45 x 0.20 mm) are equant or tabular with resorption rims and contain pyrite and chalcopyrite as inclusions. The magnetite grains have exsolution lamellae of ilmenite. By using the Fe-Ti oxide geothermometry as for Fe-Ti oxide in basalt, the temperature of equilibration of the magnetite and ilmenite ranges from 985-800°C with log fO_2 ranging from -10.8 to -14 (Table 2.3, Appendix 2).

2.2.4 Rhyolite

The rhyolites may be divided into two types, based on the presence or the absence of biotite. Biotite-free rhyolite mostly occurs in the central province, whereas rhyolites from the southern province mostly contain biotite. Other phenocrysts are plagioclase (maximum size 3 x 1.9 mm) and quartz (maximum size 2.7 x 2 mm). Muscovite fills the amygdales, in the rocks from the central province. It appears to be an autometamorphic mineral. Mudstone xenoliths (0.2 mm) occur in the rocks from the central province (69363 and 69361); there is no evidence of metamorphism of these xenoliths, implying very rapid quenching. The presence of muscovite flakes may be due to hydrothermal activity due to contact metamorphism of the country rocks. The groundmass of rhyolites are holocrystalline to hypocrystalline, and rarely holohyaline. It contains plagioclase, quartz, K-feldspar and minor magnetite and ilmenite. One sample from the southern province(69365) has phenocrysts of K-feldspar and arfvedsonite,

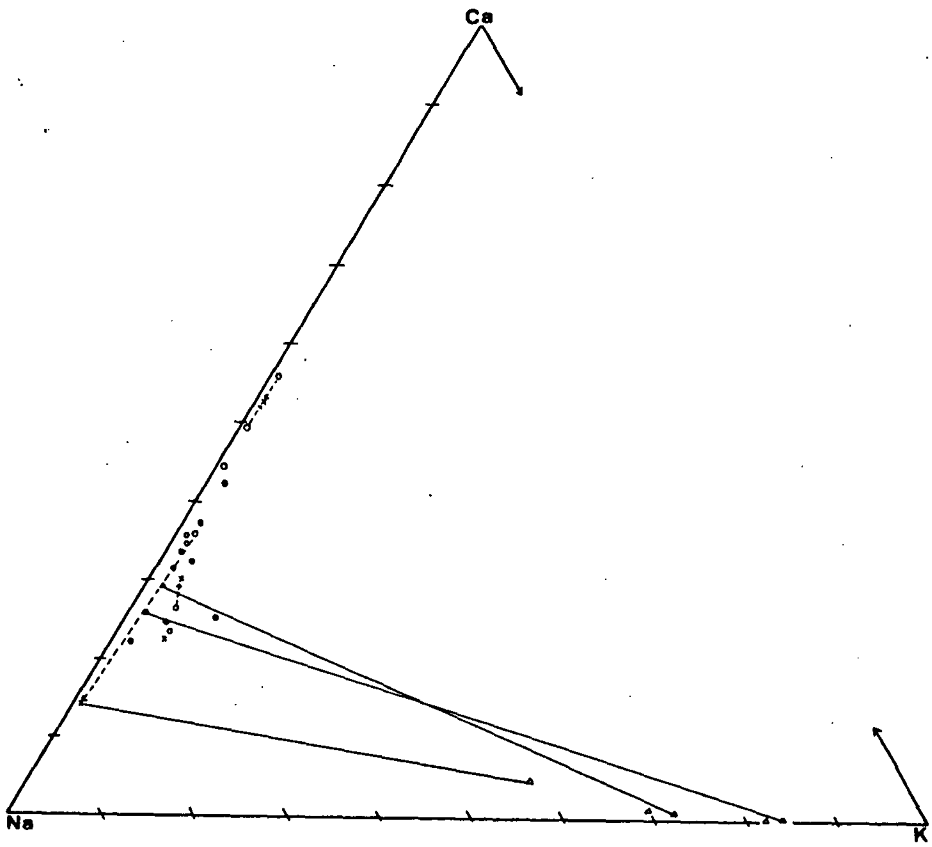


Fig. 2.14 Feldspar compositional variation of the rhyolites. Symbols as in Fig. 2.2.

suggesting a highly evolved magma type. A few rocks have fibrous spherulitic structure.

The plagioclase grains are anhedral to subhedral, and are partly corroded. The plagioclase composition ranges from An_{14} to An_{56} (Fig. 2.14, Appendix 2). The plagioclase phenocrysts have normal, and rarely reversed, zoning. The plagioclases of sample 69375 are the most calcic, but they have textures suggestive of a xenocrystic origin, because the quartz phenocrysts are highly embayed. The biotite grains (maximum size 0.5 x 0.2 mm) are subhedral to euhedral. The biotite reflects a moderate Mg content in the rhyolite (Fig. 2.10). They are similar in composition to those of andesites (Fig. 2.12, Appendix 2), except for a few biotite grains in sample 69360, which are possibly of metamorphic origin (Mg* < 50). Hornblende grains are anhedral. They are edenitic hornblende (Figs 2.10 and 2.11a,b; Appendix 2). Fe-Ti oxides are mostly magnetite and less ilmenite. The exsolution temperature of ~~crystallization~~ ilmenite from magnetite of these oxides ranges from 690-640°C and log fO_2 ranges from -16.30 to -18.25 (Table 2.3, Appendix 2). Garnet and pinite occur in the rocks from the Southern region (sample 69368). The pinite is interpreted as a pseudomorph after cordierite. The garnet is almandine. Schmutzer (1910) reported garnet in siliceous subvolcanic rocks from the central-west of Sintang Sheet. Almandine-rich garnet occurs in the more siliceous orogenic volcanic rocks (Baker, 1982; Green & Ringwood, 1968), and may have formed at lower crustal or upper mantle pressures (Green & Ringwood, 1968). The presence of pinite (after cordierite) is evidence of sialic crustal contamination.

2.3 MAJOR ELEMENTS

2.3.1 Basalt

The chemical characteristics of the basalts are typically tholeiitic: AL_2O_3 = 15-19 wt%, total of Fe+MgO+CaO = 25-30 wt%, Na_2O = 2.40-3.75 wt%, K_2O = 0.15-0.82 wt%, and TiO_2 = 1.0-2.3 wt% (Tables 2.4 and 2.5). These chemical variations are typical of volcanic rocks (Turner & Verhoogen, 1960).

Sample 69292 has a chemical composition that is readily distinguishable from those of the other analysed basalts. It is especially low in SiO_2 (47 wt%), but high in K_2O (0.82 wt%), TiO_2 (2.31 wt%) and P_2O_5 (0.82 wt%).

The Mg value ([100Mg/(Mg+Fe*)] of the basalts ranges from 41.4 to 63.0. This is low compared to some MORBs (Mid Oceanic Ridge Basalt) that have an Mg value > 70 (e.g. Frey et al., 1974). Green (1971) proposed that rocks with an Mg value < 65 are unlikely to have been in equilibrium with

Table 2.4 Major chemical analyses and CIPW norms for the rocks from the southern province.

	69292	69293	69295	69294	69299	69303	69301	69355
SiO_2	46.06	48.26	48.60	49.67	51.11	55.22	55.92	61.17
TiO_2	2.26	0.97	0.98	1.01	1.00	1.12	1.13	0.74
Al_2O_3	15.54	16.91	17.00	19.04	18.28	17.57	17.80	16.69
Fe_2O_3	15.10	9.94	9.73	10.66	9.65	7.94	7.32	5.17
MnO	0.22	0.18	0.16	0.17	0.16	0.08	0.13	0.15
MgO	5.51	8.64	7.50	4.34	4.26	3.45	2.73	0.75
CaO	8.47	9.97	9.75	10.14	7.53	6.80	6.57	4.21
Na_2O	3.18	2.33	2.32	3.73	3.53	4.15	4.27	3.94
K_2O	0.80	0.22	0.59	0.26	1.30	1.83	1.52	2.19
P_2O_5	0.80	0.23	0.28	0.21	0.25	0.41	0.61	0.34
LOI	2.36	.15	.05	1.13	2.60	1.40	1.44	4.15
Total	100.30	99.80	99.96	100.36	99.67	99.97	99.44	99.50
Q						2.78	5.69	17.81
C								1.00
Or	4.73	1.30	3.52	1.54	7.76	10.89	8.98	12.94
Ab	26.91	19.71	19.81	31.56	30.14	35.37	36.13	33.34
An	25.77	35.04	34.55	34.45	30.47	24.09	24.92	18.67
Di	9.20	10.51	10.14	12.08	4.63	5.97	3.08	
Hy	6.25	19.12	21.14	4.12	18.61	15.21	13.92	8.18
Ol	15.38	7.25	3.81	10.57	1.55			
Mt	2.19	1.44	1.42	1.55	1.41	1.16	1.06	0.75
Il	4.29	1.84	1.88	1.92	1.91	2.14	2.15	1.41
Ap	1.89	0.54	0.67	0.50	1.56	0.98	1.44	0.80
Mg value	41.41	63.03	60.00	44.85	45.94	45.03	42.32	23.25
Al/Na +K+Ca								1.011

Explanation: Q = quartz, C = corundum, Or = orthoclase, Ab = albite, An = anorthite, Di = diopside, Hy = hypersthene, Ol = olivine, Mt = magnetite, Il = ilmenite, Ap = apatite.

Table 2.4 cont.

	69350	69375	69372	69368	69365	69366	69379
SiO_2	63.40	69.74	71.72	72.20	75.43	75.48	75.50
TiO_2	0.43	0.31	0.22	0.05	0.17	0.13	0.14
Al_2O_3	15.22	16.14	15.57	16.13	12.64	13.09	12.92
Fe_2O_3	3.82	2.71	1.39	1.07	1.22	0.71	1.12
MnO	0.07	0.05	0.07	0.06	0.03	0.04	0.06
MgO	1.69	0.73	0.39	0.26		0.05	0.50
CaO	4.77	3.31	0.88	1.66	.07	0.49	0.81
Na_2O	3.88	3.53	4.27	4.09	3.46	3.05	3.46
K_2O	1.00	1.61	2.73	2.40	4.99	4.45	3.67
P_2O_5	0.20	0.12	0.13	0.08	0.02	0.02	0.01
LOI	5.08	1.57	2.30	2.05	1.32	1.86	1.64
Total	99.56	99.82	99.67	100.05	99.35	99.37	99.83
Q	22.99	33.66	33.55	34.81	35.43	39.25	38.21
C		2.89	4.30	3.98	1.47	2.41	1.81
Or	5.93	9.52	16.14	14.19	29.49	26.30	21.69
Ab	32.95	29.87	36.13	34.61	29.27	25.81	29.27
An	21.24	15.64	3.52	7.71	0.22	2.30	3.95
Di	0.99						
Hy	8.53	.20	.69	2.18	1.49	0.98	2.70
Ol							
Mt	0.56	0.39	0.20	0.16	0.18	0.10	0.16
Il	0.82	0.59	0.42	0.09	0.32	.25	0.27
Ap	0.47	.28	0.31	0.19	0.05	.05	0.02
Mg value	46.57	36.21	32.34	32.34		12.40	41.34
Al/Na +K+Ca	0.943	1.194	1.345	1.306	1.127	1.220	0.903

Table 2.5 Major chemical analyses and CIPW norms for the rocks from the central province.

	69307	69343	69341	69347	69345*	69344	69481*	69340	69342
SiO_2	60.36	60.63	61.91	62.40	62.50	62.70	64.00	64.27	64.61
TiO_2	0.50	0.65	0.75	0.37	0.45	0.73	0.37	0.41	0.45
Al_2O	17.13	16.55	17.70	16.59	17.60	15.95	16.50	16.88	17.45
Fe_2O_3	5.44	4.81	7.48	3.97	0.62	4.77	0.90	3.77	4.01
FeO					3.50		2.30		
MnO	0.10	0.10	0.16	0.08	0.11	0.08	.07	.05	0.10
MgO	3.05	2.68	1.13	2.82	1.75	2.67	2.96	2.01	0.98
CaO	6.48	3.35	1.65	5.29	6.20	5.03	4.55	4.31	3.93
Na_2O	3.78	4.89	5.53	4.16	3.66	3.97	4.48	5.26	4.86
K_2O	0.85	164	0.86	0.88	1.39	3.17	1.06	1.08	1.59
P_2O_5	0.10	0.39	0.50	0.10	0.16	0.29	0.11	0.19	0.29
LOI	2.25	4.20	2.94	3.27	1.55	1.40	2.04	1.68	1.69
Total	100.04	99.89	100.61	99.93	99.49	100.76	99.69	99.91	99.96
Q	14.69	13.22	29.92	17.59	18.48	12.41	18.68	15.89	18.88
C		1.58	9.16						1.28
Or	5.02	9.74	5.08	5.20	8.22	18.74	6.27	6.38	9.40
Ab	31.98	41.56	29.87	35.20	31.00	33.59	37.91	44.50	41.12
An	27.27	14.12	4.92	24.00	27.49	6.34	21.79	19.27	17.60
Di	3.49		1.30	1.85	5.53	0.06	0.72		0.04
Hy	12.87	12.60	12.38	11.50	8.80	9.57	10.34	9.36	.51
Ol									
Mt	0.79	0.70	1.08	0.58	0.90	0.69	1.30	0.55	0.58
Il	0.95	1.24	1.42	0.70	0.85	1.39	0.70	0.78	0.85
Ap	0.24	0.93	1.18	0.24	0.38	0.68	0.26	0.45	0.68
Mg value	54.03	51.13	23.36	58.28		50.94		49.85	30.38
Al/Na +K+Ca	0.871	1.040	1.359	0.941	0.937	0.835	0.983	0.987	1.035

* samples analysed by AMDEL.

Table 2.5 cont.

	69338*	69325	69336	69327	69337	69363*	69361	69362
SiO_2	64.90	65.68	65.69	65.75	65.87	72.20	72.80	73.87
TiO_2	0.41	0.35	0.38	0.32	0.34	0.05	0.03	0.07
Al_2O_3	16.60	16.47	15.75	15.48	16.68	15.80	15.77	15.52
Fe_2O_3	1.17	2.74	3.45	2.67	3.13	0.37	0.93	0.93
FeO	1.20					0.55		
MnO	0.06	0.04	0.07	0.05	0.05	0.06	0.04	0.05
MgO	1.90	1.71	2.21	1.57	1.73	0.30	0.25	0.35
CaO	4.18	4.30	4.33	4.47	4.50	2.50	2.72	1.98
Na_0O	4.62	4.47	3.90	3.77	5.18	4.24	4.22	4.86
K_2O	1.73	1.47	1.40	0.99	1.61	2.38	2.21	.59
P_2O_5	0.19	0.15	0.13	0.11	0.19	0.07	0.04	0.10
LOI	1.51	2.50	2.58	4.65	0.49	0.83	1.07	1.49
Total	99.40	99.88	99.89	99.83	99.77	99.67	100.08	100.81
Q	19.86	21.19	23.46	26.91	16.87	32.49	3.10	34.45
C		0.07	0.26	0.34		1.87	1.59	2.45
Or	10.22	8.69	8.27	5.85	9.52	14.07	13.06	9.40
Ab	39.09	37.82	33.00	31.90	43.83	35.88	35.70	41.12
An	19.45	20.35	20.63	21.46	17.51	1.94	13.23	9.17
Di	0.04				2.95			
Hy	5.38	7.60	9.85	7.22	6.78	1.48	1.95	2.15
Ol								
Mt	1.70	0.40	0.50	0.39	0.45	0.53	0.13	0.13
Il	0.78	0.66	0.72	0.61	0.65	0.10	0.06	0.13
Ap	0.45	0.35	0.31	0.26	0.45	0.17	0.09	0.24
Mg value		53.01	54.81	55.63	53.63		31.00	43.40
Al/Na +K+Ca	0.973	0.983	0.997	1.005	0.910	1.121	1.106	1.180

Table 2.6 Major chemical analyses and CIPW norms for the rocks from the northern province.

	69297	69308	69306	69310	69334	69328
SiO_2	49.91	54.00	56.46	56.76	63.47	63.53
TiO_2	1.99	1.56	0.85	1.28	0.66	.88
Al_2O_3	15.48	15.32	18.78	16.75	15.93	15.80
Fe_2O_3	10.99	10.84	6.86	7.95	4.96	5.62
MnO	0.18	0 .28	0.11	0.12	0.09	0.13
MgO	7.64	4.13	4.13	3.32	2.57	1.18
CaO	9.74	6.69	7.27	6.89	4.68	3.44
Na_2O	2.75	3.23	3.83	3.36	3.78	4.97
K_2O	0.15	1.31	1.19	1.39	2.48	1.85
P_2O_5	0.47	0.47	0.21	0.29	0.29	0.26
LOI	0.05	2.51	0.27	1.30	0.98	2.16
Total	99.35	100.34	99.96	99.41	99.62	99.82
Q	0.13	6.48	5.54	10.02	16.83	16.11
C						
Or	0.89	7.74	7.03	8.22	14.66	10.93
Ab	23.27	27.33	32.41	28.43	31.98	42.05
An	29.46	23.44	30.54	26.52	19.18	15.35
Di	12.89	5.57	3.41	4.79	1.77	0.02
Hy	25.21	20.67	17.04	15.16	11.19	9.61
Ol						
Mt	1.59	1.57	0.99	1.15	0.68	0.81
Il	3.78	2.96	1.61	2.43	1.25	1.67
Ap	1.11	1.11	0.50	0.68	0.68	0.61
Mg value	57.42	42.68	59.91	45.75	53.12	29.27
Al/Na +K+Ca		0.811	0.947	0.857	0.915	0.962

normal mantle material. All the basalts in this CWK suite are strongly evolved.

The basalts have a high normative feldspar content (> 50%) (Tables 2.4 and 2.6).

Sample 69292 has high normative olivine (15.93%) and low normative hypersthene (6.5%). It contains less normative anorthite (26.5%) than other basalts.

The petrological characteristics of basalts from the northern province have shown them to be tholeiitic. In agreement with this classification, the Na_2O+K_2O content plotted against SiO_2 of the single analysed northern province basalt places it near the maximim concentration of subalkaline basalts on Le Maitre's discrimination diagram (in Best, 1983, p.52) (Fig. 2.15). Its Al_2O_3 versus normative plagioclase contents and Irvine & Baragar's (1971) classification (Figs 2.16 and 2.17) classify it as tholeiitic, and it is Q-normative.

Three of the four basalts from the southern province (Table 2.4) are tholeiitic, and one is alkaline. By using the same classification as above, one basalt plots on the alkaline field and three basalts plot on the subalkaline field (Fig. 2.15). On their Al_2O_3 versus normative plagioclase contents (Fig. 2.16), one basalt (69294) is calcalkaline and three basalts are tholeiitic. On the Irvine & Baragar (1971) classification (Fig. 2.17) they are all tholeiitic. The four basalts are olivine-normative.

2.3.2 Andesite

The chemical composition of the andesites is Al_2O_3 = 15.68-18.84 wt%, total FeO+MgO+CaO = 15.31-22.17, Na_2O = 3.30-4.36 wt%, K_2O = 0.87-1.34 wt% and TiO_2 = 0.51-1.60 wt% (Tables 2.4, 2.5 and 2.6). Many of them have higher TiO_2 and FeO, and lower CaO contents than the common orogenic andesite (Gill, 1981). One sample (69308) contains very high MnO (0.29 wt%). It may be due to pyrite (hauerite/MnS_2, Deer et al., 1966) concentration in that rock. The Mg value of the andesite ranges from 42.3 to 54.0.

The andesites are characteristically quartz-normative, except sample 69299 (olivine normative) (Tables 2.4, 2.5 and 2.6). They have very high normative feldspar contents (> 60%).

By using the same chemical classification scheme as used for basalts the three andesites from the northern province are subalkaline (Fig. 2.15). On the Al_2O_3 versus normative plagioclase contents (Fig. 2.16), one andesite falls in the calcalkaline field and two andesites fall in the tholeiite field. On the Irvine & Baragar (1971) classification (Fig. 2.17) these andesites fall in the calcalkaline field.

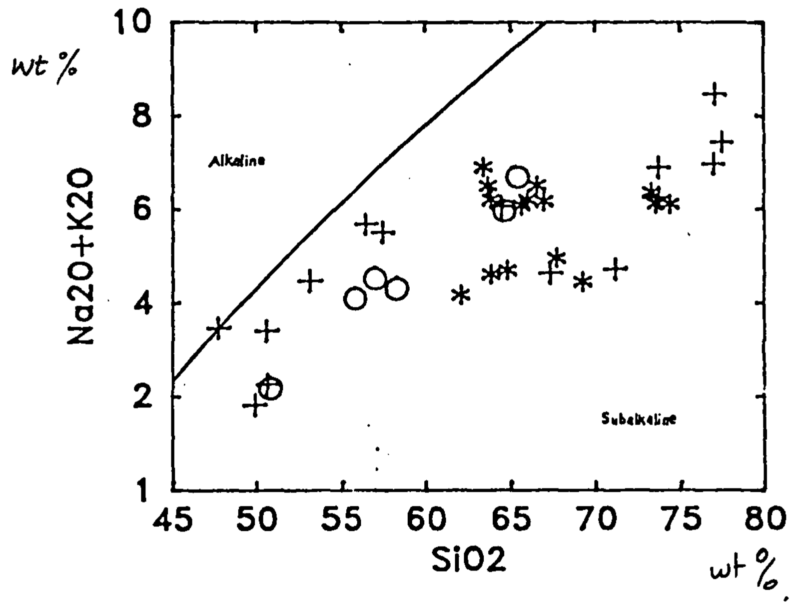


Fig. 2.15 Le Maitre's discrimination diagram of the rocks from the southern province (+), central province (✳), and northern province (o).

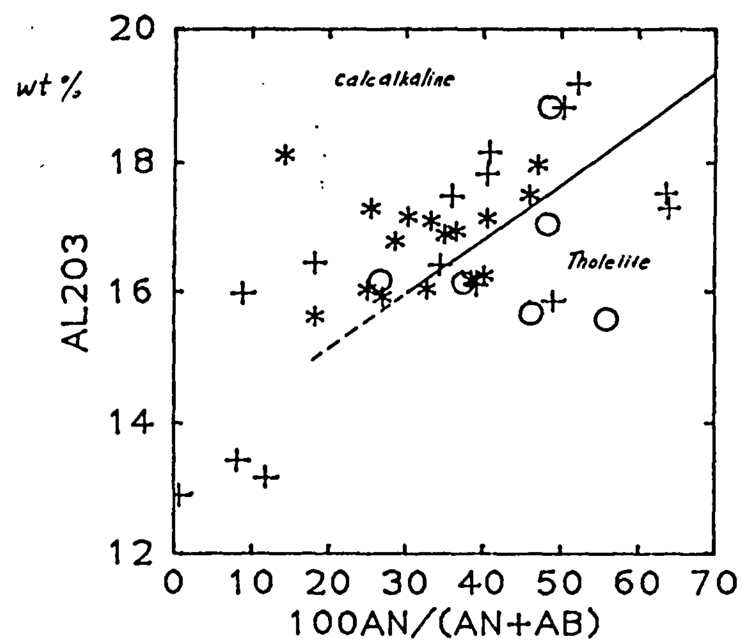


Fig. 2.16 Al_2O_3-100An/An+Ab diagram. Symbols as in Fig. 2.15.

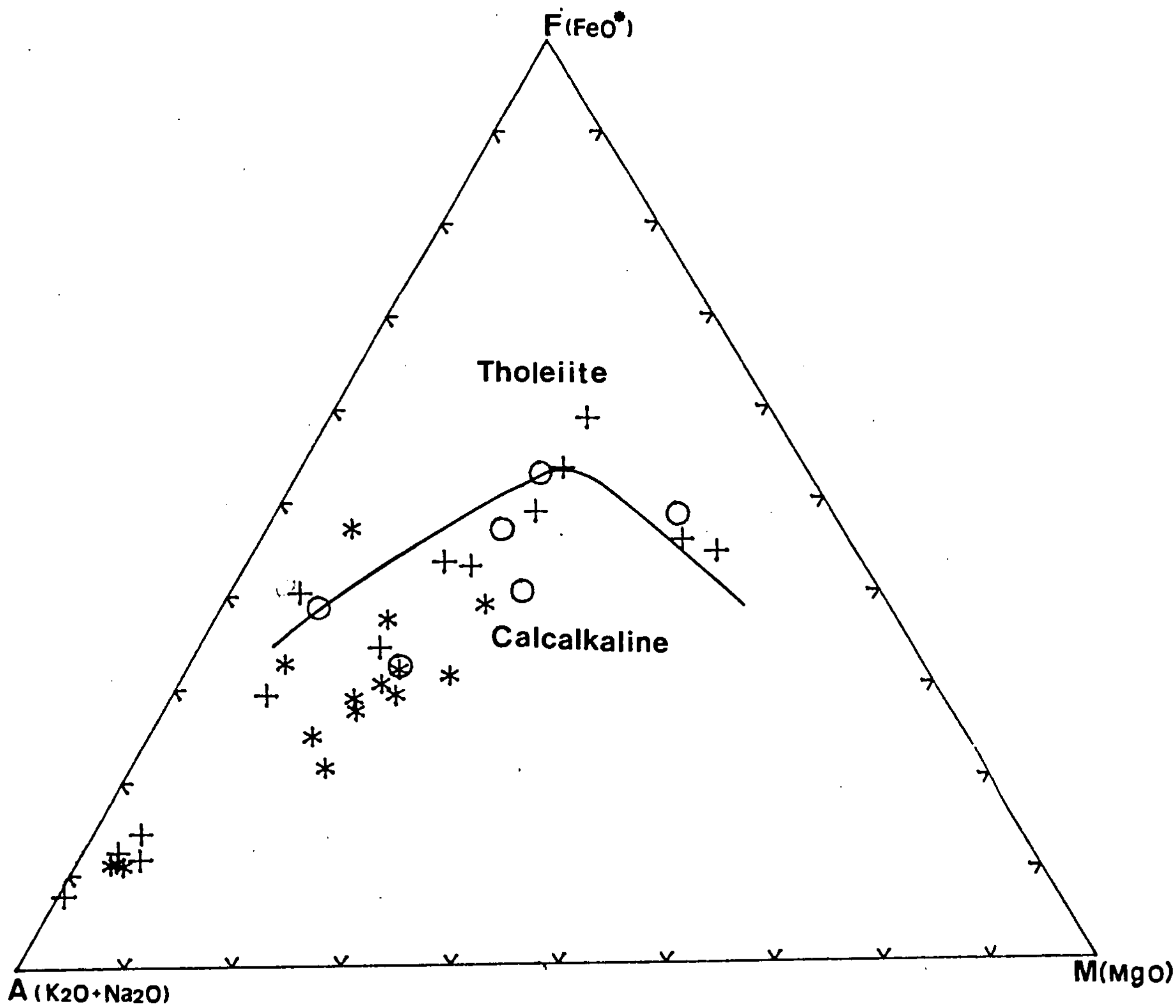


Fig. 2.17 AFM diagram for the rocks from CWK. Symbols as in Fig. 2.15. After Irvine & Baragar (1971).

The andesites from the southern and central provinces all fall in the subalkaline field of Fig. 2.15, and they fall in the calcalkaline field of Fig. 2.16 and Fig. 2.17.

2.3.3 Dacite

The chemical characteristics of the dacites are Al_2O_3 = 16-18.12 wt%, total FeO+MgO+CaO = 8.57-12.50 wt%, Na_2O = 3.74-5.66 wt%, K_2O = 0.88-3.19 wt%, and TiO_2 = 0.34-0.90 wt% (Tables 2.4, 2.5 and 2.6). These featurs are characteristic of the acid members of the calcalkaline assemblage in island arcs and other subduction zones (Tomblin, 1979). They are similar to other dacites from other parts of Indonesia (Ewart, 1979), and they are higher in Al_2O_3 and Na_2O compared with S.W. Pacific rocks. One rock (69341) contains high Na2O (5.66 wt%), P_2O_5 (0.51 wt%), FeO (7.66 wt%) and low CaO (1.69 wt%). This is possibly due to hydrothermal alteration, as pyrite is the main opaque phase. The Mg value of the dacites ranges from 23 to 54.8.

Corundum appears in the norm of some dacites (Tables 2.4, 2.5 and 2.6). The dacites are oversaturated and their normative quartz is greater than 12%. Their normative anorthite is generally lower than that of andesites and basalts, while normative orthoclase and albite are higher than andesites. In the albite, orthoclase and quartz normative diagram (Fig. 2.18) these rocks occupy a similar field to typical calcalkaline rocks (Baker, 1983, p.273).

The dacites are mostly medium-K dacites (calcalkaline). They are classified as subalkaline in Fig. 2.15. On Fig. 2.16, they are all in the calcalkaline field except for samples 69334, 69336, 69350 and 69327 which are in the tholeiite field. On the AFM diagram they fall in the calcalkaline field (Fig. 2.17) except for sample 69341 which falls in the tholeiite field. The mineralogy of calcalkaline rocks shows abundant evidence of non-equilibrium relationships (see Section 2.2.3) (Ehler & Blatt, 1980). The dacites are mostly metaluminous. The molecular Al_2O_3/K_2O+Na_2O+CaO ratio ranges from 0.84 to 0.99, with a few samples having ratios of 1.0 to 1.3, which is peraluminous (Shand, 1951) (Tables 2.4, 2.5 and 2.6).

2.3.4 Rhyolite

The chemical characteristics of the rhyolites are: Al_2O_3 = 12.89-16.46 wt%, total FeO+MgO+CaO = 1.28-9.16 wt%, Na_2O = 3.13-4.89 wt%, and K_2O = 1-5 wt% (Tables 2.5 and 2.6). The rhyolites from the southern province, except sample 69375, are richer in silica and potassium (74-76 wt% and 3-5 wt%, respectively) and poorer in TiO_2 (< 0.2 wt%), MgO (<0.5 wt%), CaO (<2 wt%), P_2O_5 (<0.03 wt%).

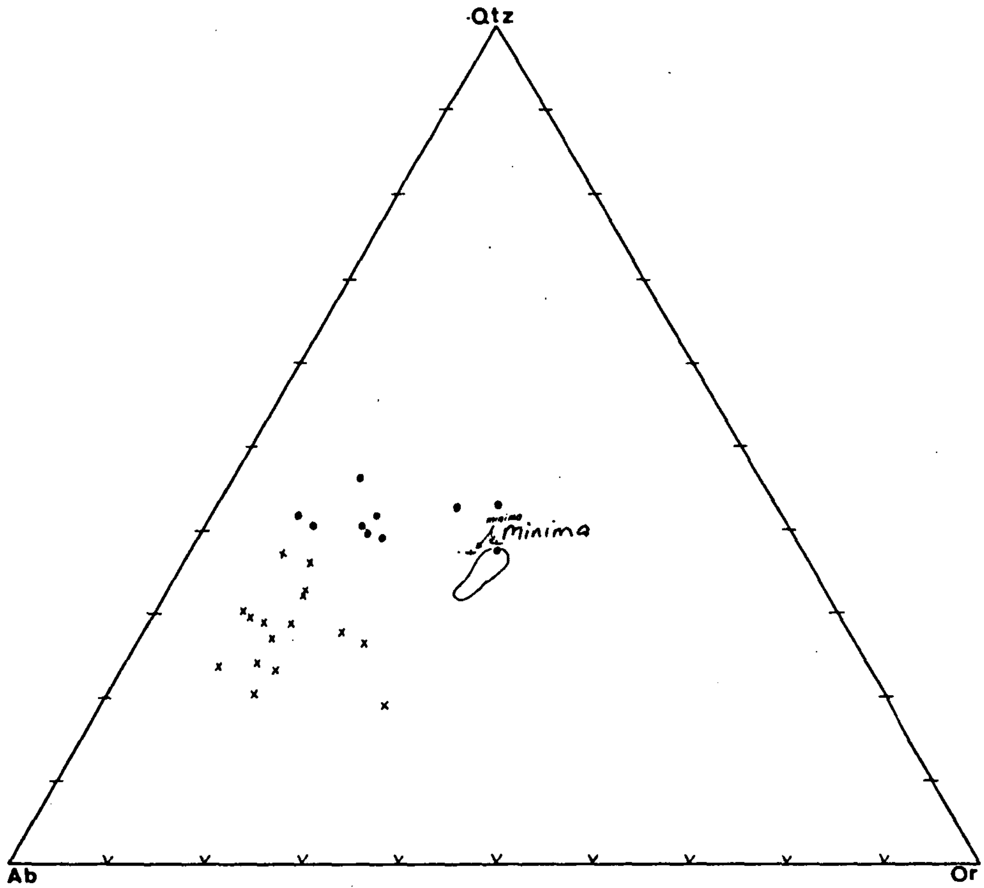


Fig. 2.18 Ab-Qz-Or normative diagram, showing the distribution of rhyolites (•) and dacites (×). Circled area represents maximum concentration of granitoid rocks, and also the low pressure minima plotted by Tuttle & Bowen (1958).

The rhyolites fall in the calcalkaline field (Fig. 2.17). They are all corundum normative (> 1.5%). They are silica-oversaturated with >28% normative quartz (Tables 2.4 and 2.5). The rhyolites from the southern province (except sample 69375) have a higher normative corundum (up to 4.4%) and normative orthoclase (up to 30%) and lower normative anorthite (0.2-8%) than the rhyolites from the central province. Samples 69379, 69366 and 69365 are relatively Or-rich and fall near the low pressure minima (Fig. 2.18), whereas the other samples are Or-poor but plot close to the Q-Ab lines and above, especially the two samples 69327 and 69362 from the central province. One sample (69365) falls in the field of maximum concentration of granitic rocks of Tuttle & Bowen (1958). It corresponds with a granitic composition (see also Section 2.2.4), and may be the most evolved rock in this area.

2.3.5 Harker Diagram

The chemical variation is well shown by Harker diagram (Fig. 2.19 and 2.20). Compositional affinities within the range of volcanic rocks in the three provinces have been looked for using Harker variation diagrams. Smooth curves and tight groupings could suggest a compositional connection.

In general, when rocks of all three provinces are lumped together, there is considerable scatter. However, when each province is considered separately, there is good chemical-composition coherence, in the northern, central and southern provinces, confirming the original divisions based on tectonic setting. The central province rocks tend to form a more compact group within the overlap of the northern and southern province groups, with more resemblance to the southern province group.

Fractional crystallization may have contributed to the compositional variation in the CWK rocks. Plagioclase fractionations leads in general to decreasing CaO and Al_2O_3 with increasing SiO_2 contents, whereas fractionation of mafic phases, such as pyroxene, will lead to decreasing MgO, FeO and TiO_2.

2.4 TRACE ELEMENTS

2.4.1 Basalt

The trace element composition of the basalts is shown in Tables 2.7 and 2.9.

Rb, Ba, and Sr (large cation/potassium type) contents range widely, from 1-13, 95-473 and 329-603 ppm respectively. Zr and Nb (large, highly charged cations/zirconium type) range from 12-269 and 1-8 ppm respectively. Ni, Sc, Cr, and V (feromagnesian elements) range from 35-194, 25-36, 33-281 and 186-327 ppm respectively. The Y content ranges from 19-46 ppm

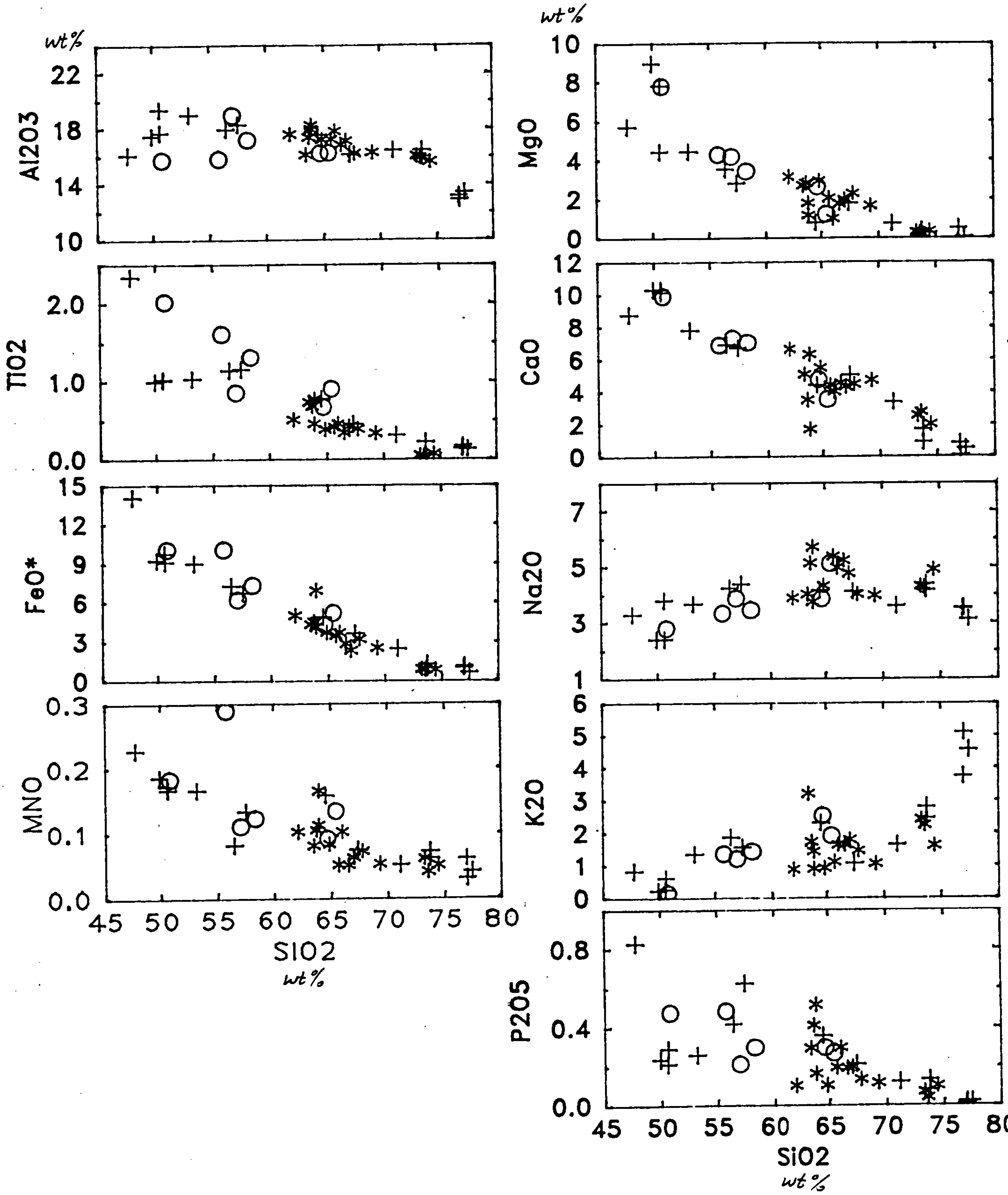


Fig. 2.19 Harker diagram (SiO_2-major elements).
Symbols are as in Fig. 2.15.

+ southern
* central
O northern

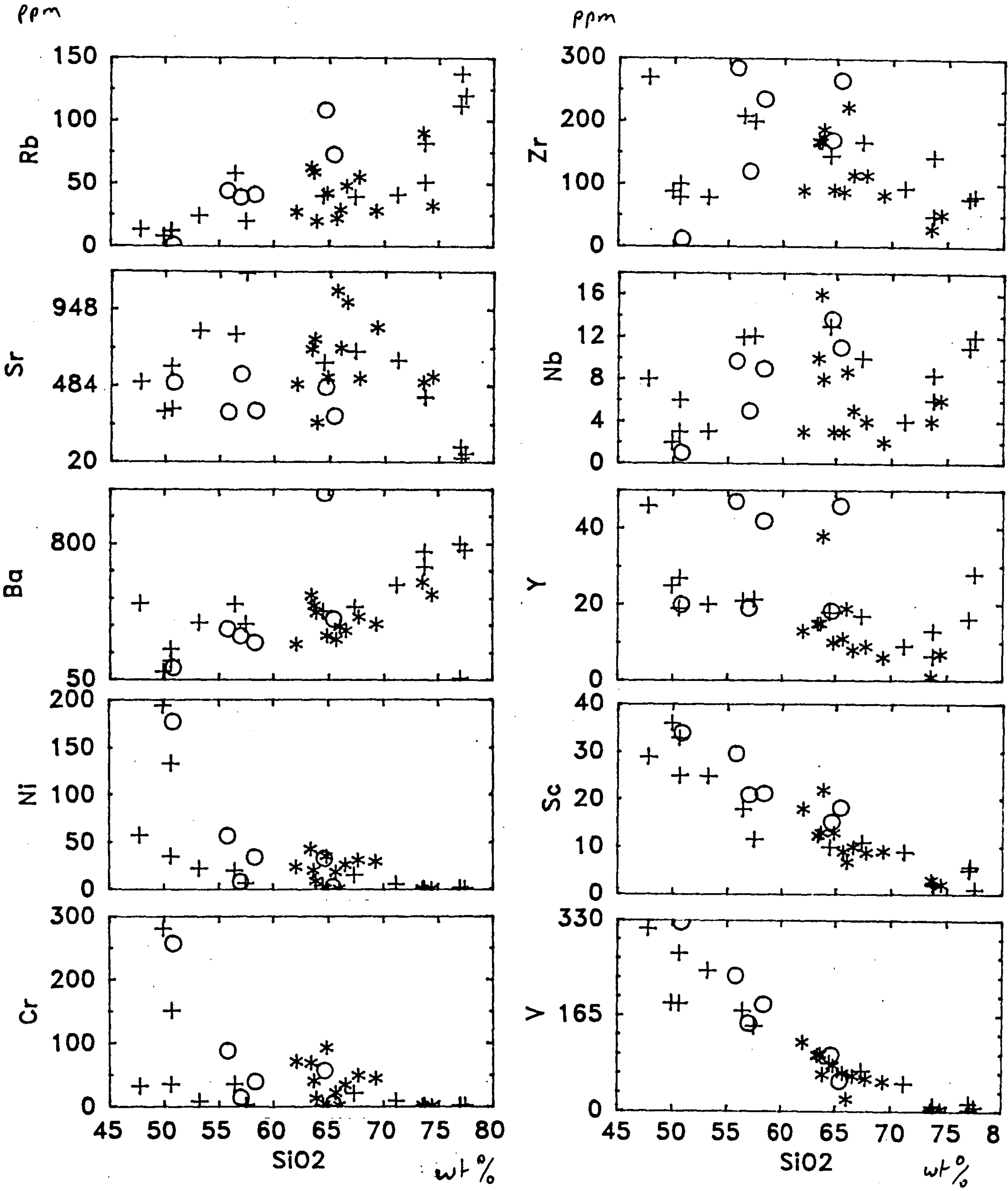


Fig. 2.20 Harker diagram (SiO_2-trace elements).
Symbols as in Fig. 2.15.

Table 2.7 Trace element analyses of the rocks from the southern province.

	69292	69293	69306	69295	69294	69299	69303	69355
Rb	13	8	12	12	24	58	20	40
Ba	473	95	155	220	366	467	360	430
Sr	508	329	343	603	818	798	1172	624
La	28	9	15	10	9	21	29	25
Ce	69	23	33	22	22	53	67	53
Pr	8.94	3.16	4.22				7.87	
Nd	40	14	18	15	16	28	32	23
Sm	9.29	3.26	3.96				5.49	
Eu	3.04	1.20	1.11				1.61	
Gd	9.10	3.96	4.15				4.38	
Dy	8.21	4.52	4.51				3.54	
Er	5.31	2.98	2.84				1.84	
Yb	4.79	2.98	2.46				1.42	
Y	46	25	27	19	20	21	21	18
Zr	269	88	100	78	78	208	199	145
Nb	8	2	6	3	3	12	12	13
Sc	29	36	25	33	25	18	12	10
V	316	187	186	272	243	174	147	84
Cr	33	281	151	36	9	36	3	2
Ni	58	194	133	35	23	20	7	4
K/Rb	524	239	180	422	464	266	640	477

Table 2.7 cont.

	69350	69375	69372	69368	69365	69366	69379
Rb	39	41	82	60	137	120	112
Ba	453	574	758	674	60	766	801
Sr	694	639	413	416	45	72	113
La	28	16	22	18	117	43	28
Ce	61	30	46	41	140	78	49
Pr							
Nd	25	13	16	19	99	29	14
Sm							
Eu							
Gd							
Dy							
Er							
Yb							
Y	17	9	13	6	89	28	16
Zr	167	93	143	48	549	81	77
Nb	10	4	6	8	34	12	11
Sc	11	9	2	2	6	1	5
V	71	49	10	3	3	8	15
Cr	22	10	2	2	2	2	2
Ni	15	6	1	1	2	1	1
K/Rb	226	332	283	400	278	308	315

Table 2.8 Trace element analyses for the rocks from the central province.

	69307	69343	69341	69347	69344	69340	69342
Rb	27	59	20	42	63	22	29
Ba	247	460	423	294	518	274	344
Sr	492	768	260	536	706	1060	714
La	10	30	27	11	28	12	28
Ce	22	68	66	18	59	26	58
Pr	2.48			2.10	6.48	2.89	6.21
Nd	11	28	33	9	24	12	25
Sm	2.33			1.77	4.07	2.06	4.25
Eu	0.64			0.63	1.16	0.73	1.27
Gd	2.39			1.78	3.37	1.89	3.40
Dy	2.20			1.55	2.53	1.61	2.82
Er	1.02			0.93	1.54	0.94	1.63
Yb	1.00			0.70	1.09	0.73	1.39
Y	13	15	38	10	15	11	19
Zr	89	167	187	0	168	87	223
Nb	3	16	8	3	10	3	9
Sc	18	13	2	13	12	9	7
V	119	99	64	80	97	66	21
Cr	71	41	13	92	69	22	2
Ni	24	20	9	35	43	19	1
K/Rb	267	423	241	365	180	415	465

Table 2.8 cont.

	69325	69336	69327	69337	69361	69362
Rb	38	55	28	48	90	32
Ba	309	399	358	21	589	520
Sr	1099	526	838	992	04	538
La	13	5	12	18	2	15
Ce	29	27	24	36	4	34
Pr					0.38	
Nd	9.40	11.30	9.00	15	1.88	14
Sm					0.46	
Eu					0.22	
Gd					0.48	
Dy					0.19	
Er					0.17	
Yb					0.17	
Y	6	9	6	8	1	7
Zr	107	114	82	114	28	51
Nb	3	4	2	5	4	6
Sc	6	9	9	10	3	2
V	50	57	52	62	3	4
Cr	29	50	44	35	3	2
Ni	28	31	29	26	1	1
K/Rb	280	1956	1358	308	206	415

Table 2.9 Trace element analyses for the rocks from the northern province.

	69297	69308	69306	69310	69334	69328
Rb	1	4	39	41	108	73
Ba	117	332	293	257	1078	387
Sr	503	323	556	333	475	298
La	8	26	16	19	22	25
Ce	21	65	34	43	46	58
Pr	3.02	4.19				
Nd	16	33	17	25	19	31
Sm	3.77		3.70			
Eu	1.53		1.19			
Gd	4.11		3.48			
Dy	3.88		3.36			
Er	2.02		1.81			
Yb	1.36		1.52			
Y	20	47	19	42	18	46
Zr	12	285	120	235	170	265
Nb	1	10	5	9	14	11
Sc	34	30	21	21	15	18
V	327	235	152	185	98	53
Cr	258	88	15	40	57	5
Ni	177	6	8	34	33	3
K/Rb	1245	253	253	553	192	857

Sample 69292 has high Ba (473 ppm), Nb (8 ppm), Zr (269 ppm) and Y (46 ppm) contents, and low Ni and Cr contents (58 and 33 ppm respectively) compared to the other basalts. The Y/Nb ratio of this basalt is similar to ocean-floor tholeiites (Pearce & Cann, 1973). Sample 69297 has the lowest Rb content (1.0 ppm). This low value is commonly found in oceanic tholeiites (1.2 ppm, Taylor, 1968). In general, the Rb contents of the basalts are lower than the average basalts (i.e. 20 ppm, Taylor, 1968). The K/Rb ratio of the basalts varies between 180 and 435 (except sample 69297, which is 1245). It is lower than the common basic magma (i.e. 400-1200, Carmichael et al., 1974), and the average calcalkaline rocks (i.e. 400-500, Jakes & White, 1970). The Ba is high. It is about twice that of the average contents in the island arc tholeiitic basalts (i.e. 75 ppm, Jakes & White, 1972). It is much higher than the value of abyssal tholeiite (i.e. 6-30 ppm, Jakes & Gill, 1970). A similar high value of Ba has been reported from Quaternary island arc volcanics from Japan (i.e. 105-224 ppm, Masuda et al., 1974). Although Sr is high compared with the basalts from New Zealand (i.e. 300 ppm, Ewart & Taylor, 1969), it is within the range of average basalts (Taylor, 1968).

The Ni contents of the basalts is low compared with most basalts (i.e. ~200-300 ppm, Frey et al., 1978; Hart & Davis, 1978; Sun & Hanson, 1975) reflecting the evolved nature of these rocks, as shown by the Mg values. Similarly, the Cr contents are less than average MORB. However, some of them fall within the range of oceanic basalts and upper mantle values (i.e. 160-460 ppm, Engel et al., 1965). These data suggest fractionation of a chrome spinel (Hughes, 1982). The same general comment on abundances could be applied to nickel which averages 133-194 ppm in the same rocks. By comparing the average basalts (i.e. 200 ppm Cr, Hughes, 1982) a few rocks (69294, 69292, 69299) contain very low Cr contents. V content is low in two samples (69295, 19293). It is lower than average basalts (i.e. 250 ppm, Taylor, 1968). Y content in sample 69292 is high. It is similar to the Y content found in oceanic tholeiites (Taylor, 1968).

On the Ti-Zr-Y diagram of Pearce & Cann (1973) (Fig. 2.21), the basalts fall within the plate margin and ocean floor field (except sample 69297, which does not fit in this diagram). There are four rocks within the ocean-floor basalts field (OFB) and one (69292) within the calcalkali basalt (CAB) field. In the Ti-Zr diagram (Fig. 2.22) four rocks fall within the CAB, and the others are unidentified. On the Zr-Nb-Y diagram of Meschede (1986) (Fig. 2.23), four rocks fall within the N-type MORB, and two rocks (69292, 69297) are identified as volcanic arc basalts (VAB) and unidentified

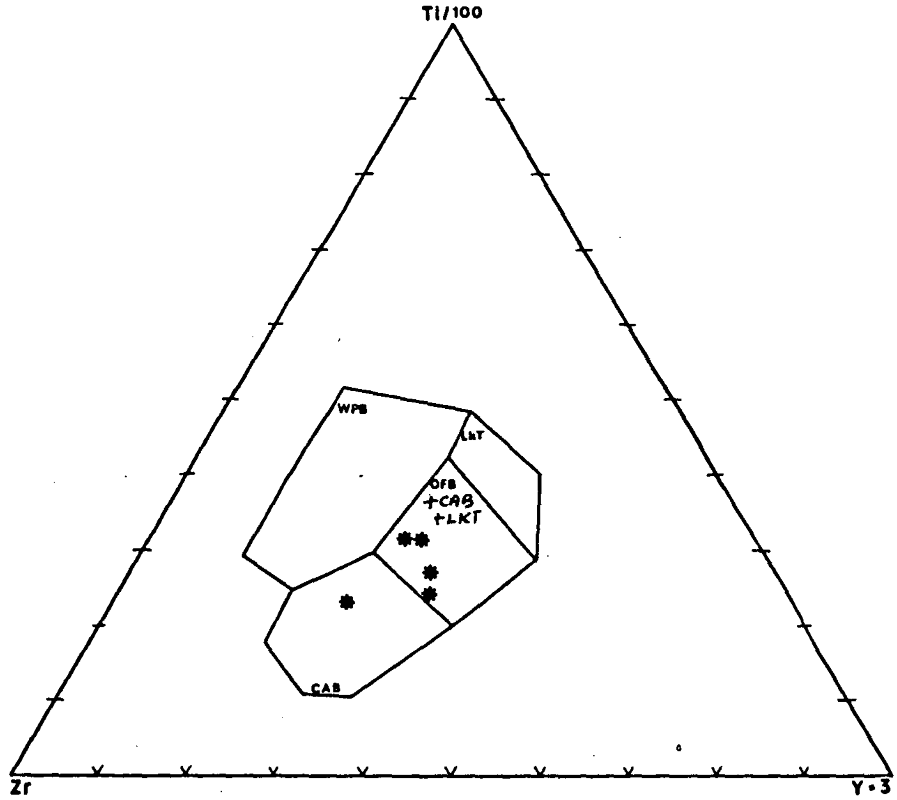


Fig. 2.21 Discrimination diagram using Ti, Zr and Y (after Pearce & Cann, 1973) of basalts. Within-plate basalts (WPB), ocean-floor basalts (OFB), low-potassium tholeiites (LKT) and calcalkali basalts (CAB).

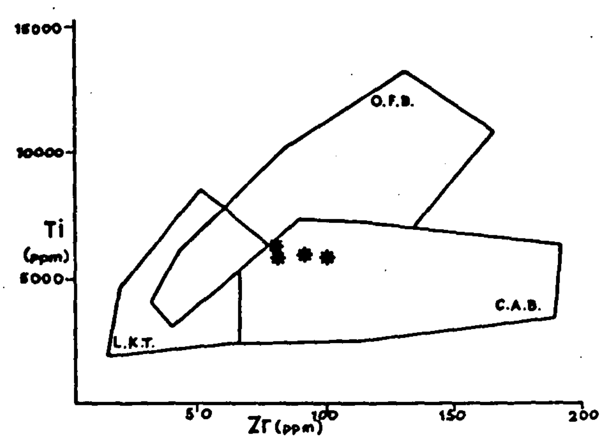


Fig. 2.22 Discrimination diagram using Ti and Zr (after Pearce & Cann, 1973) of basalts. Fields as in Fig. 2.21.

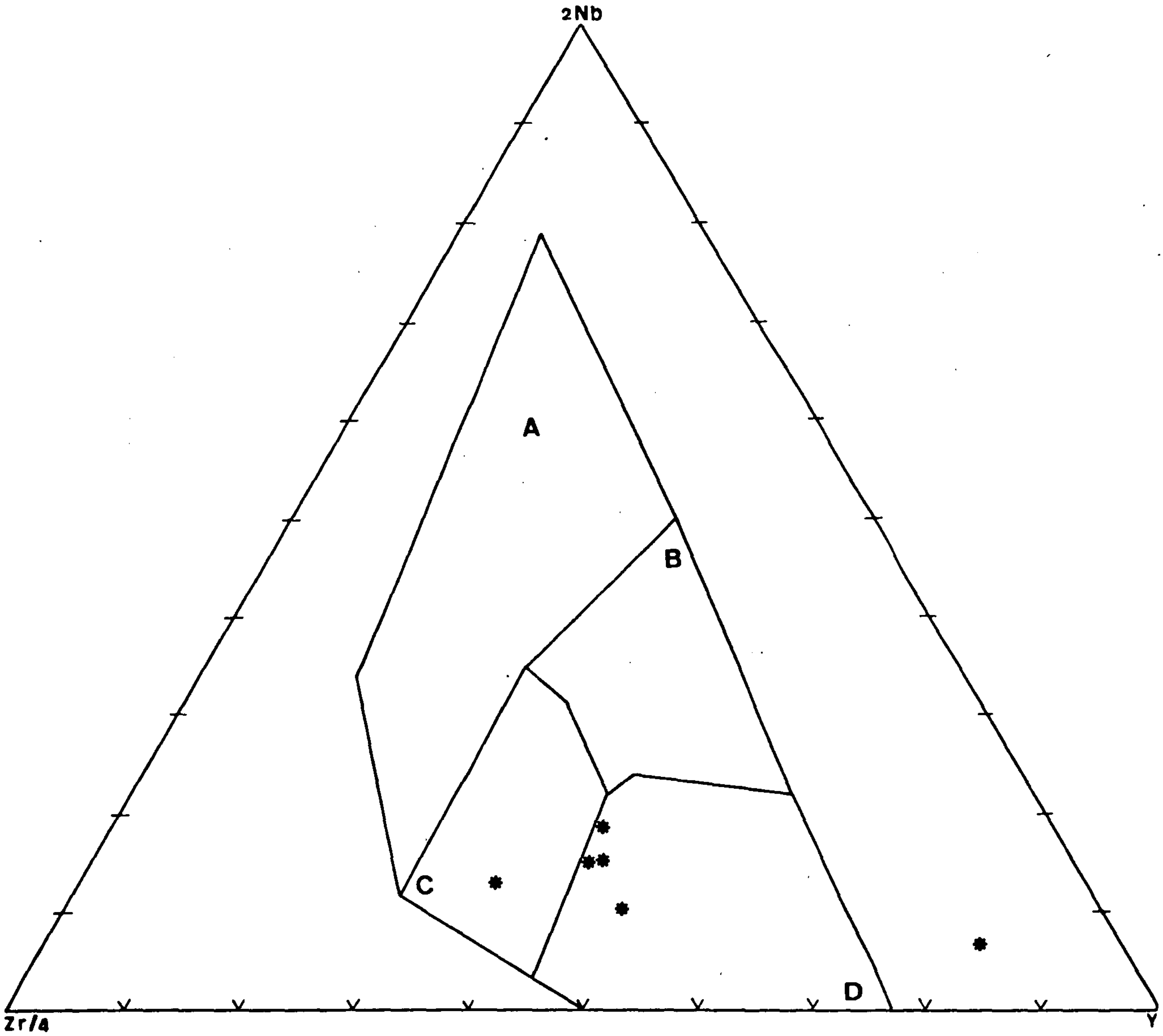


Fig. 2.23 Discrimination and classification diagram using Zr, Nb and Y (after Meschede, 1986) of basalts. Within plate basalts (A), volcanic-arc basalts (C), P-type (enriched) MORB (B), and N-type (depleted) MORB (D).

respectively. Meschede (1986) proposed that the VAB field and N-type MORB field cannot be differentiated.

2.4.2 Andesite

The trace element characteristics of the andesites is shown in Tables 2.7, 2.8 and 2.9. Rb, Ba and Sr range from 20-58, 247-467 and 323-1172 ppm, respectively. Zr and Nb range from 78-285 and 3-12 ppm, respectively. Ni, Sc, Cr and V range from 7-56, 18 - 30, 3-88 and 119-243 ppm, respectively. The Y content ranges from 13-47 ppm.

The K/Rb ratio is 253-640. Three rocks (69308, 69303, 69306) have a low K/Rb ratio compared with typical calcalkaline rocks (Jakes & White; 1970; Gill, 1981). The low K/Rb ratio (i.e. < 300 ppm, Lo, 1981) in andesites results from a high degree of fractional crystallization. When compared with andesites of hypersthene rocks series in Japan (Taylor & White, 1966), the Rb content in the andesites from CWK are high (average 19 ppm in Japan). This could be due to the higher potassium and calcium concentration in CWK (K_2O = 1.8 wt% and CaO = 8.5 wt% in average) than in Japan (K_2O = 0.9 wt% and CaO = 8.1 wt% average). By comparison with orogenic andesites (Gill, 1981), the Zr contents of the CWK andesits are extremely high, and Nb values also higher. Most of the andesites have Nb contents close to typical high-K tholeiite (Gill, 1981).

2.4.3 Dacites

Trace element analyses for the dacites appear in Tables 2.7, 2.8 and 2.9. Rb, Ba, and Sr range from 20-108, 294-1078 and 260-1099 ppm, respectively. Zr and Nb range from 87-223 and 3-16 ppm, respectively. Ni, Sc, Cr and V range from 1-43, 6-22, 2-92 and 21-99 ppm, respectively. Y contents range from 6-46 ppm.

These values mostly fall within the range typical of dacites from the SW Pacific and from elsewhere in Indonesia (Ewart, 1979). A few elements, such as Sr and Y, are higher and lower respectively than both regions. The Rb and Ba contents are low, compared with the average value in granodiorites (Taylor, 1968). The K/Rb ratio ranges from 180-1959.

2.4.4 Rhyolites

The trace element compositions of the rhyolites are shown in Tables 2.7 and 2.8. Rb, Ba and Sr range from 28-137, 60-801 and 45-838 ppm, respectively. Zr and Nb range from 28-549 and 2-34 ppm, respectively. Ni, Sc, Cr and V range from <1-29, 1-9, <2-44 and 3-52 ppm, respectively. Y contents range from 1-89 ppm.

Sample 69365 may be distinguished from the other rhyolites by the high contents of Nb (34 ppm), Zr (549 ppm) and Y (89 ppm); and its low content of Ba (60 ppm) and Sr (45 ppm). It is typical of an alkaline rhyolite.

In general, the rhyolites from CWK are similar in K/Rb ratio (206-400) to the Taupo zone rhyolites (Ewart et al., 1968). A few elements, such as Rb and Ba are lower than the Taupo zone rhyolites (i.e. 108 and 870 ppm, respectively), while Sr is higher (except sample 69366). V and Ni are high in samples 69327 and 69375, suggesting they are the least differentiated of the rhyolites.

Chondrite-normalized comparison diagrams ("spidergrams") are useful for discriminating various rocks types in CWK (Figs 2.24-2.37). These are a convenient means of handling the trace element data. They are all typical arc-volcanic profiles as shown by the Nb trough (Varne & Foden, 1986).

The basalts may be divided into three types: type 1 is the northern province basalts (69297) (Fig. 2.24). It is extremely depleted in Zr, Nb and Rb, and high in Ba with respect to Rb. Type 2 is the southern province basalts (69293, 69299, 69294) (Fig. 2.25). They are characterised by Sr enrichment with smooth valley curve from Yb to P. They are higher in Nb and K elements than the type 1 basalts. Type 3 basalts are also from the southern province (69292, 69295) (Fig. 2.26). They are higher in Nb to Yb elements than the types 1 and 2 basalts, and are depleted in Sr. The slope from P to Ti is steeper than for the type 2 basalts.

The andesites may be divided into two groups: group 1 (Fig. 2.27) corresponds with the type 2 andesite (see Section 2.2.2). Like the type 2 basalts, both are Sr enriched. They are different in slope from Yb to Sr, where the andesites has a steeper slope than the basalts. Group 2 (Fig. 2.28) corresponds with type 1 andesites (see Section 2.2.2). They are different from group 1 by a strong depletion in Sr and Ti, and higher in Zr to Y. This group has a similar profile to the magma contaminated by sediments (Thompson et al., 1983). They are similar to type 3 basalts, as both are Sr depeleted and have the same Nb contents (24-34 times chondrite).

The dacites may be divided into three types: type 1 (Fig. 2.29) resembles the group 1 andesites. They are slightly different in Sr and Nb, where the dacites do not show Sr enrichment and have higher Nb contents (25-45 times chondrite). Type 2 dacites (Fig. 2.30) are lower in trace element content (except Sr) than the type 1 dacites. They are strongly enriched in Sr, and strongly depleted in Nb and are comparable with the

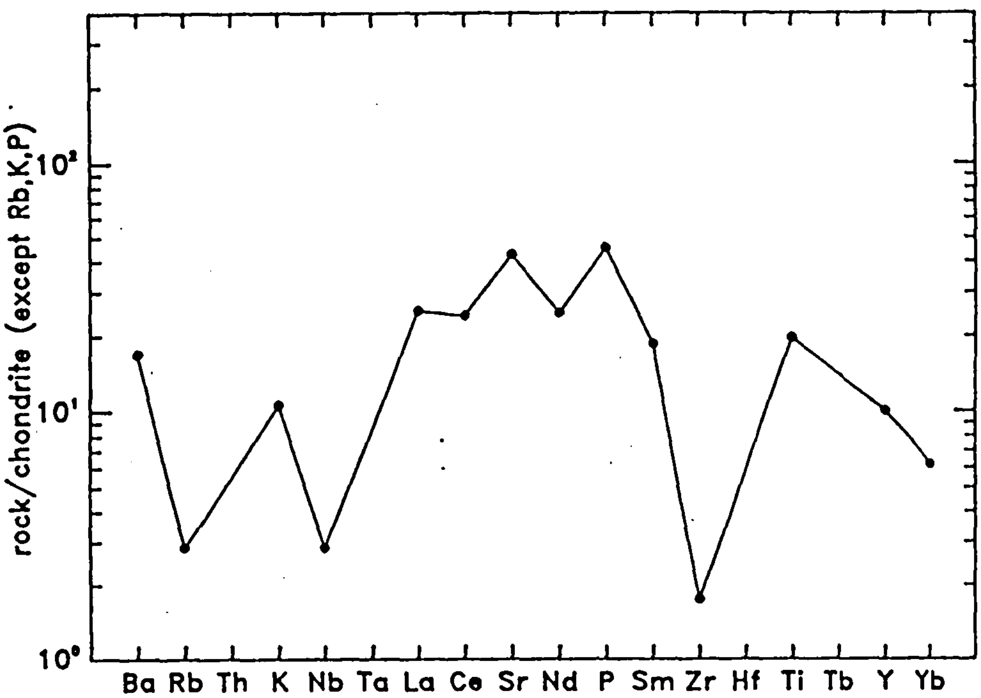


Fig. 2.24 Chondrite normalized comparison diagram for the basalt from the northern province (sample 69297).

Normalizing factors are Ba: 6.9, Rb: 0.35, K: 120, Nb: 0.35, La: 0.328, Ce: 0.865, Sr: 11.8, Nd: 0.63, P: 46, Sm: 0.203, Zr: 6.84, Ti: 620, Y: 2.0, Yb: 0.22 (Thompson, 1982; Varne and Foden, 1986)

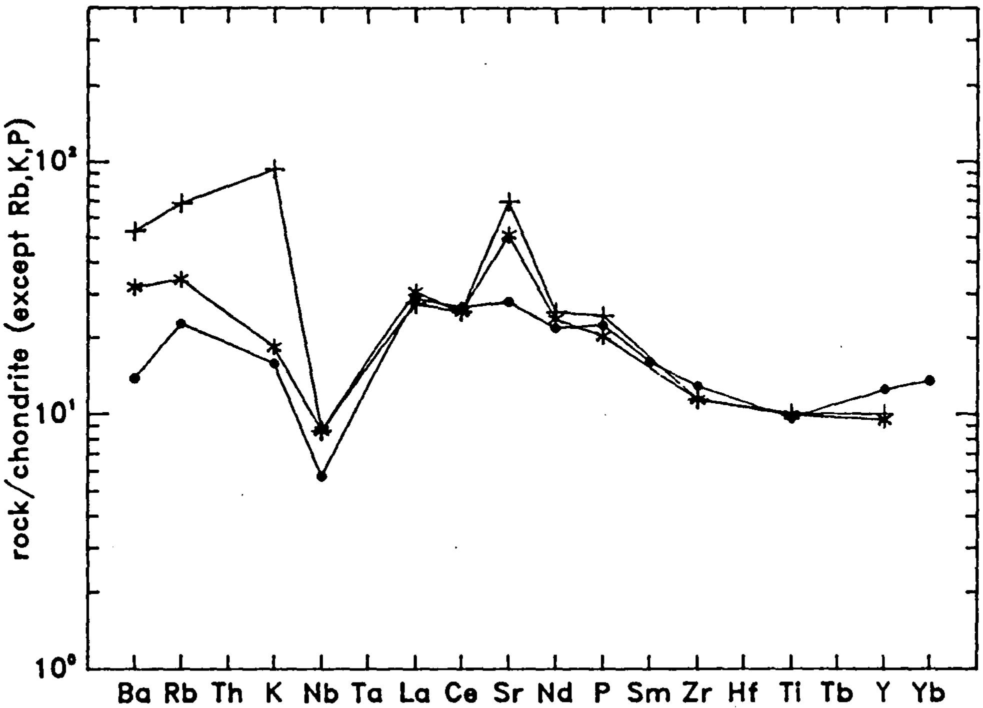


Fig. 2.25 Diagram for the type 2 basalts [samples 69293 (•), 69299 (+), and 69294 (✻)].

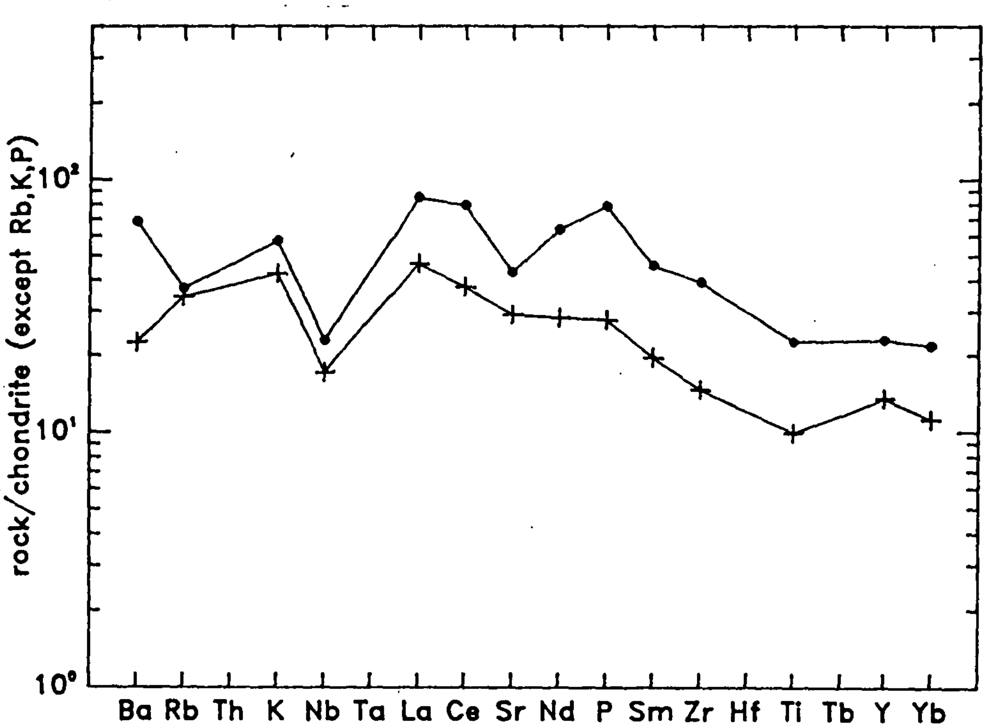


Fig. 2.26 Diagram for the type 3 basalts [sample 69292 (•) and 69295 (+)].

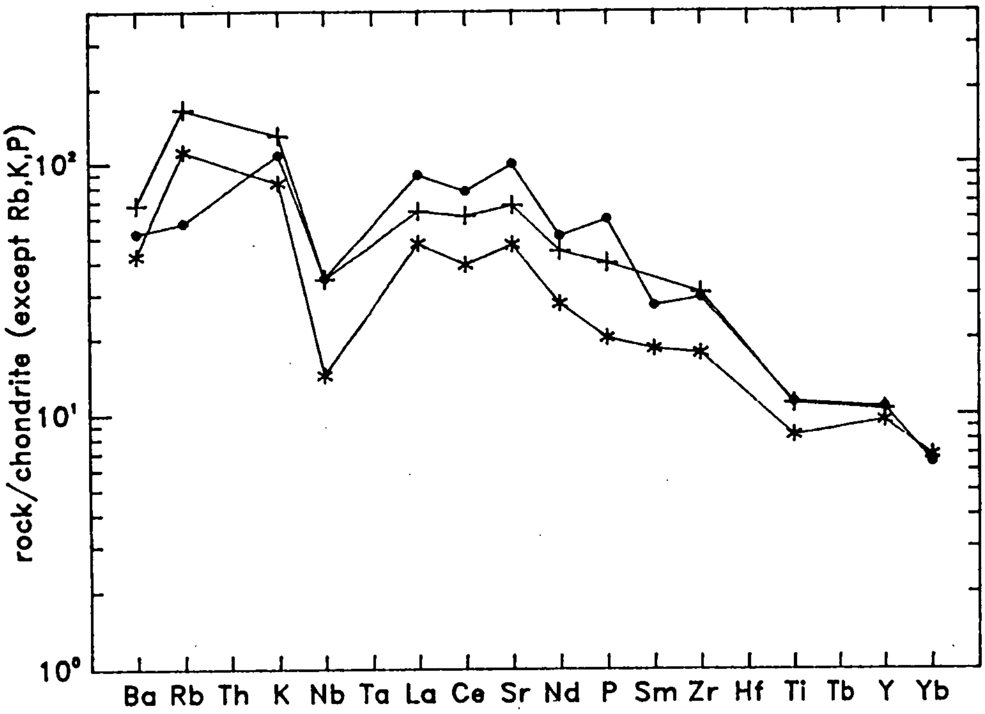


Fig. 2.27 Diagram for the group 1 andesites [69301 (•), 69303 (+) and 69306 (✳)].

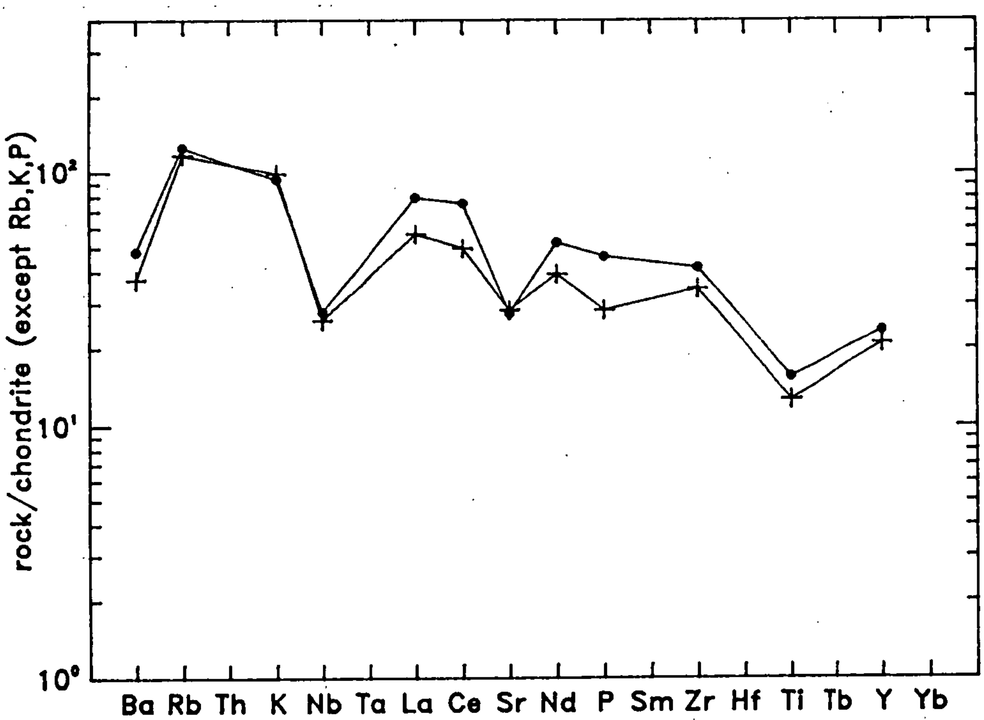


Fig. 2.28 Diagram for the group 2 andesites [69308 (•) and 69310 (+)].

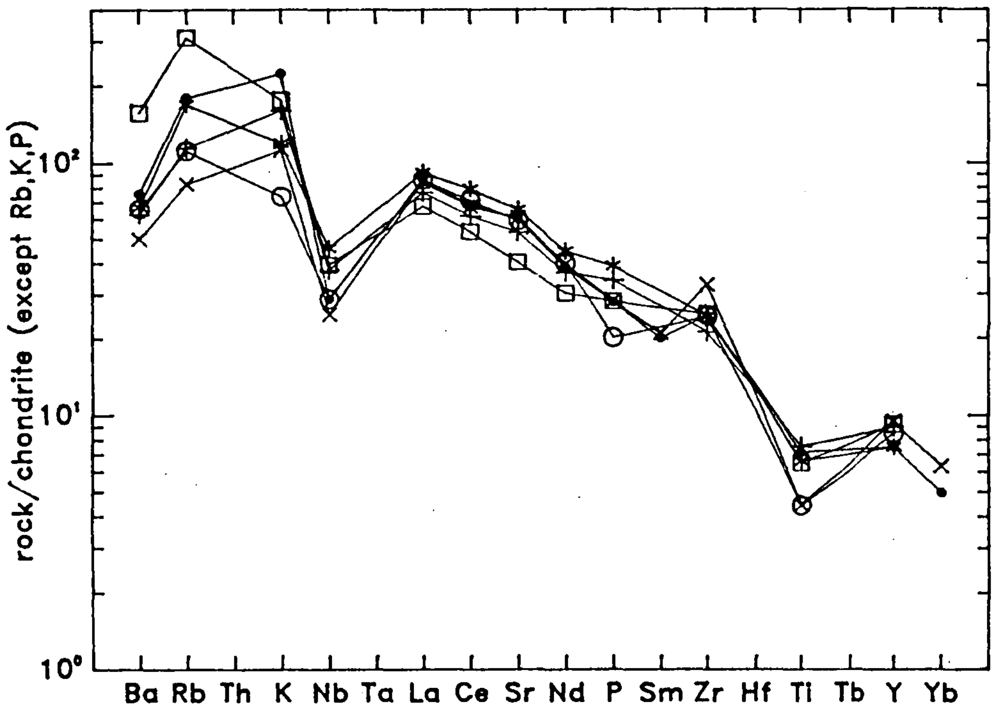


Fig. 2.29 Diagram for the type 1 dacites [69344 (•), 69355 (+), 69343 (✳), 69350 (o), 69342 (×) and 69334 (□)].

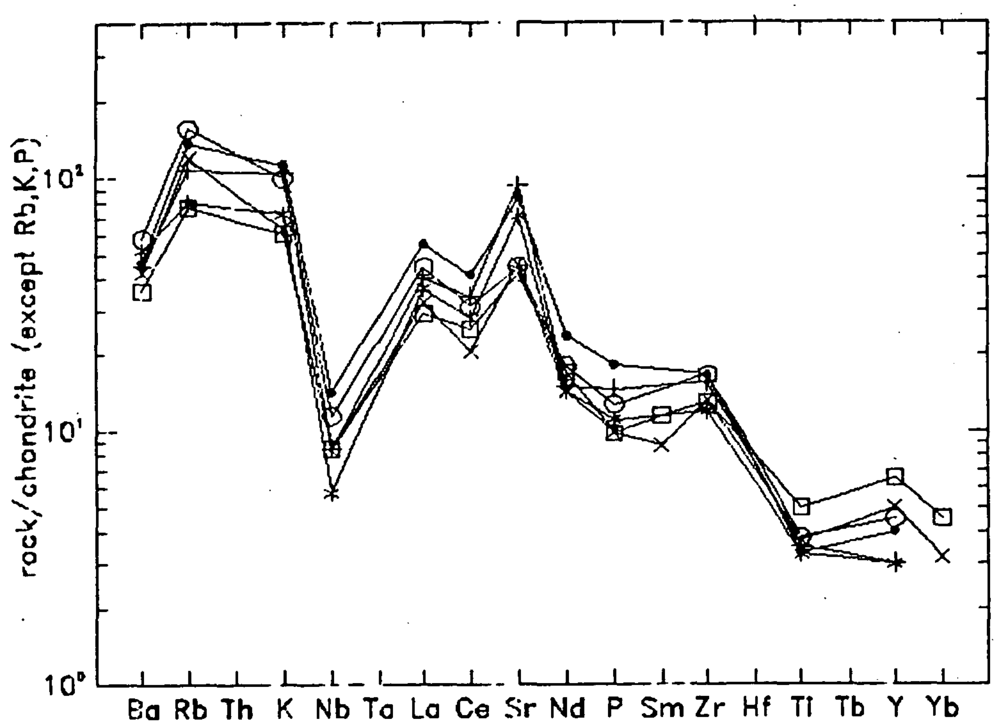


Fig. 2.30 Diagram for the type 2 dacites [69337 (•), 69325 (+), 69327 (✳), 69336 (o), 69347 (×) and 69307 (□)].

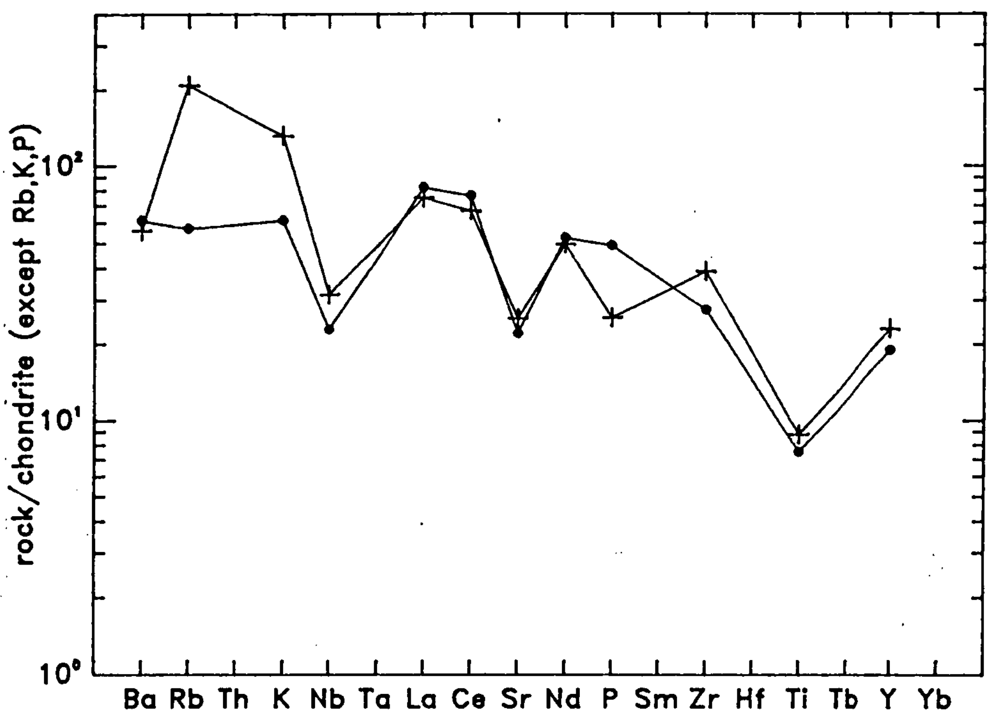


Fig. 2.31 Diagram for the type 3 dacites [69341 (•) and 69328 (+)].

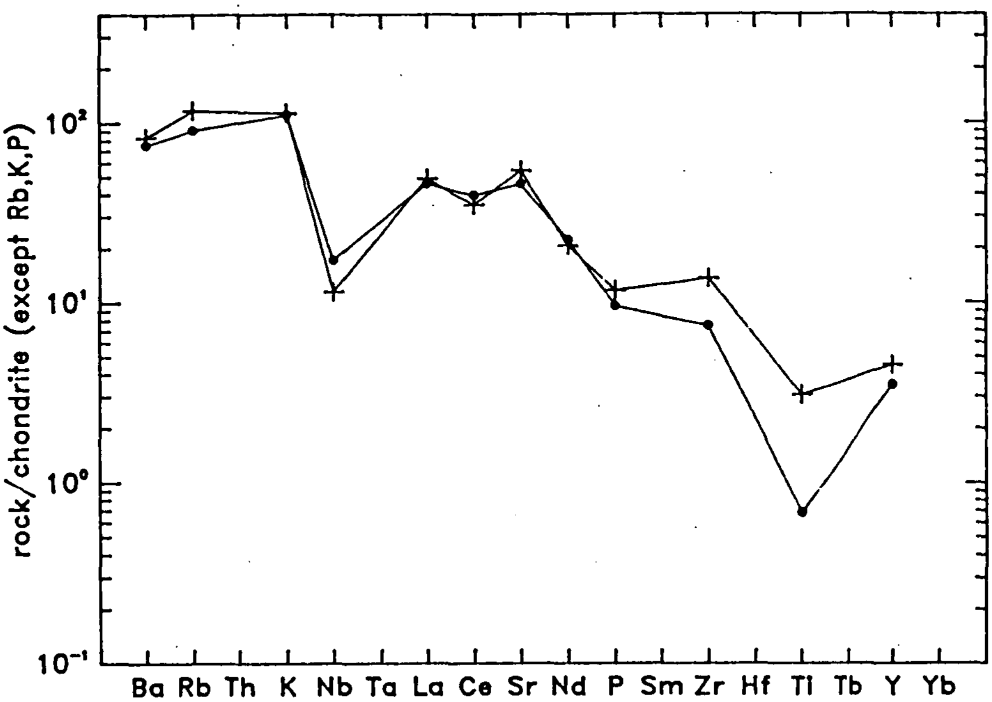


Fig. 2.32 Diagram for the group 1 rhyolites [69362 (•) and 69375 (+)].

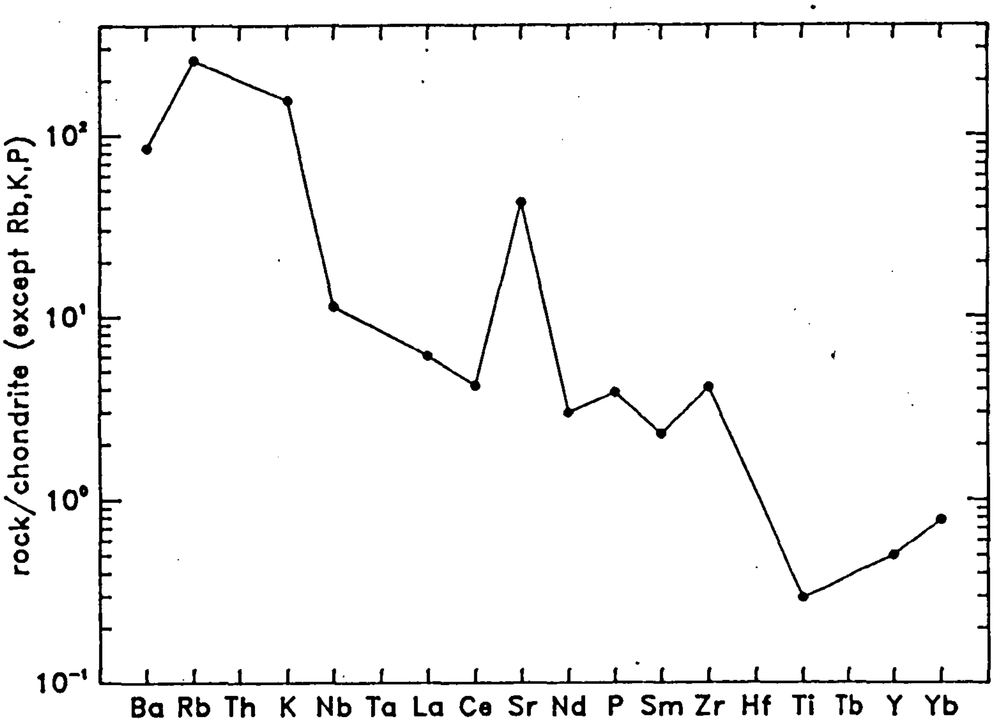


Fig. 2.33 Diagram for the group 2 rhyolites [69361].

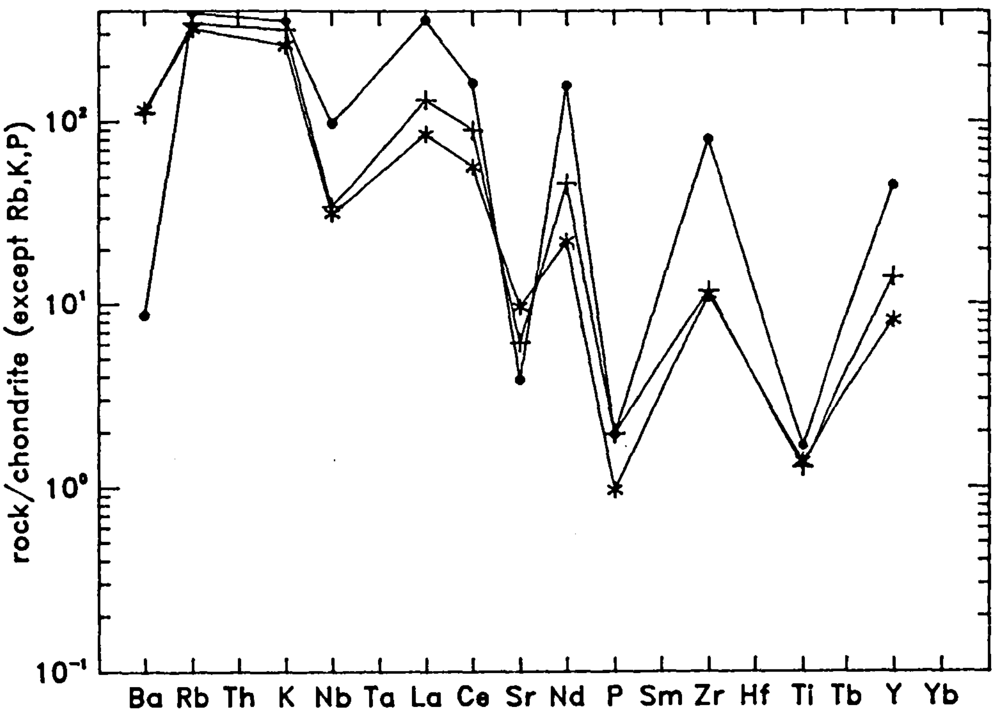


Fig. 2.34 Diagram for the group 3 rhyolites [69365 (•), 69366 (+) and 69379 (✳)].

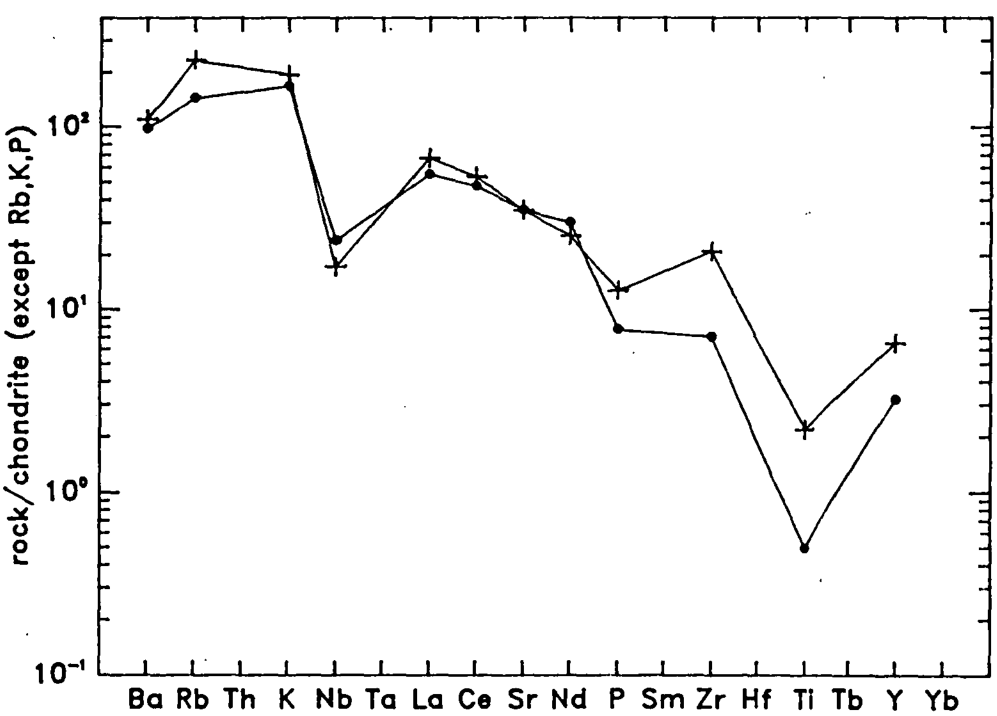


Fig. 2.35 Diagram for the group 4 rhyolites [69368 (•) and 69372 (+)].

type 2 basalts and group 1 andesites. Type 3 dacites (Fig. 2.31) are similar to group 2 andesites.

The rhyolites may be divided into four groups: group 1 (Fig. 2.32) resembles the pattern of type 2 dacites. They are differentiated from these dacites by a deep Ti trough and lower element contents from Nb to Yb. Group 2 rhyolites (Fig. 2.33) are extremely Sr enriched with no Nb depletion. They are much lower in Nb to Yb contents than group 1 rhyolites. Group 3 rhyolites (Fig. 2.34) are strongly depleted in Ti, P and Sr (1-2 times chondrite), and strong Nd and Zr enrichments (20-175 and 12-80 times chondrite). Group 4 (Fig. 2.35) resembles the group 1 dacites.

The spidergrams illustrate the differences between a group of andesites and dacites from the three provinces. This may be seen from the Sr and Nb behaviour, and the enrichment of the elements with respect to chondrite in each province. The northern province rocks (except 69306 and 69334) have an element enrichment from 4-300 times chondrite (Fig. 2.36), while the central province (except 69343) (Fig. 2.37) and southern province (Fig. 2.38) from 7-200 and 3-175 times chondrite respectively. Most obvious in these diagrams is the differences in Sr behaviour. The Sr in the northern province rocks is depleted, while in the central province the rocks are strongly enriched in Sr, and there is no anomaly in the southern province rocks. Nb is strongly depleted in the southern province rocks compared with the other two provinces.

2.5 RARE EARTH ELEMENTS (REE)

2.5.1 Basalt

The REE characteristics of the basalts are shown in Tables 2.7 and 2.9. La, Ce and Nd contents range from 8 — 28, 18-74 and 13-39 ppm, respectively. Pr, Sm, Eu, Gd, Er, Dy and Yb range from 3.02-8.94, 3.26-9.29, 1.11-3.04, 3.96-9.10, 2.02-5.31, 3.88-8.21 and 1.36-4.79 ppm, respectively.

Sample 69292 is again readily distinguishable from other analysed basalts by its higher REE content.

2.5.2 Andesite

The REE characteristics of the andesits is presented in Tables 2.7, 2.8 and 2.9. La, Ce and Nd contents range from 9-29, 22 - 67 and 11 — 33 ppm, respectively. Pr, Sm, Eu, Gd, Er, Dy and Yb contents range from 2.48-7.87, 2.33-5.49, 0.64-1.61, 2.39-4.38, 1.02-1.84, 2.20-3.54 and 1-1.52 ppm, resectively.

The Ce content of these andesites is higher than that of orogenic andesites (Gill, 1981).

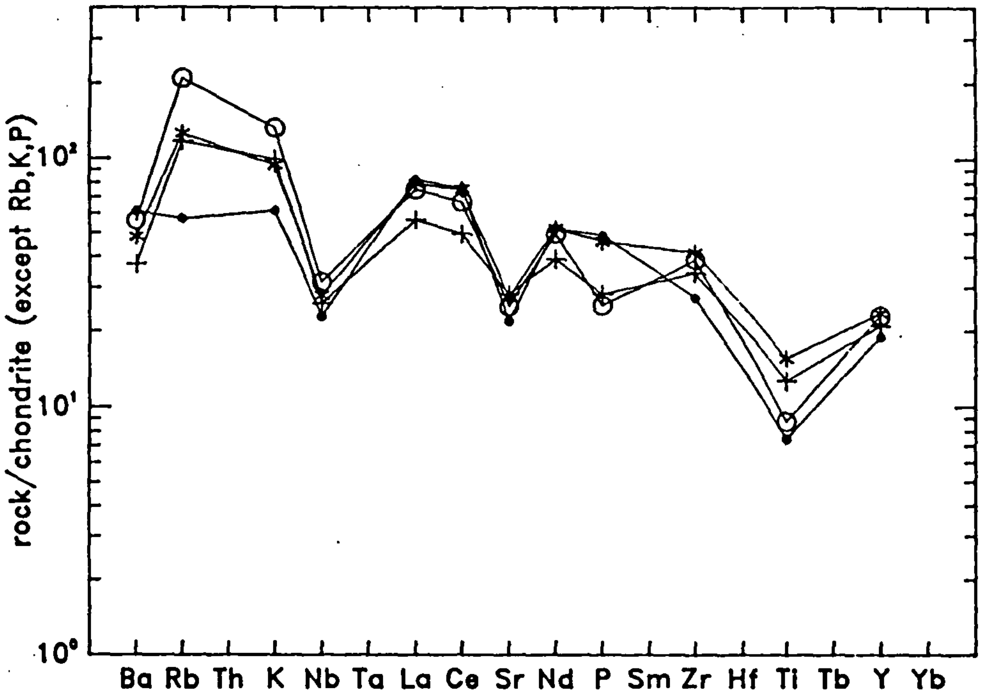


Fig. 2.36 Chondrite normalized comparison diagram for andesite and dacite groups from the northern province. Sample 69334 is not included, its pattern is similar to the pattern from the southern province.

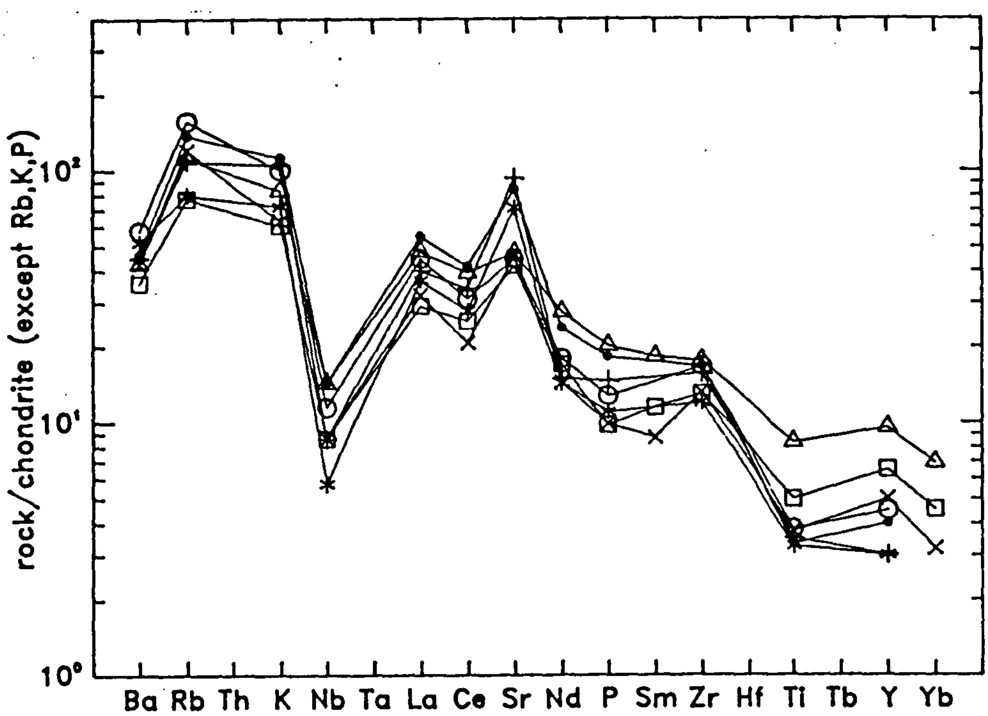


Fig. 2.37 Chondrite normalized comparison diagram for andesite and dacite groups from the central province. Sample 69343 is not included, its pattern is similar to the pattern from the southern province.

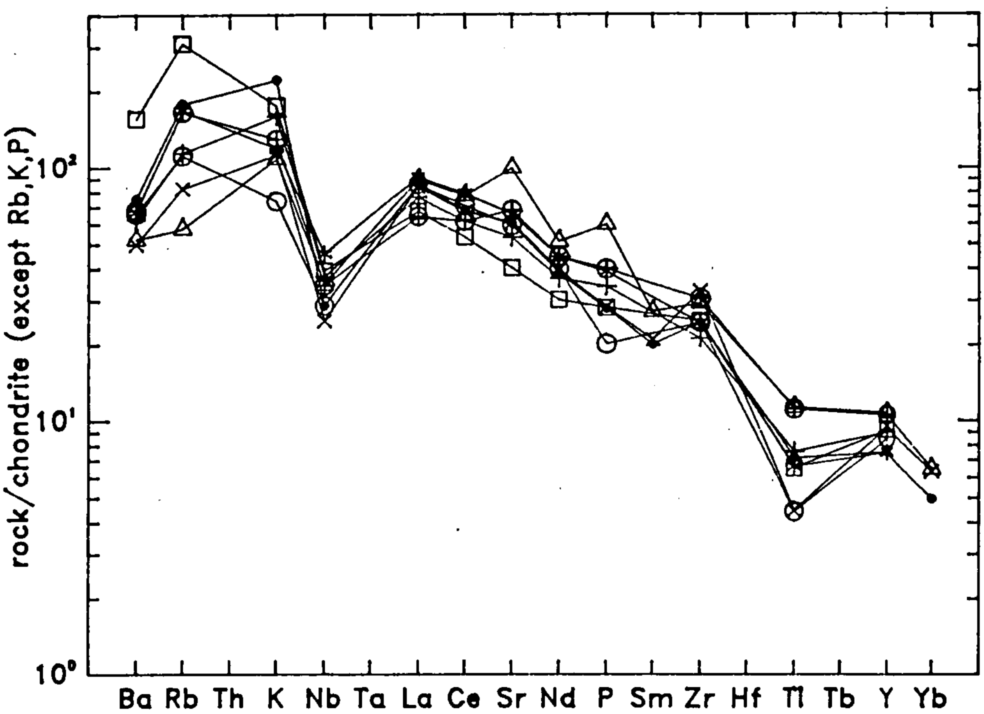


Fig. 2.38 Chondrite normalized comparison diagram for andesite and dacite groups from the southern province.

2.5.3 Dacite

The REE characteristics of the dacites is shown in Tables 2.7, 2.8 and 2.9. La, Ce and Nd contents range from 12 - 30, 18 - 68 and 9 - 31 ppm, respectively. Pr, Sm, Eu, Gd, Er, Dy and Yb range from 2.10-6.48, 1.77-4.25, 0.63-1.27, 1.78-3.40, 0.93-1.63, 1.55-2.82 and 0.70-1.39 ppm, respectively.

The La content in most of the dacites is higher than the average in the SW Pacific, and generally lower than the average from other parts of Indonesia (Ewart, 1979).

2.5.4 Rhyolite

The REE characteristics of the rhyolites are shown in Tables 2.7 and 2.8. La, Ce and Nd contents range from 2 - 117, 4 - 140 and 2 - 99 ppm, respectively. In one sample (69361), Pr, Sm, Eu, Gd, Er, Dy and Yb contents are 0.38, 0.46, <0.22, 0.48, <0.17, <0.19 and 0.17 ppm, respectively.

Sample 69365 contains extremely high amounts of La, Ce and Nd (Table 2.7). This again is typical of alkali granite (Vlasov, 1966). In contrast, sample 69361 contains extremely small amounts of these elements. These low values are commonly found in Trondhjemite-type rocks (Cullers & Graf, 1984).

2.5.5 REE Patterns

The REE patterns show that various rock types exist in CWK. They are all enriched relative to chondrite, and all have light REE (LREE) enrichments. The REE pattern of the basalts may be divided into three types by their slopes and these correlated with the spidergrams. Sample 69293 (Fig. 2.39) has a weak fractionated LREE (La-Sm) and almost unfractionated heavy REE (HREE) pattern. This pattern is similar to tholeiite REE pattern (Baker, 1983, p.319). Sample 69297 (Fig. 2.39) has an unfractionated La to Nd and fractionated HREE pattern, suggesting garnets present at depth (Hughes, 1983, p.275). Its slight positive anomaly suggests a feldspar cumulate origin (Schnetzler & Philpotts, 1970). Samples 69292 and 69295 (Fig. 2.40) have a steeply sloping REE pattern. Sample 69292 has a high REE enrichment level, which is 25-90 times chondrite. This pattern is similar to an alkaline basalt REE pattern (Hughes, 1983, p.294). Andesites and dacites may be divided into three types of pattern, which correspond to the geographic provinces. They are also correlated with the spidergrams. The andesites from the northern province (sample 69306) (Fig. 2.41) have LREE enrichment and HREE depletion or about 7.5-50 times chondrite. This pattern is similar to medium-K andesites (Gill, 1981). The andesites and dacites REE patterns from the

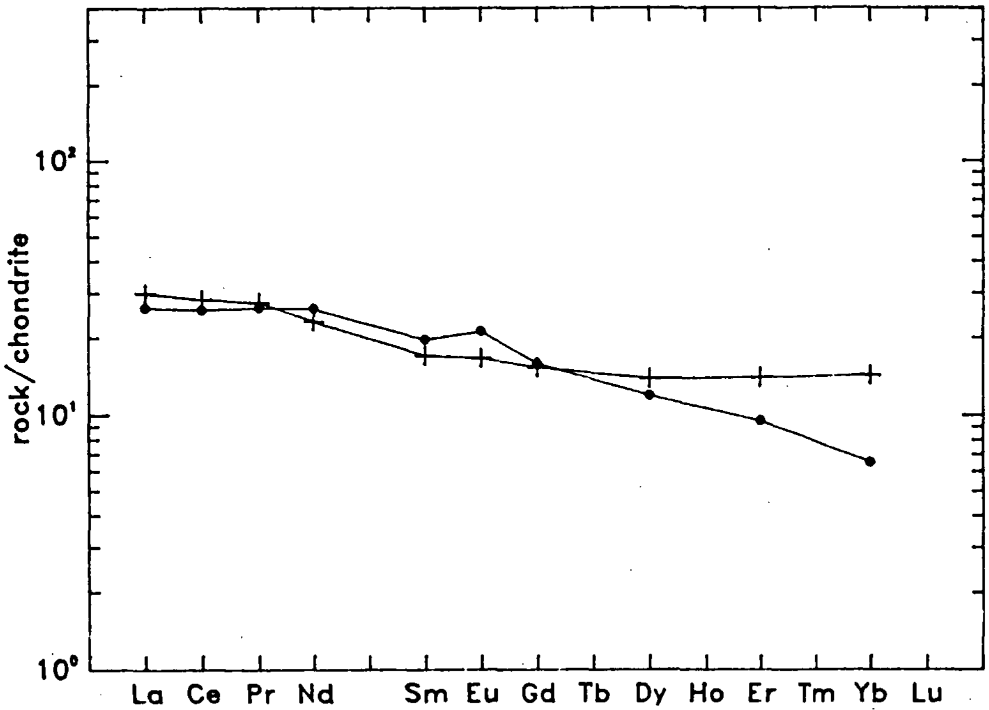


Fig. 2.39 Chondrite normalized REE pattern for basalts [69293 (+) and 69297 (•)].

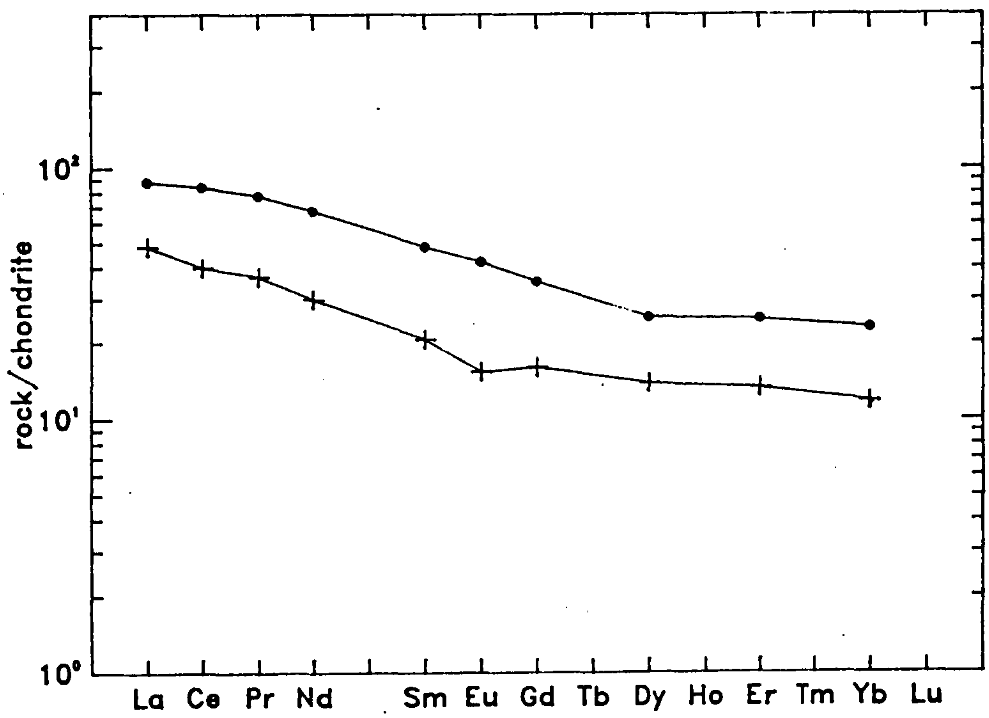


Fig. 2.40 Chondrite normalized REE pattern for basalts [69292 (•) and 69295 (+)].

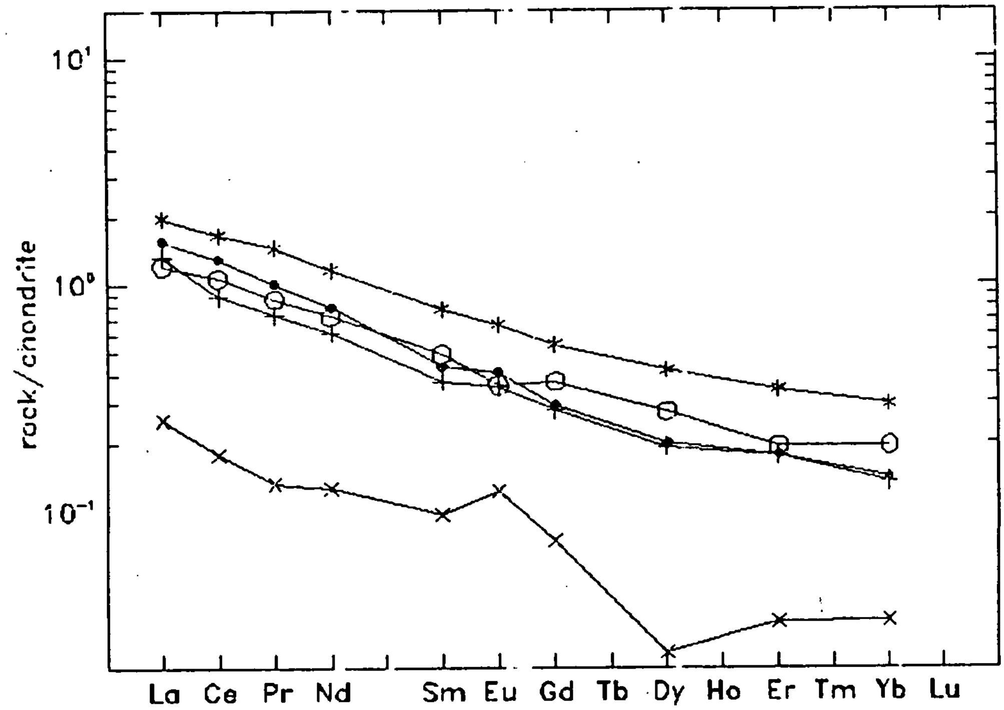


Fig. 2.41 Chondrite normalized REE pattern for andesites, dacites and rhyolites from the northern and central provinces [69340 (•), 69347 (+), 69306 (✱), 69307 (o) and 69361 (x)].

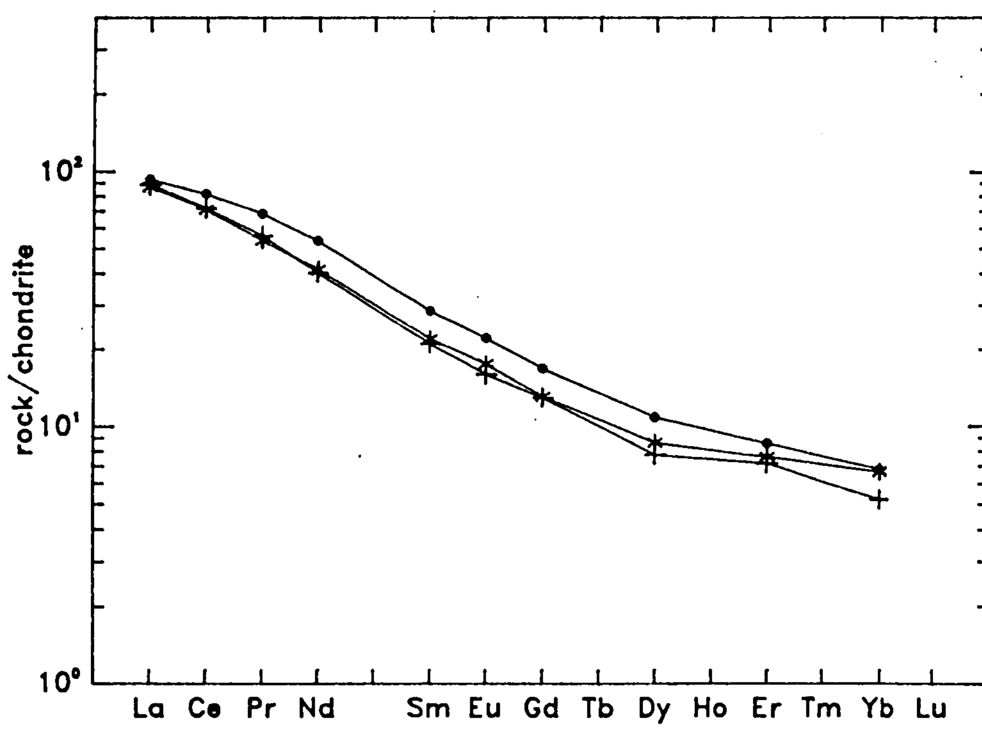


Fig. 2.42 Chondrite normalized REE pattern for andesites and dacites from the southern province [69301 (•), 69344 (+) and 69342 (✱)].

central province are similar to the andesites from the north. However, there are differences in the enriched elements: the central province rocks are lower or about 30-40 to 3.4-4.8 times chondrite, respectively. Unlike the northern province pattern, the central province pattern has a slightly positive and negative Eu anomaly. The andesites and dacites REE pattern from the southern province (Fig. 2.42) also slopes down from La to Yb. It is different from the other pattern, by the steeper slope of LREE of about 5.3-90 times chondrite. This pattern resembles the typical arc andesites (Taylor, 1977) and the high-K suites of Gill (1981, p.128). The rhyolite (69361) pattern (Fig. 2.41) is similar to that of andesites and dacites from the central province (except for the Dy element). There is a positive Eu anomaly. This pattern is similar to the silicic trondhjeimites reported by Cullers & Graf (1984).

2.6 CONCLUSIONS

This petrological investigation of the subvolcanic and volcanic rocks from Central West Kalimantan has reached the following conclusions:

1. **General** Their mineralogical characteristics show that the rocks from CWK are typical orogenic volcanics. Zoning in plagioclase, clinopyroxene and hornblende phenocrysts and the presence of plagioclase xenocrysts and xenoliths of basic igneous rocks in the dacites, suggest that magma mixing and contamination of dacitic magma has occurred. The compositional variations show that source fractionating might have also occurred.

Pyroxene thermometry suggests crystallization temperatures ranging from 948-1211^{o}C for the pyroxenes of basalts, 955-1170^{o}C for andesites, and 972-1091^{o}C for the dacites. The temperature and log fO_2 at closure of the Fe-Ti oxides is 625-765^{o}C and -18 to -13.5 for the basalts, 800-950^{o}C and -14 to -10.8 for the dacites, and 640-690^{o}C and -18.3 to -16.3 for the rhyolites.

The northern province basalts are quartz tholeiites, while the southern province basalts are mostly olivine tholeiites with one unusual mugearitic differentiate.

The andesites and dacites are calcalkaline, and the rhyolites calcalkaline, except for one alkaline granite. The REE pattern of a quartz tholeiite suggests that this rock has a different source than the basalts to the south, because the andesites and dacites from the three provinces can also be distinguished using their trace element concentrations. The andesites and dacites from the northern province have a negative Sr anomaly, while the central and southern province groups have positive and no Sr anomaly respectively. The northern province rocks have apparently plagioclase fractionation, whereas in the central province rocks, plagioclase accumulation has occurred. The andesites and dacites from the northern and central provinces do not display very marked LREE enrichment, unlike the andesites and the dacites from the southern province, where LREE/HREE are high. The spidergrams and REE patterns also suggest that the andesites and the dacites have the same source signature, but the samples considered here are not consanguinous. The alkaline granite has some geochemical resemblance to the ignimbrite tuffs and the porphyritic rhyolites, suggesting a similar origin. The REE patterns of the mudstone xenolith-bearing rhyolites have a trondhjemitic character. Based on their geochemical characteristics the type 1 rhyolites are grouped with the andesites and dacites of the central province, whereas the magmatic affinity of the type 2 rhyolites is similar to the andesites and dacites of the southern province.

There is a zonation in potassium, with the southern province rocks having higher K_2O contents than the northern province at 57 wt% SiO_2.

2. **Tectonic settings of the igneous rocks.** The chemistry of most of the CWK volcanics is typical of arc volcanics. These may be the result of a southeastward subduction zone, as proposed by many geologists (see Section 1.2.2). Dacites are the dominant rock type, while basalts, andesites and rhyolites are less abundant. The K/Ar dating and geological data have confirmed that the magmatic activity commenced first in the southern magmatic province. Field relationships have shown that these rocks were intruded into relatively stable regions, within three different country rocks, such as the Ketungau sedimentary basin in the north, the Melawi sedimentary basin in the centre, and the granite and metamorphic rocks in the south. All the volcanics are strongly evolved and contain evidence of contamination either from wall rocks or magma mixing.

The spidergrams demonstrate graphically the differences between the volcanics from the three different provinces (see Section 1.2.2). The northern province magmatic affinity has a similar profile to spidergrams of Thompson et al. (1983, in Hawkesworth & Norry, 1983, p.184). They postulated that this type of profile can be produced by the addition of small amounts of sediments into basaltic magma with an ocean island basalt (OIB) spidergram. The central province volcanics have high Sr enrichment similar to the spidergram of Thompson et al. (op. cit.) which may result from contamination of OIB by sialic crust. However, they differ in K-group element contents. The southern province volcanics could not be compared.

3. PETROLOGY OF CRETACEOUS SUBVOLCANIC AND VOLCANIC ROCKS FROM THE WESTERN PART OF WEST KALIMANTAN

3.1 INTRODUCTION

The igneous rocks from the western part of West Kalimantan (WWK) (Fig. 1.1 and 1.4) were sampled by IAGMP. There are less data from this region, but it appears to be dominated by basalts and andesites. They occur as dykes, plugs and massive tuffs. One sample (69392) deriving from Pulau Laut (Singkawang sheet - Fig. 1.1) has been dated (K/Ar) at ~121 m.y. They are distinguished from the Tertiary subvolcanic and volcanic rocks from CWK by their higher degree of metamorphism (up to greenschist facies). The basalts are characterised by the presence of quartz xenocrysts and biotite. The tuffs are characterised by the abundance of xenoliths and xenocrysts. All the rocks contain metamorphic minerals, such as actinolite, chlorite and carbonate.

Six rock samples have been analysed. They fall in the basalt, basaltic andesite, andesite and dacite field of the TAS diagram (Fig. 1.5).

3.2 PETROGRAPHY AND MINERAL CHEMISTRY

Table 3.2 shows representative modal compositions of the rocks, and Table 3.1 summarizes their petrography.

The basalts are fine grained, phaneric and aphanitic rocks, with porphyritic texture, and are black and dark brown in colour. Some samples have amygdaloidal structures and glomeroporphyritic textures. Two types of basalts have been distinguished: type 1 basalts (69381) are made up of phenocrysts of plagioclase, clinopyroxene, magnetite and ilmenite, set in a groundmass of the same composition. Type 2 basalts (69382 and 69393) are plagioclase phyric, with groundmasses composed of plagioclase and biotite. Mineral descriptions of both types of basalts follow.

The plagioclases (maximum 1.8 x 0.5 mm) are subhedral to anhedral, and range in composition from An_{42} to An_{93} for phenocrysts, An_{45} to An_{79} for groundmass. The zoned plagioclase phenocrysts range from An91(core) to An60 (rim) (Fig. 3.1, Appendix 2). The clinopyroxenes are subhedral, and partly intergrown with actinolite. They are augite (Fig. 3.2; Appendix 2), with an Mg value of 77. The clinopyroxenes are non-alkaline type (Fig. 3.3a,b). The biotite flakes have Mg values of 64-60, and have high TiO_2 contents (4 wt%) (Appendix 2). The magnetite and ilmenite exsolution lamellae have a closure temperature of 1040°C and log fO_2 of -9.8.

TABLE 3.1 SUMMARY OF PETROGRAPHY

ROCK TYPE	Phenocryst										Groundmass									
	pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol	pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol
Basalt	+	-	+E	+	-	-	-	-	-	-	+	-	-	+	-	-	+	+	-	-
Andesite	+	-	-	+	-	-	-	-	-	-	+	-	+	+	-	-	-	+	-	-
Dacite	+	-	-	-	-	+	-	-	-	-	+	+	+	-	-	+	-	+	-	-

TABLE 3.2 MODAL COMPOSITION OF BASALTS

Sample no.	pl phe.	pl lath	cpx	act	gr(act+ pl+ep)	qtz	cpx lath	sec./vesicular	biot	mg
69384	3.62	12.82	9.38	-	57.21	-	11.10	2.85	-	3.03
69381	48.42	7.13	8.08	4.42	26.14	1.45	-	-	-	4.36
69383	18.30	35.14	-	25.55	13.45	-	0.43	-	2.33	4.79
69382	16.24	28.88	-	49.77	-	0.26	-	0.98	1.19	2.66

Explanation: ep = epidote, sec = secondary minerals, phe = phenocryst.
Other abbreviations as in Table 2.1.

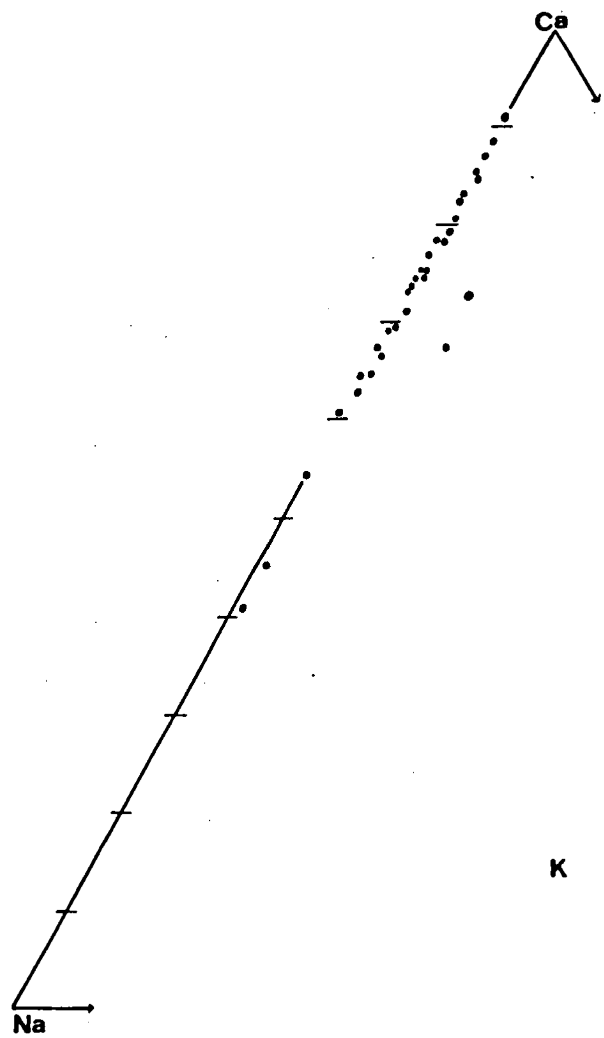


Fig. 3.1 Plagioclase compositional variation.

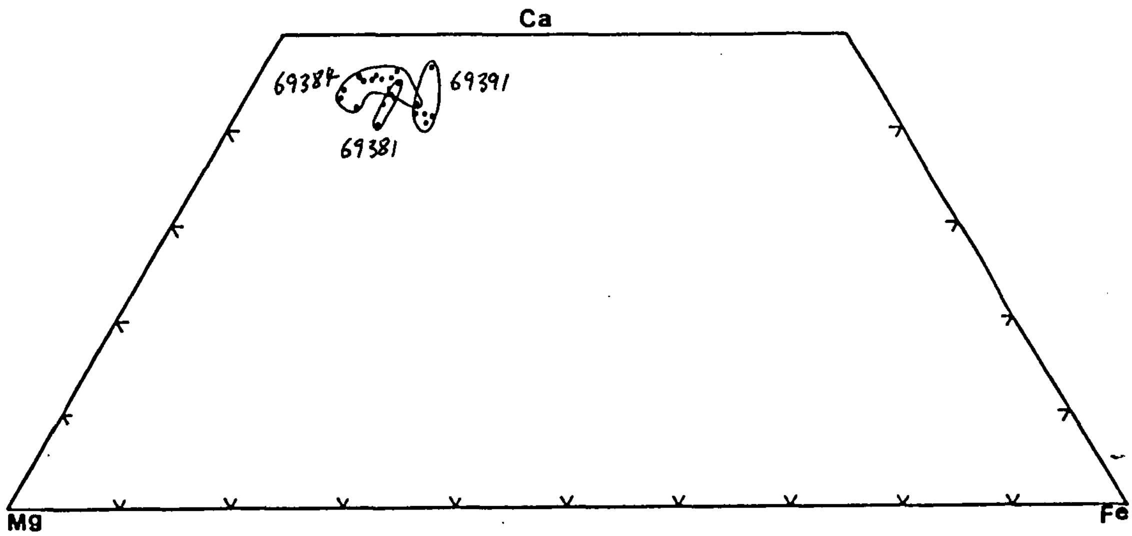


Fig. 3.2 Clinopyroxene compositional variation. Each field denotes a different sample.

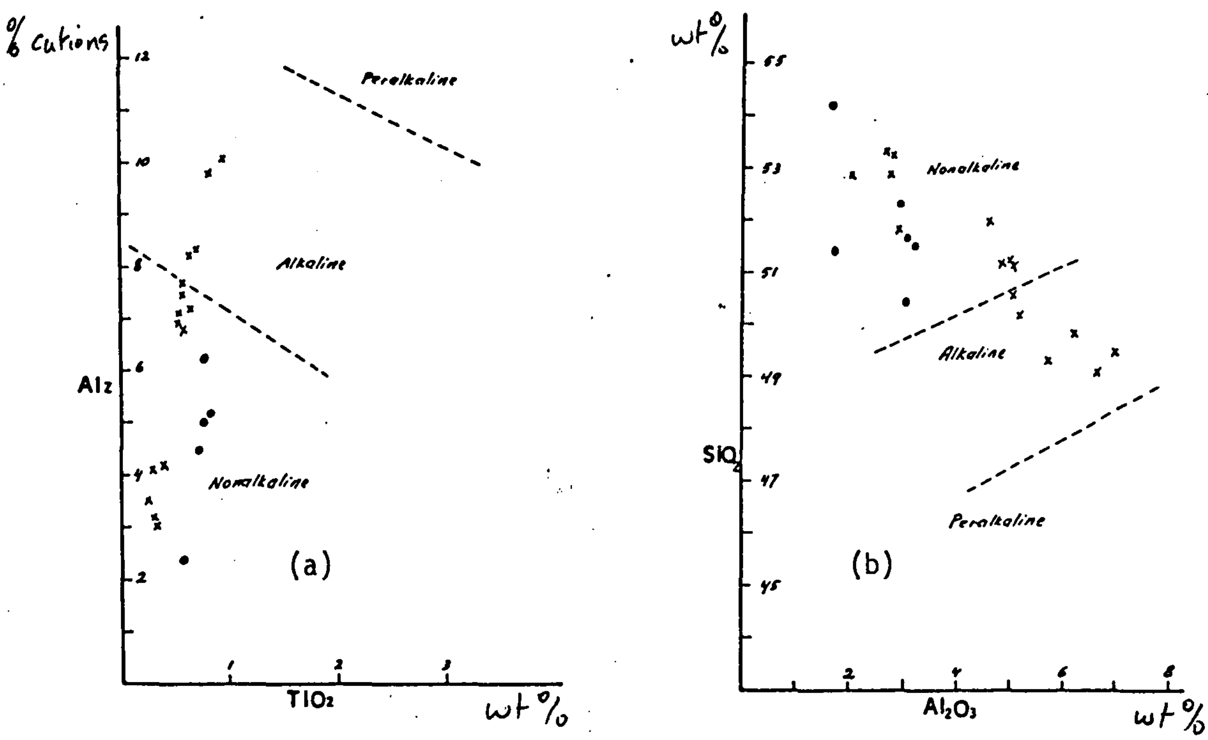


Fig. 3.3 Plot of TiO_2 - Al_z (a) and Al_2O_3 - SiO_2(b) for clinopyroxene in basalts [69381 (•) and 69382 (×)]. Fields after Lebas (1962).

$Al_z = \frac{(100 \times \text{tetrahedral Al})}{2}$ based on 6 O=

The andesites, including basaltic andesites (69384 and 69391) are porphyritic and amygdaloidal. The phenocrysts are of clinopyroxene, plagioclase and magnetite; while the groundmass has all these minerals. The plagioclases (maximum 7 x 4 mm) are subhedral, prismatic, and include clinopyroxene inclusions. The plagioclase compositions range from An_{67} to An_{83} (Fig. 3.1; Appendix 2). The clinopyroxene (maximum 6 x 5 mm) are euhedral to anhedral, with hourglass structures and zoning. They are mostly augite, some endiopside and salite, with an Mg value of 70-85 (Fig. 3.2; Appendix 2). The zonation is reverse, with Mg values of 73 (core) to 81 (rim). The clinopyroxene is nonalkaline to alkaline type (Fig. 3.3a,b).

The dacites comprise phenocrysts of plagioclase and hornblende, set in a groundmass of plagioclase, quartz, K-feldspar and magnetite.

The lithic tuffs were not analysed chemically. They are dark grey, fine grained, porphyritic, with volcanic fragments in some rocks. They are andesitic in composition. The phenocrysts are plagioclase, quartz, magnetite and pyroxene, while the groundmass is composed of devitrified glass, quartz, plagioclase and magnetite.

3.3 GEOCHEMISTRY

3.3.1 Major Elements

The major element chemical compositions and CIPW normative compositions of the rocks are shown in Table 3.3. They differ from the CWK basalts in their higher SiO_2 and lower TiO_2 and P_2O_5 contents. Their Mg values range from 47.7 to 57.3, like the basalts from CWK. The sample 69381 is lower in K_2O, and higher in TiO_2 and P_2O_5 contents than the other basalts. The basalts are olivine to quartz normative. They are classified as olivine tholeiite and quartz tholeiite, or subalkaline (Yoder & Tilley, 1962; Chayes, 1966).

On the AFM diagram (Fig. 3.4) the rocks show a mild iron-enrichment trend (Irvine & Barager, 1971).

3.3.2 Trace Element and REE

The trace element analyses are presented in Table 3.4. In general, the trace element characteristics are similar to the rocks from CWK, except for elements La and Zr. The La and Zr contents of the WWK rocks are lower than the CWK rocks. The low content of Cr and Ni in sample 69383 correlates with the absence of mafic phases in this rock.

On the Ti-Zr-Y diagram (Fig. 3.5) the basalts fall in the OFB field, on the Ti-Zr diagram (Fig. 3.6) in the OFB/LKT/CAB field, and on the Ti-Nb-Zr diagram (Fig. 3.7) in the N-type MORB field, but these all reflect their low Zr contents.

Table 3.3 Major chemical analyses and CIPW norms.

	69383	69384	69382	69381	69391	69392
SiO_2	50.82	50.83	51.52	51.65	55.96	63.41
TiO_2	0.77	0.76	0.71	0.92	0.63	0.44
Al_2O_3	19.91	16.58	17.27	17.76	17.26	17.11
Fe_2O_3	9.30	8.98	10.10	9.70	9.37	5.48
MnO	0.17	0.15	0.19	0.16	0.17	0.15
MgO	4.23	6.83	6.41	6.70	4.31	1.54
CaO	9.75	9.96	10.35	9.19	8.49	5.12
Na_2O	3.94	2.18	2.12	3.45	2.44	4.32
K_2O	0.44	0.70	0.23	0.11	0.71	1.23
P_2O_5	0.21	0.17	0.20	0.11	0.14	0.28
LOI	0.80	2.32	0.77	0.28	0.41	0.92
Total	100.34	99.46	99.87	100.03	99.89	100.00
Q		2.35	3.88		12.43	17.80
C						0.04
Or	2.60	4.14	1.36	0.65	1.0	7.27
Ab	33.34	18.44	17.94	29.19	20.64	36.55
An	35.35	33.39	36.93	32.66	35.65	23.57
Di	9.69	12.19	10.78	10.01	4.62	
Hy	4.85	22.68	24.02	19.65	20.87	11.08
Ol	9.58			3.31		
Mt	1.35	1.30	1.46	1.41	1.36	0.79
Il	1.46	1.44	1.35	1.75	1.20	0.84
Ap	0.50	0.40	0.47	0.26	0.33	0.66
Mg value	47.69	50.67	54.82	50.67	48.59	34.72

Table 3.4 Trace element analyses.

	69383	69384	69382	69381	69391	69392
Rb	7	33	7	3	18	30
Ba	151	213	138	139	307	419
Sr	793	588	487	386	431	560
La	14	8	7	4	5	12
Ce	31	21	19	11	12	28
Pr			2.82	1.60		
Nd	23	15	13	8	9	17
Sm			2.82	2.42		
Eu			0.95	0.95		
Gd			2.85	3.23		
Dy			3.25	3.98		
Er			1.98	2.69		
Yb			1.76	2.45		
Y	21	21	20	23	19	23
Zr	55	63	47	74	38	67
Nb	1	2	2	1	2	2
Sc	36	34	42	30	39	17
V	273	257	287	191	258	46
Cr	40	187	155	160	45	2
Ni	16	41	60	89	16	1
K/Rb	529	181	273	304	327	343

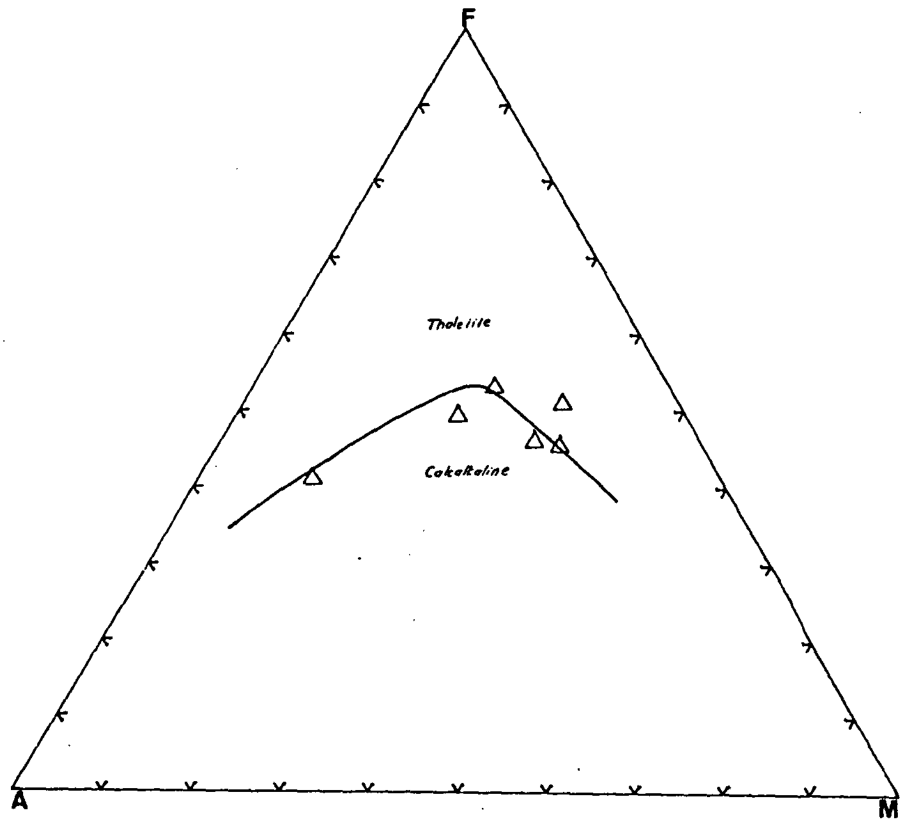


Fig. 3.4 AFM diagram (after Irvine & Baragar, 1971).

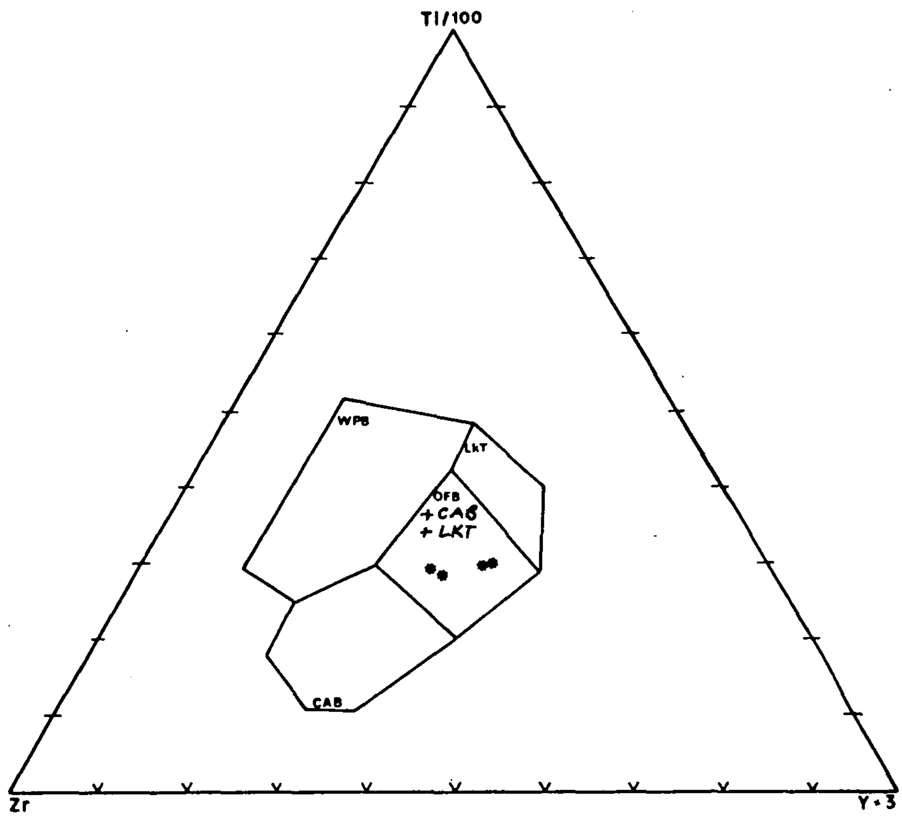


Fig. 3.5 Discrimination digram using Zr, Ti and Y for basalts (after Pearce & Cann, 1973). Fields as in Fig. 2.21.

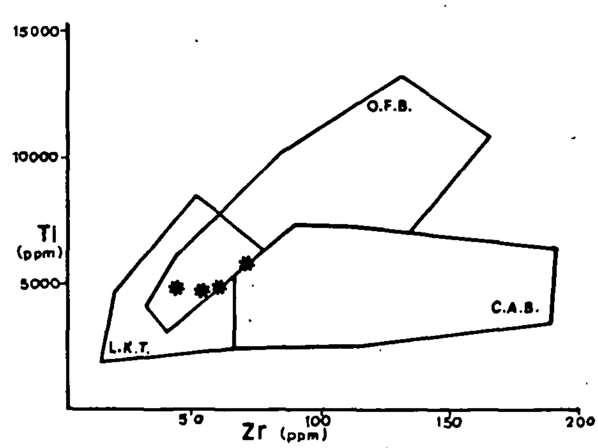


Fig. 3.6 Discrimination diagram using Ti and Zr for basalts (after Pearce & Cann, 1973). Fields as in Fig. 2.21.

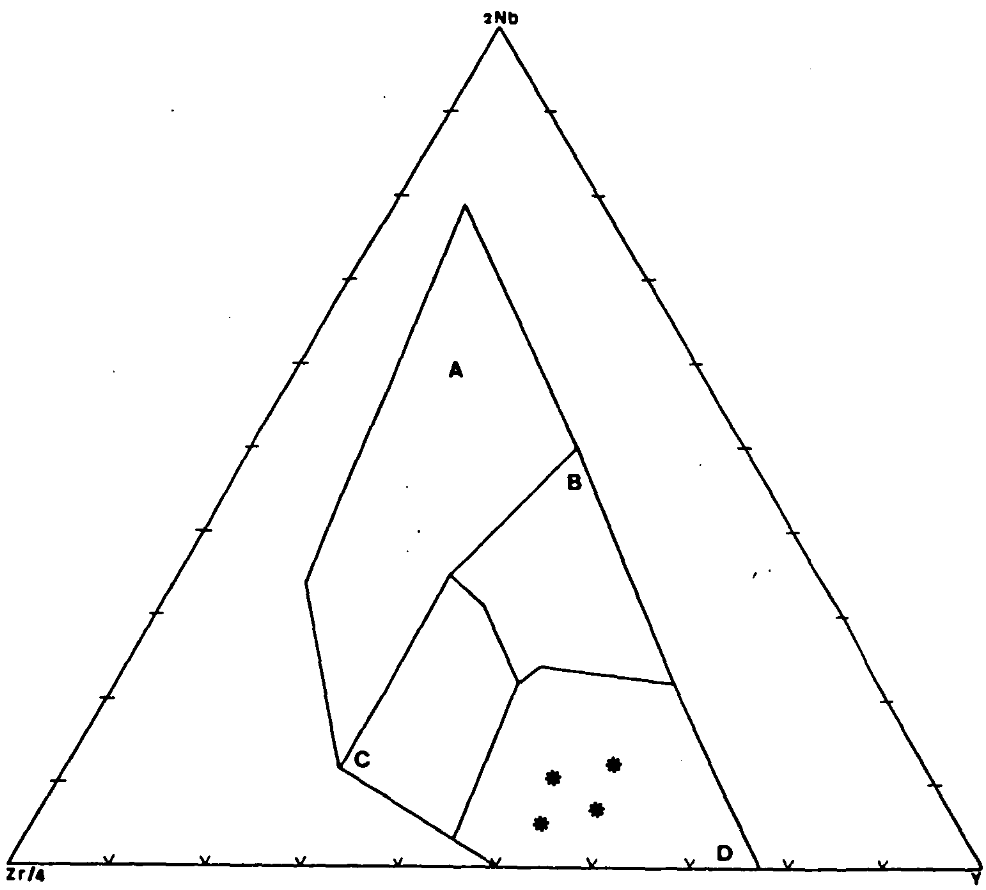
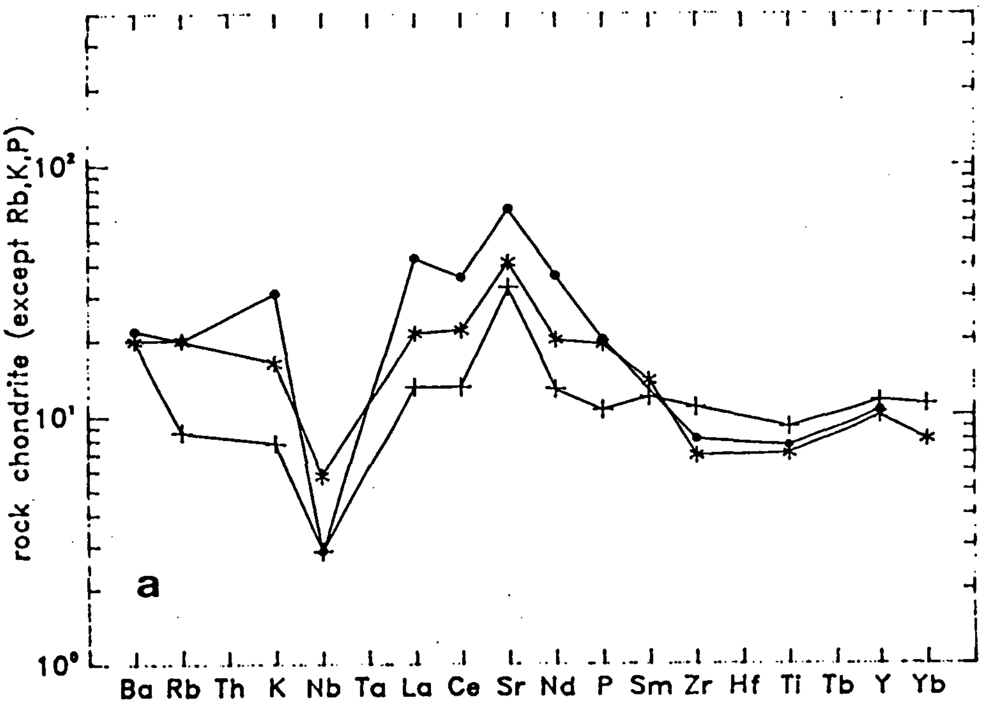


Fig. 3.7 Discrimination diagram using Zr, Nb and Y. Fields as in Fig. 2.23.



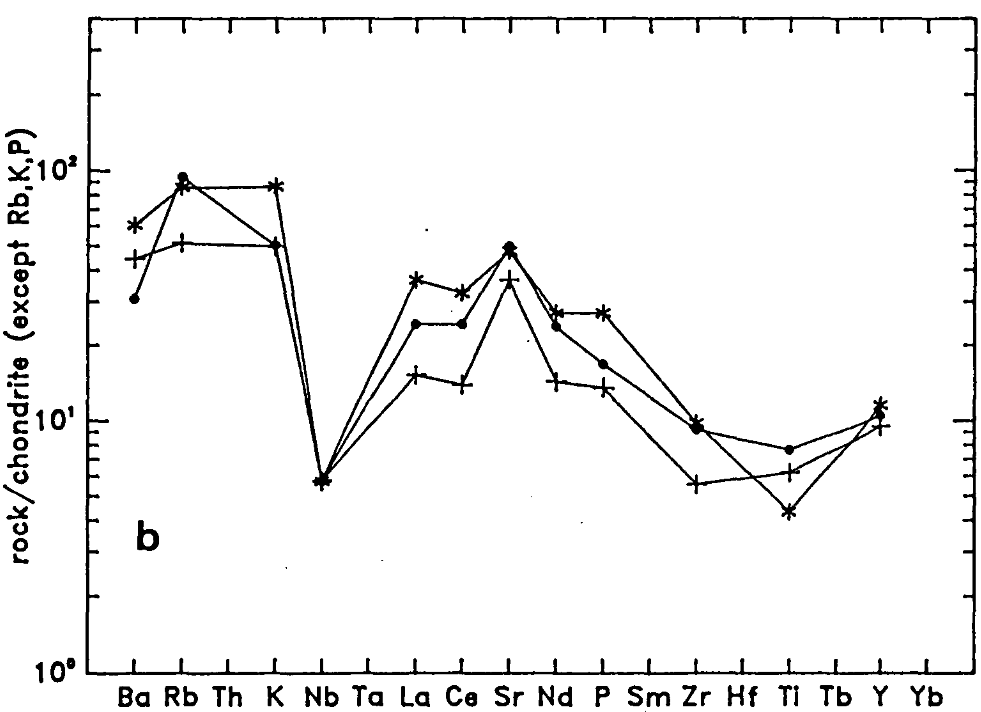


Fig. 3.8 (a) Chondrite normalized comparison diagram for basalts [69383 (•), 69381 (+) and 69382 (✳)]. (b) diagram for andesites [69384 (•), 69391 (+) and 69392 (✳)].

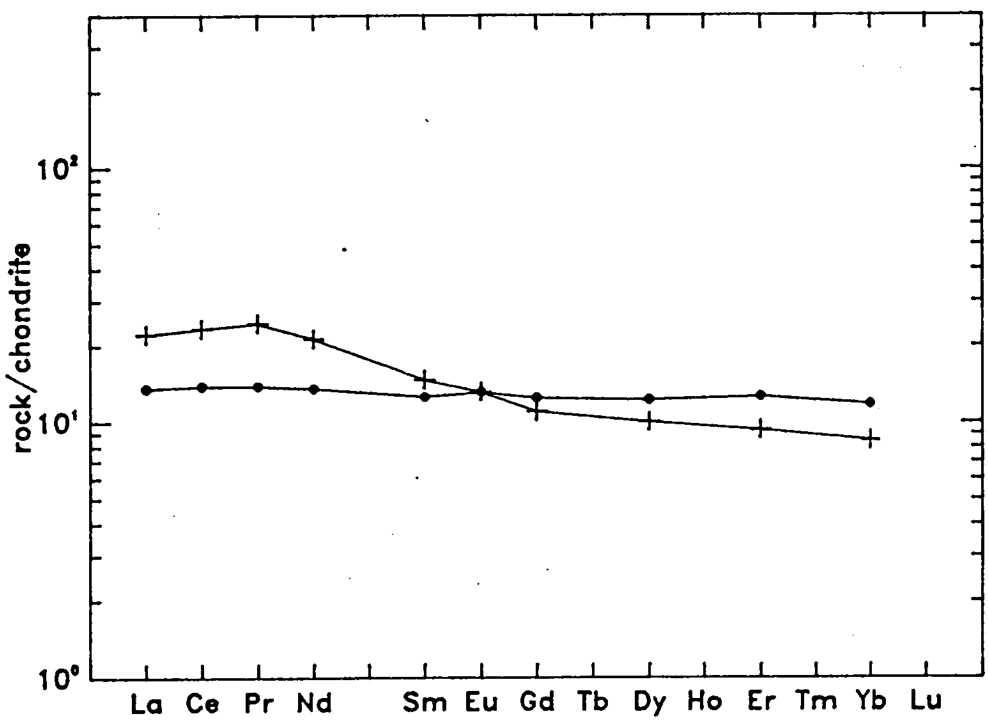


Fig. 3.9 Chondrite normalized REE pattern for basalts [69381 (•) and 69382 (+)].

The spidergrams (Fig. 3.8) display similar patterns in all the Cretaceous rocks analysed. They are typical of arc volcanics (Varne & Foden, 1986). The andesites and dacites have higher abundances of K-group elements compared to the basalts. The andesites and dacites from the WWK region have patterns similar to the patterns of andesites and dacites from the CWK region.

REE analyses of the rocks are given in Table 3.4. Chondrite normalized abundance patterns of the rocks are given in Fig. 3.9. Sample 69381 has a flat REE pattern, like some MORB basalts (Baker, 1973). The lack of depletion in the HREE suggests the absence of garnet in the petrogenesis of this rock. Sample 69382 has a smooth HREE enrichment with very weak positive Eu anomaly.

3.4 CONCLUSIONS

The rocks from the WWB region petrographically consists of biotite-plagioclase basalts, clinopyroxene-plagioclase basalts, clinopyroxene-plagioclase basaltic andesites, hornblende-plagioclase phyric dacites, and lithic tuffs. They have been metamorphosed to greenschist facies. The basalts have the chemical and normative compositions of olivine and quartz tholeiites, although all have quartz xenocrysts. The tuffs contain andesitic and dacitic xenoliths. The basalts have higher SiO_2 and lower TiO_2, P_2O_5, La and Zr contents than the Tertiary subvolcanic and volcanic rocks from the CWK region (see Chapter 2). The spidergrams of all the rocks have positive Sr anomalies, suggesting plagioclase accumulation. The rocks are characterised by low Nb abundances relative to the REE and have low TiO_2 contents typical of an island-arc volcanic association (Varne & Foden, 1986; Baker, 1983). In the Pearce & Cann (1973) discrimination diagram, they fall in the field of volcanic-arc basalts (low-K tholeiite). The flat REE patterns could be found in both MORB and island-arc tholeiitic suites, but the low TiO_2 and Nb contents are distinctly different from typical MORB and confirm an island-arc association.

4. PETROLOGY OF QUATERNARY LAVAS FROM MOUNT NIUT

4.1 INTRODUCTION

The best known Quaternary volcanism in Kalimantan is the Mt Niut (Fig. 4.1). Rutten (1927) reported that the volcano was active in Quaternary time and became extinct in the Recent. Mt Niut retains a well formed cone shape. The highest point of the volcano is 1701 m. The main products of this volcano are lava flows comprising basaltic andesites and trachybasalts (Fig. 1.5), while the cone itself is made up of andesites (Rutten, 1927). The flows have filled valleys up to 20 km from the cone, mainly to its west. These volcanics erupted through Jurassic sediments (Fig. 1.2).

Katili (1971), in his palaeotectonic scheme for the evolution of the Sundaland region, postulated that the Mt Niut basalt flows are due to back-arc activity as a result of Late Cainozoic subduction along the Java Trench.

4.2 PETROGRAPHY AND MINERALOGY

Five representative samples were selected for detailed study. Tables 4.1 and 4.2 present petrographic and modal data. These rocks are black vesicular or amygdaloidal.

The basaltic andesites are hypocrystalline, containing dark brown devitrified glass. They may be divided into two groups: orthopyroxene-bearing basaltic andesites and clinopyroxene-bearing basaltic andesites.

One rock contains orthopyroxenes (69396). This rock consists of plagioclase and orthopyroxene set in a groundmass of the same phases plus olivine, with interstitial glass and abundant needles of magnetite. The orthopyroxene grains (maximum 0.7 x 2.7 mm) are subhedral, some zoned. Their margins are partly resorbed and olivine crystallized as a result of this reaction. The crystals are normally zoned, i.e. Mg value ranges from 79 (core) to 71 (rim), while the microphenocrysts have a composition of Mg value 71 (Fig. 4.3, Appendix 2). The olivines (maximum 0.5 x 0.4 mm) are anhedral. Some crystals enclose plagioclase laths. The olivine has a narrow compositional range (Fo_{65-66}) (Fig. 4.3, Appendix 2).

The plagioclase grains (maximum 1.8 x 0.9 mm) are anhedral to subhedral. Some are embayed with glass, and have orthopyroxene and plagioclase inclusions, suggesting equilibrium with the melt. They have oscillatory zoned rims and simple zoned cores. The plagioclase phenocrysts have normal zoning, i.e. An_{58} (core) to An_{55} (rim), while the plagioclase

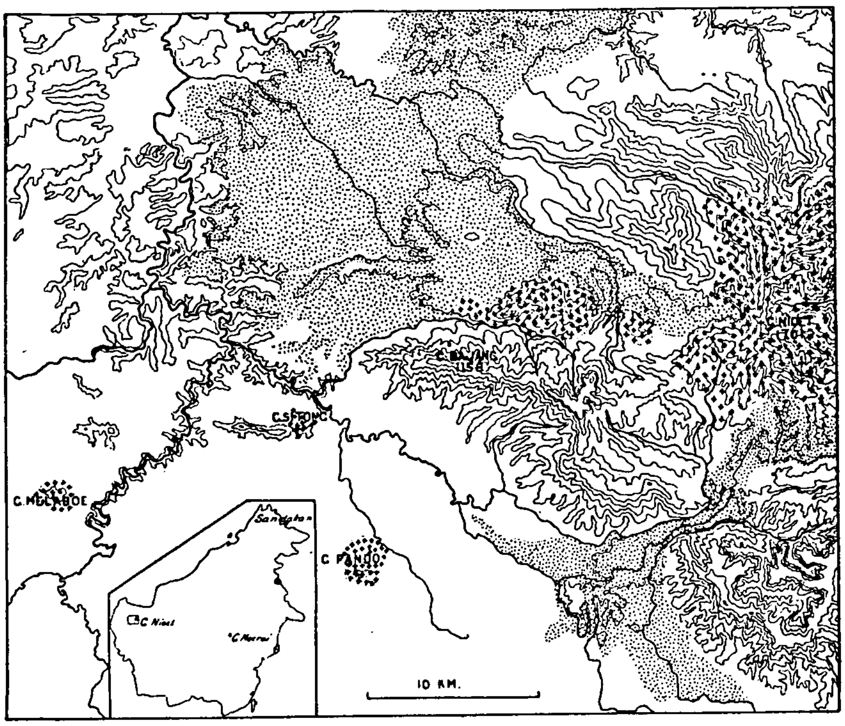


Fig. 4.1 Rock distribution of the Mt Niut volcano. Dots are lava flows with basaltic composition. Pluses are cone of volcano with andesitic composition (after Rutten, 1927).

TABLE 4.1 SUMMARY OF PETROGRAPHY

Rock type	Phenocryst										Groundmass									
	pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol	pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol
Trachy basalt	-	+	-	+	-	-	-	-	-	-	-	+	-	+	-	-	-	-	+	-
Basaltic ande site.	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+	-	-	+	-	+

Explanation: op = opaques, xlth = xenolith, gl = glass. Other symbols as in Table 2.1 and 2.2, and 3.1 and 3.2.

TABLE 4.2 MODAL COMPOSITION

Rock type	Sample no.	pl phe	pl lath	opx	cpx	Fe-Ti oxides	ol	gr(gl+ op+chl)	vesicular +chl	xlth	san	chl
Trachy basalt	69396	5.45	22.77	1.19	-	tr	9.38	54.22	3.81	3.19	-	-
Basaltic andesite	69399	4.89	47.46	-	6.94	0.87	15.49	22.86	1.49	-	-	-
,, ,,	69395	-	-	-	14.56	3.17	-	47.04	1.71	-	30.53	2.99

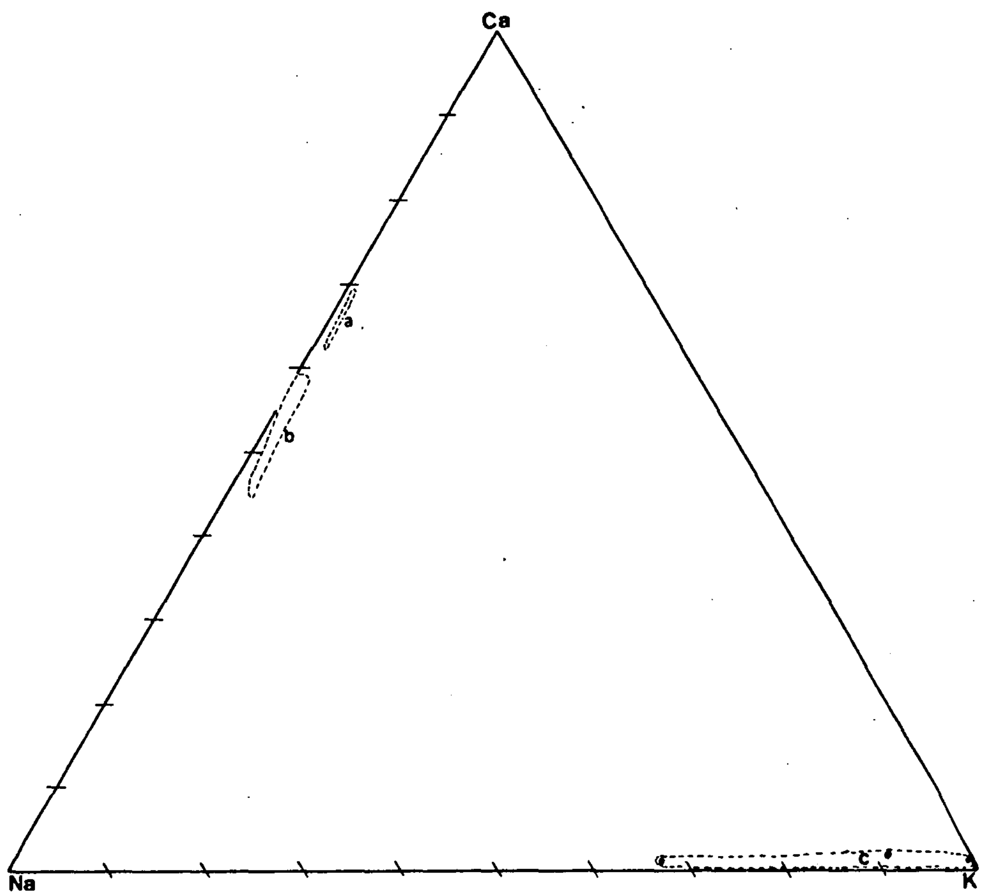


Fig. 4.2 Compositional variations of feldspar. Field a is xenolith, field b is phenocryst and groundmass, and field c is sanidine from trachybasalts.

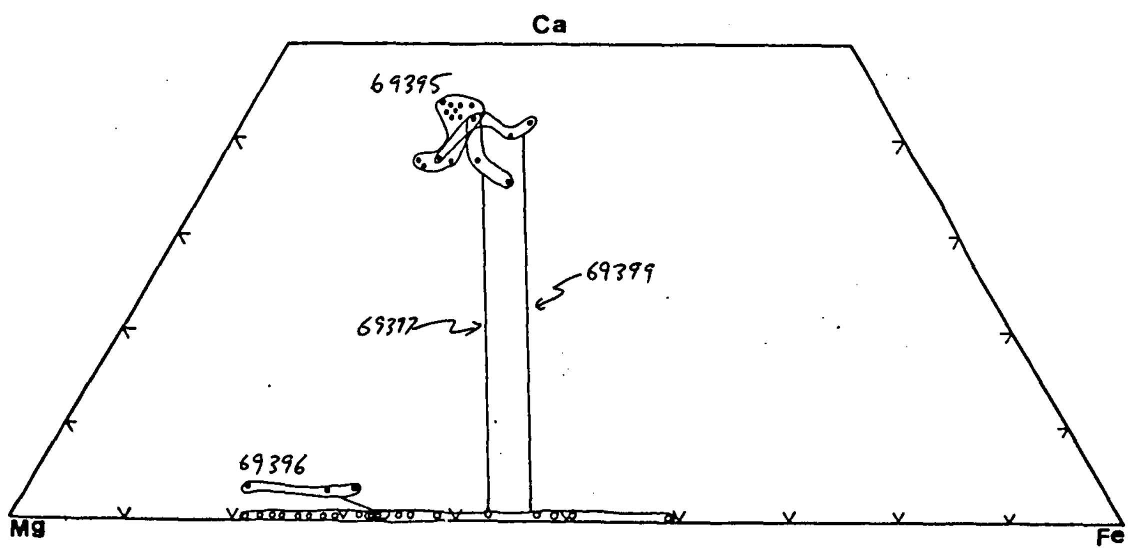


Fig. 4.3 Compositional variation of the pyroxene (•) and olivine (o). Analyses of phases from the same sample are enclosed by a line; tie lines connect fields of coexisting phases.

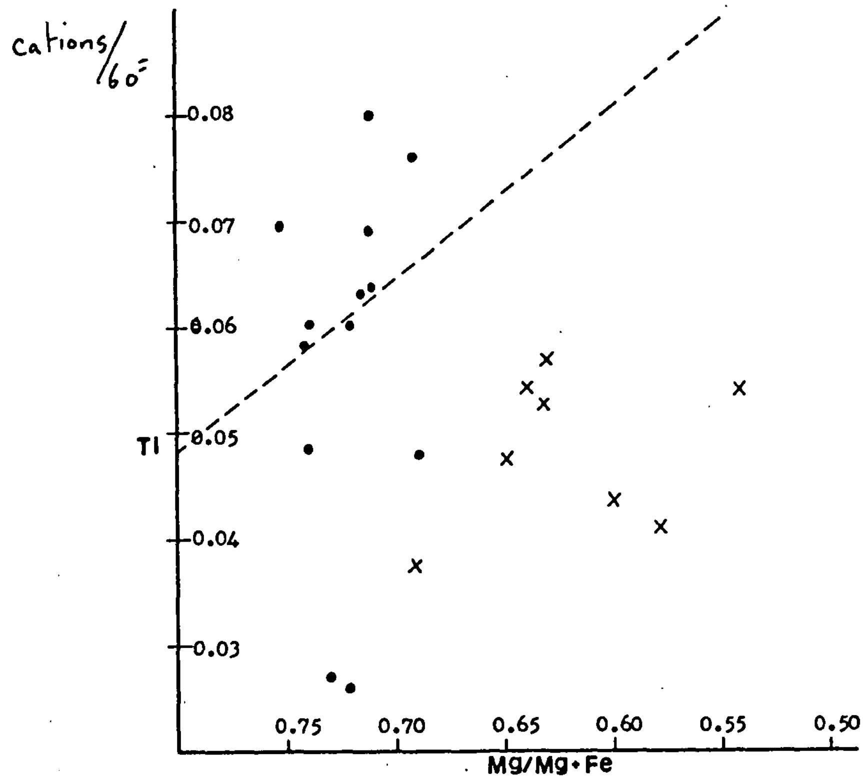


Fig. 4.4 Ti versus Mg/Mg+Fe. The two groups are clinopyroxene in trachybasalts (•) and basaltic andesites (x). The dashed line distinguishes pyroxene from alkali basalt (above the line) and tholeiitic basalts (below the line) (after Schweitzer et al., 1978).

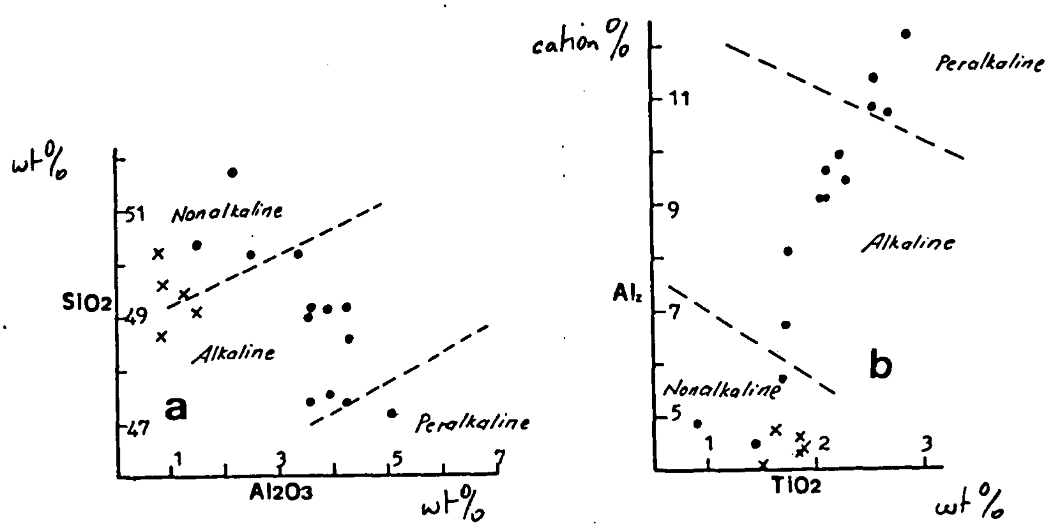


Fig. 4.5 Plot of Al_2O_3 versus SiO_2 (a) and TiO_2 versus Al_z (b) contents for clinopyroxene. Symbols as in Fig. 4.4. Fields from Lebas (1962).

Al_z = (100 x tetrahedral Al)/2 per 6 O=

in the groundmass is An_{50} (Fig. 4.2; Appendix 2). They are unlike the CWK rocks (see Sections 2.2.1-2.2.4) in that crystal zoning is minor and the lavas have very little compositional variation.

The glass inclusions in these plagioclases have the same composition as the glassy matrix (Appendix 2) in which the plagioclase occurred, thus suggesting a cognate origin for the plagioclase. The glassy matrix is andesitic in composition: characteristically high in FeO and TiO_2 and low in MgO contents (Appendix 2). This rock contains two types of xenoliths: cumulate plagioclase including pink spinel and plagioclase, and orthopyroxene rocks with pinkish dark spinel as inclusions.

The plagioclase in the xenoliths (6 x 3 mm) ranges in composition from An_{62} to An_{69} (Fig. 4.2; Appendix 2). The pink spinels are Al-rich (62.4 wt%), with 19 wt% FeO, 15 wt% MgO, 0.40 wt% Cr_2O_3 and 0.40 wt% TiO_2. Their Mg value is 61.4 (Appendix 2).

The other basaltic andesites (69399, 69397 and 69387) are made up of phenocrysts of olivine, and rarely plagioclase, in a groundmass with subophitic to intergranular texture, composed of plagioclase, clinopyroxene, olivine, magnetite and interstitial glass rich in opaques.

The olivines are 2.15 x 0.25 mm in maximum size. A few enclose plagioclase, Cr-spinel, apatite, dark brown glass and glass inclusions. The olivine phenocrysts are normally zoned, i.e. Fo_{77}(core) to Fo_{64} (rim), and rarely Fo_{60} (core) to Fo_{41}(rim) for microphenocrysts (Fig. 4.3; Appendix 2). The plagioclase phenocrysts (0.05 x 0.20 mm) are subhedral, and rarely zoned. A few crystals contain titaniferous magnetite and glass as inclusions. The plagioclase compositions range from An_{47} to An_{60} (Fig. 4.2; Appendix 2). The clinopyroxene microphenocrysts (maximum 0.9 x 0.45 mm) are of augitic composition (Fig. 4.3; Appendix 2) and occur as anhedal grains, with a Mg value of 54 to 65. Its composition is typical of tholeiitic pyroxenes (Schweitzer et al., 1978) (Fig. 4.4) or nonalkaline and just alkaline pyroxenes (Lebas 1962) (Fig. 4.5).

The spinels range from Ti-rich magnetite and Ti-rich and Cr-rich magnetite, to Al-rich chrome spinel (Appendix 2). The Ti-rich magnetite, containing up to 26 wt% TiO_2, is a groundmass phase. The Ti-rich and Cr-rich magnetite contains up to 27 wt% TiO_2 and 18 wt% Cr_2O_3, with 100Cr/(Cr+Al) ranging from 77 to 81 and the Mg value ranging from 20 to 25. It occurs as inclusions in the plagioclase, clinopyroxene and the rim of olivine. The Al-rich Cr-spinel has Cr_2O_3 contents up to 34 wt% and 27 wt% Al_2O_3, with an Mg value of 45, and 100Cr/(Car+Al) is 46. It occurs as inclusions in the middle of the olivine. These are similar in composition to some spinels from back-arc basalts (Dick & Bullen, 1984) (Fig. 4.6).

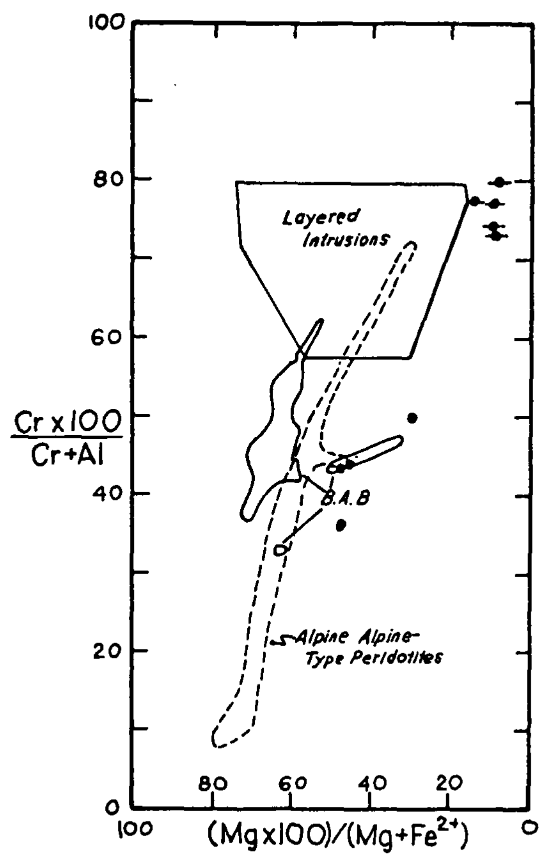


Fig. 4.6 100Cr/(Cr+Al) and 100Mg/(Mg+Fe) variations in spinel inclusions in the middle of olivine phenocrysts (•), and inclusions in rims of olivine phenocrysts, in groundmass, and inclusions in plagioclase (-•-) from Mt Niut basaltic andesites compared with spinels from back-arc basalt (BAB), alpine alpine-type peridotite and layered intrusions (Dick & Bullen 1984).

The glass inclusions in olivine are poor in Al_2O_3 (1.01 wt%), lack FeO, and have extremely high Na_2O (11.39 wt%) (Appendix 2). These are not likely to be original melt compositions and have probably been modified by continual olivine crystallization on the walls of the inclusion. The glassy matrixes are of dacitic composition, with high Al_2O_3 (16.75 wt%), TiO_2 (3.11 wt%) and Na_2O (5.29 wt%) (Appendix 2).

The trachybasalt (69395) comprises phenocrysts of clinopyroxene, sanidine and ilmenite, set in a groundmass of the same mineralogy. It contains abundant pyrite. Amygdales (maximum 0.55 mm) are filled by chlorite, carbonate and acicular crystals in glass. The clinopyroxene (maximum 0.25 x 0.1 mm) is subhedral, with hourglass structure and wavy extinction. The wavy extinction may be due to rapid cooling, suggesting the clinopyroxene crystallized at shallow depths or at the surface (Leung, 1974). The clinopyroxene is augite with Mg values ranging from 64 to 71, typical of alkaline lava pyroxene (Schweitzer et al., 1978 (Fig. 4.4), or distributed throughout the field of Lebas (1962)) (Fig. 4.5a,b). The sanidine grains (maximum 1 x 0.15 mm) are subhedral, long prismatic. They are intergrown with clinopyroxene. The sanidine composition ranges from Or_{66} to Or_{100} (Fig. 4.2, Appendix 2).

4.3 GEOCHEMISTRY

4.3.1 Major Elements

The chemical characteristics of the rocks are shown in Table 4.3. These rocks have low Al_2O_3 (13.9-15.8 wt%) and CaO (7.2-8.0 wt%) and high K_2O (0.8-1.5 wt%) compared with the rocks from CWK and WWK. The TiO_2 contents of these rocks are greater than 1.2 wt%. The Mg value ranges from 37.29 to 52.33. The rock (69395) plotting in the alkaline field of Fig. 4.7 has the lowest Mg value, the lowest SiO_2 contents, and the highest K_2O contents of the five rocks, also plot in the trachybasalt field (Fig. 1.5). The presence of sanidine phenocrysts in this rock also suggests trachybasaltic or shoshonitic affinities.

On the AFM diagram (Fig. 4.8) the Mt Niut lavas show a mild iron enrichment trend.

The CIPW norm calculation of the rocks is shown in Table 4.3. The rocks are olivine and quartz normative. They are classified as subalkaline and one rock (69395) is alkaline in the Chayes diagram or all as olivine tholeiite and quartz tholeiite (Fig. 4.7). These rocks may be recognised from the CWK and WWK by the lower normative anorthite and the higher normative ilmenite and orthoclase. The orthoclase-bearing basaltic andesite has slightly higher contents of SiO_2 and normative quartz.

Table 4.3 Major chemical analyses and CIPW norms.

	69395	69398	69397	69399	69396
SiO_2	46.94	52.67	52.80	53.44	53.70
TiO_2	2.63	1.23	1.30	1.23	1.54
Al_2O_3	13.47	15.58	15.78	16.37	15.24
Fe_2O_3	14.92	11.84	11.58	10.93	11.89
MnO	0.23	0.15	0.15	0.16	0.15
MgO	4.51	6.36	6.33	5.72	5.36
CaO	7.76	7.42	7.53	7.23	7.36
Na_2O	3.64	3.32	3.58	3.45	3.26
K_2O	1.49	0.79	0.79	1.38	0.93
P_2O_5	1.15	0.15	0.15	0.23	0.18
LOI	2.98	0.72	-0.11	-0.04	0.00
Total	99.72	100.23	99.88	100.10	99.61
Q		0.88		0.52	3.75
C					
Or	8.81	4.67	4.67	8.16	5.50
Ab	30.80	28.09	30.29	29.19	27.58
An	16.02	5.28	24.66	25.11	24.21
Di	12.56	8.71	9.67	7.65	9.23
Hy	4.12	26.41	24.55	24.08	23.20
Ol	13.27	0.61			
Mt	2.16	1.72	1.68	1.58	1.72
Il	4.99	2.34	2.47	2.34	2.92
Ap	2.71	0.35	0.35	0.54	0.42
Mg value	37.29	52.33	50.88	50.67	47.48

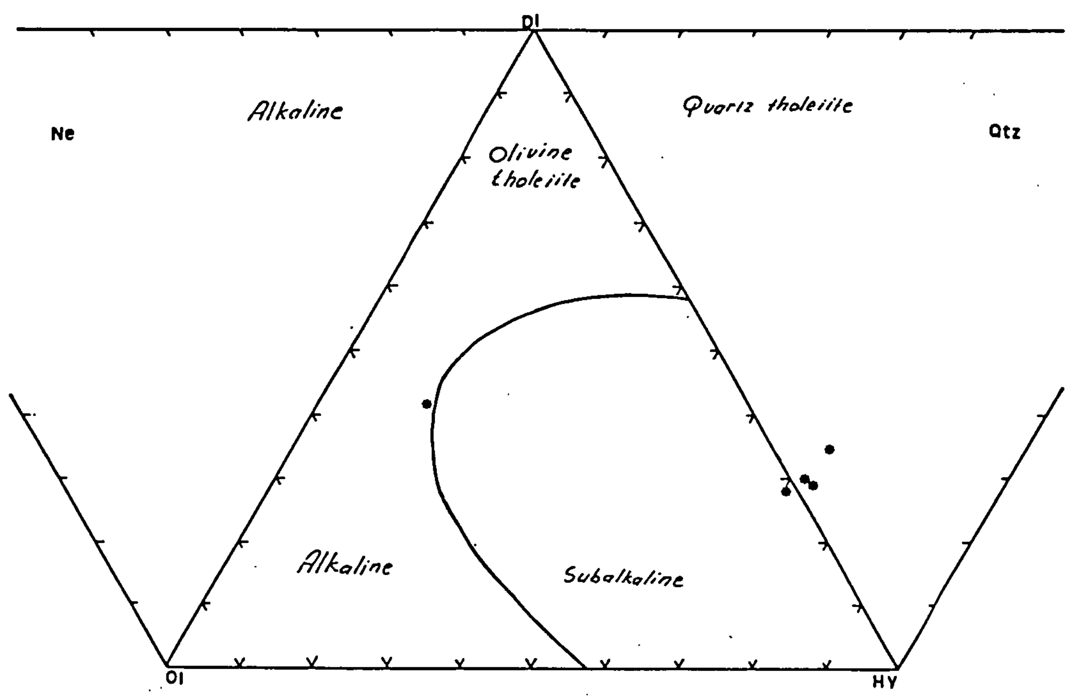


Fig. 4.7 Basalt classification (after Yoder & Tilley (1962) and Chayes (1966)).

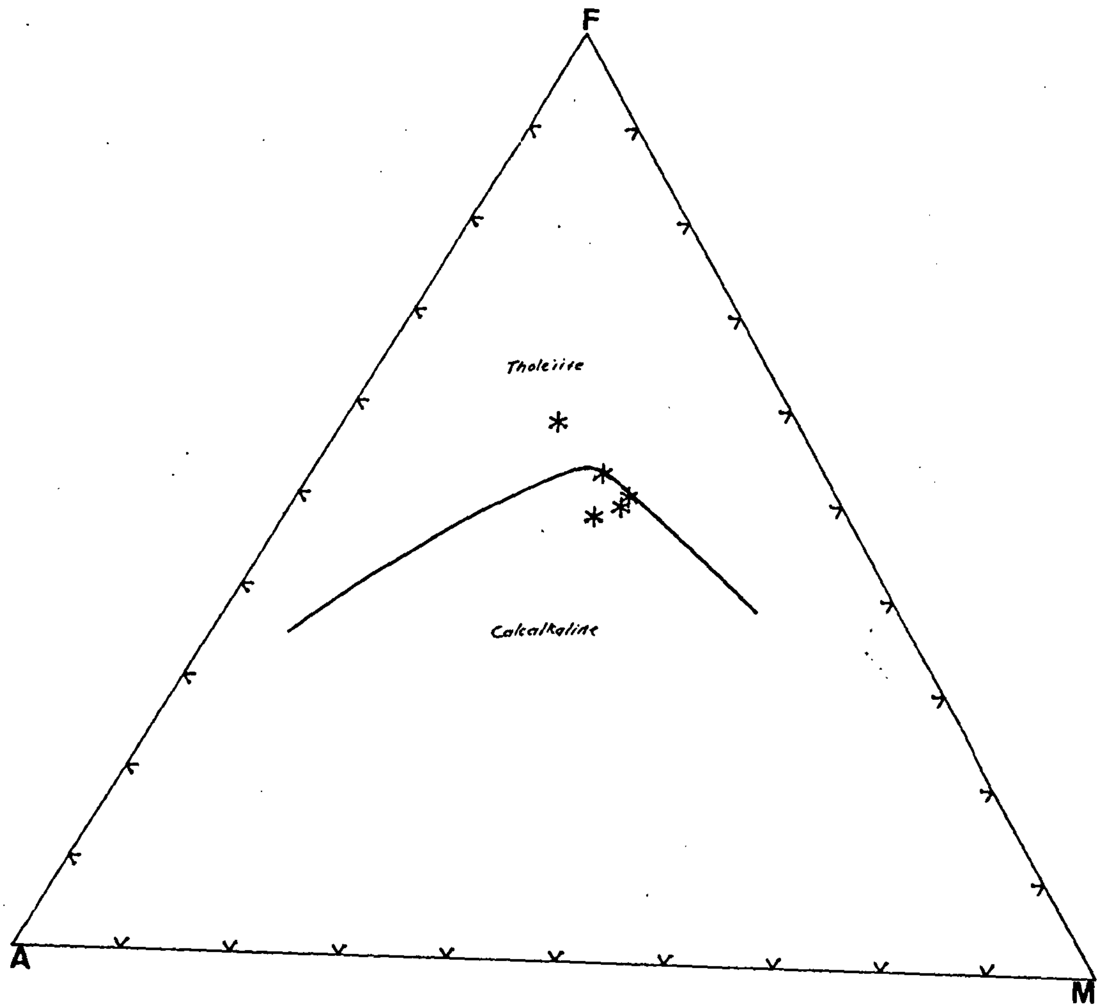


Fig. 4.8 AFM diagram (after Irvine & Baragar, 1971).

4.3.2 Trace Element and REE

The trace element and REE analyses of the rocks are shown in Table 4.4. The basaltic andesites are lower in Sr and V, and higher in Y, Nb and Zr compared with the rocks from CWK and WWK at the same SiO_2 contents. The trachybasalt is extremely high in Ba (903 ppm) and Rb (50 ppm), and has high Y (53 ppm) contents, but low Ni (20 ppm) and Cr (27 ppm) contents. High phosphorus content in the trachybasalt is due to secondary alteration. The K/Rb ratio in the Mt Niut lavas ranges from 256 to 358.

On the Zr-Nb-Y diagram (Fig. 4.9), the rocks are scattered throughout the field. On the Ti-Zr-Y diagram (Fig. 4.10), the rocks fall on the OFB field (except the trachybasalt, falling on the CAB field). On the Ti-Zr diagram (Fig. 4.11), the rocks fall on the OFB field (except the trachybasalt, which is unidentified in this diagram).

The spidergram (Fig. 4.12) shows that the basaltic andesites profile is unlike the arc-volcanics profile (Varne & Foden, 1986). They are rather similar to MORB transition (Le Roex, 1985). They are different in K elements (K, Rb and Ba) to the MORB. The Mt Niut lavas have been enriched in these elements. The trachybasalt has a significantly high trace element enrichment factor (except the Nb contents) compared with the basaltic andesites. This is a Nb-depleted profile. In general, the rocks from Mt Niut have a similar spidergram profile. The high K-element content, which enrich in the upper crust is typical of back-arc basalts (Hawkins, 1977).

The REE, normalized to chondrite (Fig. 4.13), of the three representative samples are very similar. They have a low slope from La down to Yb. The orthopyroxene-bearing basaltic andesite has a slightly steeper slope of HREE and flatter LREE than the others. The trachybasalt has a positive Eu anomaly, which may be due to secondary alteration. The other two samples have a negative Eu anomaly, suggesting plagioclase fractionation.

4.4 CONCLUSIONS

The Mt Niut lavas examined here include one orthopyroxene-plagioclase phyric basaltic andesite, three olivine-clinopyroxene-plagioclase phyric basaltic andesites, and one sanidine-clinopyroxene-bearing trachybasalt. They are commonly vesicular and amygdaloidal. The plagioclase of all the lavas displays very little compositional variation and only a few crystals are zoned. Their compositions are labradoritic. The olivine has a narrow range of composition - Fo_{76-77}. They contain chrome spinel inclusions which are similar in composition to spinels from back-arc basalts. Four

Table 4.4 Trace element analyses.

	69395	69398	69397	69399	69396
Rb	50	21	20	32	29
Ba	903	130	209	197	154
Sr	363	191	196	221	197
La	28	10	9	13	9
Ce	70	18	19	27	25
Pr	8.89			3.09	3.34
Nd	41	12	13	14	14
Sm	8.75			3.34	4.32
Eu	3.67			1.07	1.38
Gd	9.32			4.28	5.35
Du	9.30			4.82	5.68
Er	5.61			2.95	3.26
Yb	5.17			2.68	2.58
Y	53	29	26	28	28
Zr	187	99	100	133	115
Nb	8	11	11	16	10
Sc	35	24	22	23	25
V	329	56	153	143	156
Cr	27	222	215	182	162
Ni	20	196	154	86	116
K/Rb	256	328	312	358	266
Y/Nb	6.6	2.4	2.6	1.8	2.8
Zr/Nb	23.4	9.1	9.0	8.3	11.5
La/Yb	5.42			4.96	

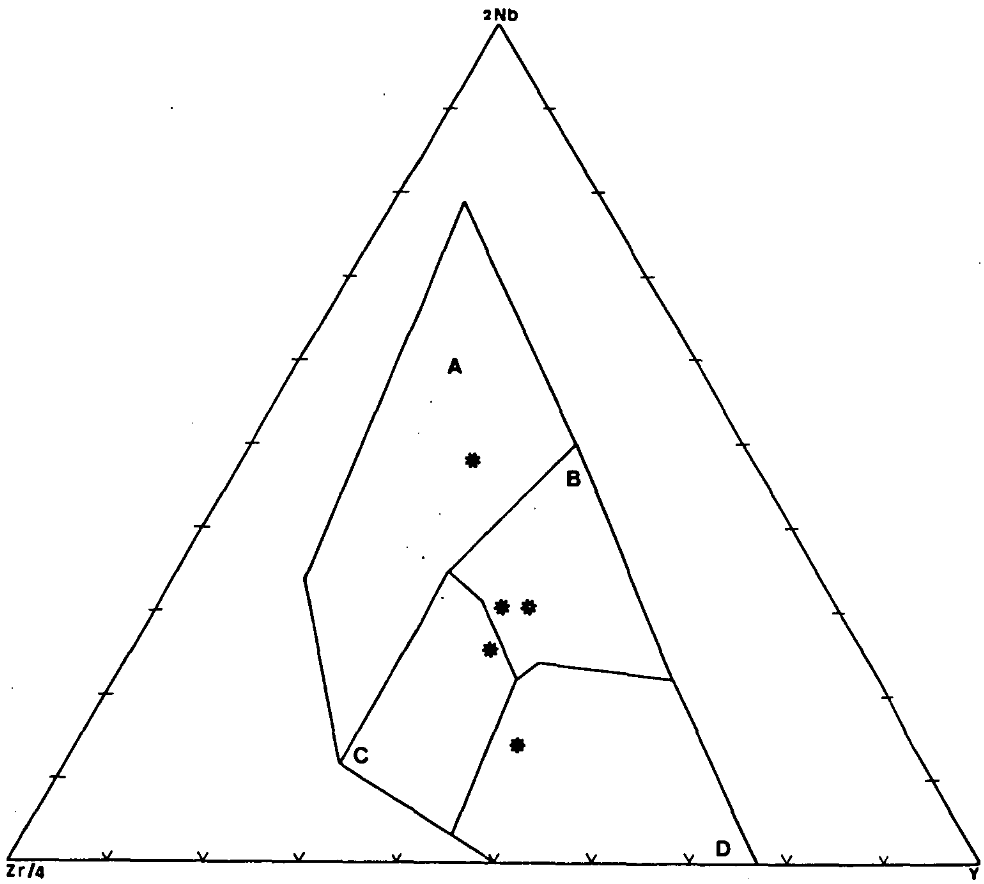


Fig. 4.9 Zr, Nb and Y contents of the rocks from Mt Niut, showing the rocks distributed in all fields. Fields as in Fig. 2.23 (after Meschede, 1986).

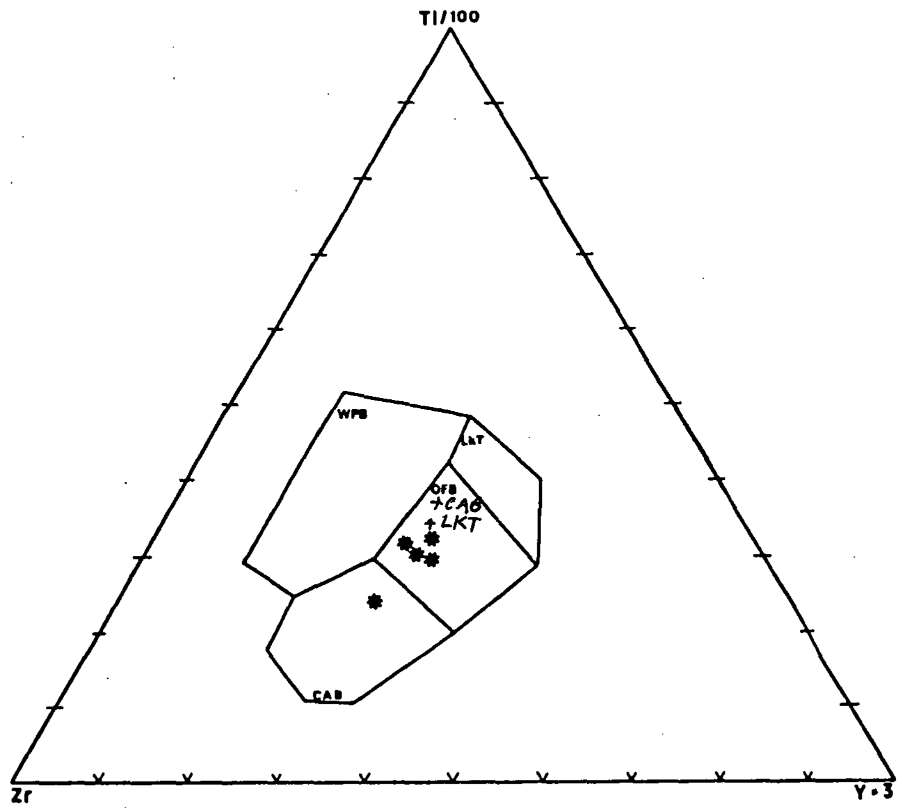


Fig. 4.10 Ti, Zr and Y contents of the rocks from Mt Niut, showing the basaltic andesites fall in the ocean-floor basalt field and the trachybasalt in the calcalkali basalt field. Fields as in Fig. 2.21.

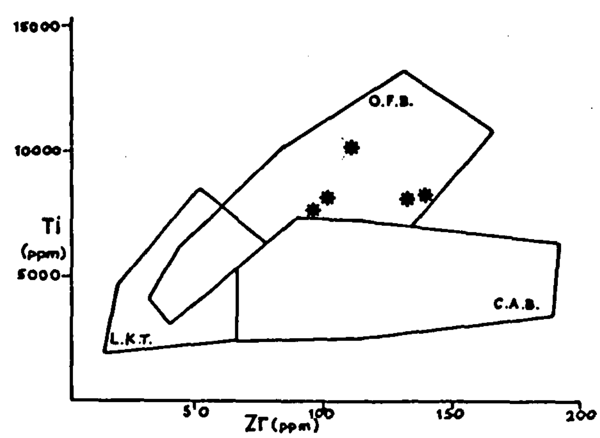


Fig. 4.11 Ti and Zr contents of the rocks from Mt Niut showing that the rocks fall in the ocean-floor basalt field. Field areas as in Fig. 2.21.

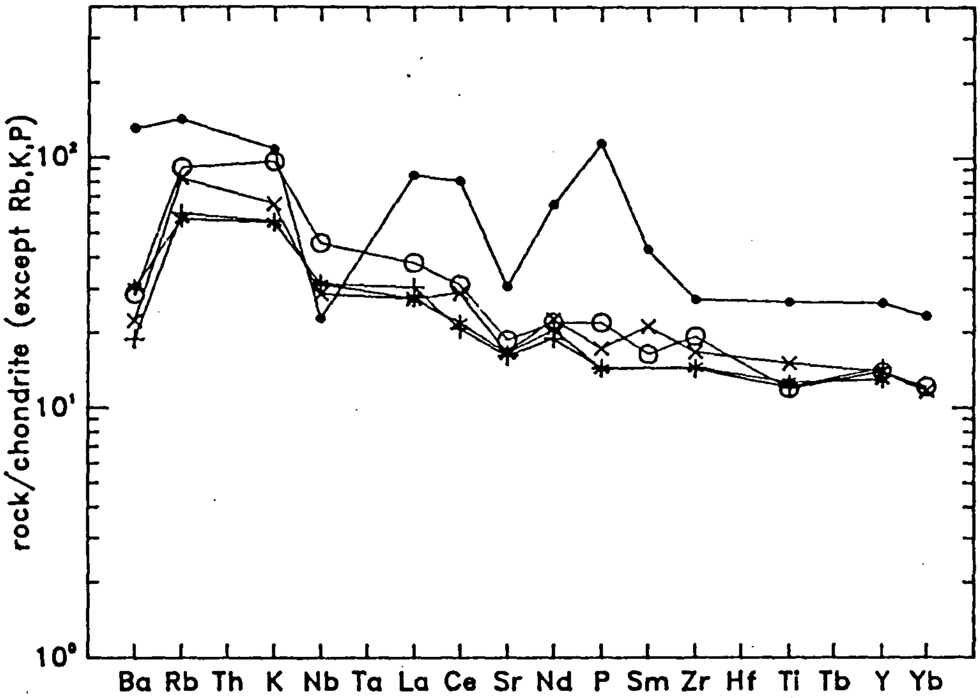


Fig. 4.12 Chondrite normalized comparison diagram for the rocks from Mt Niut [69395 (•), 69398 (+), 69397 (✱), 69399 (o) and 69396 (×)].

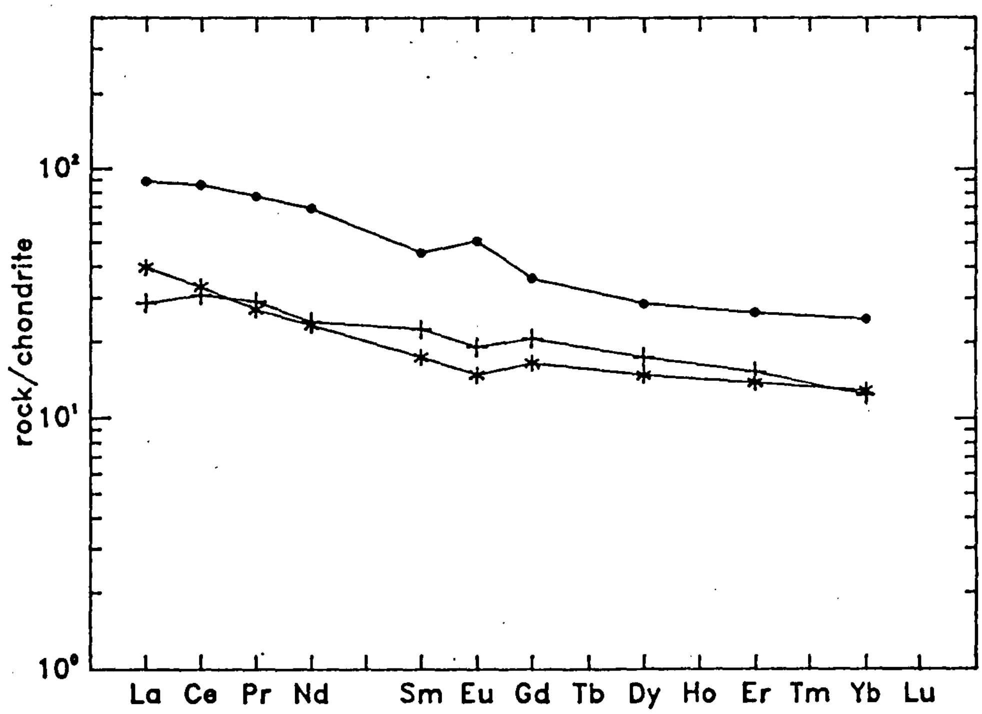


Fig. 4.13 Chondrite normalized REE pattern for the rocks from Mt Niut [69395 (•), 69396 (+) and 69399 (✱)].

types of spinel have been recognized. They are Ti-rich magnetite, Ti- and Cr-rich magnetite, Al-rich chrome spinel, and Al-rich pink spinel. The glassy matrix and glass inclusions in plagioclase are andesitic in composition.

The orthopyroxene-bearing basaltic andesite contains high normative quartz and xenoliths of Al-rich spinel-bearing cumulate plagioclase and orthopyroxene-plagioclase rocks.

The Mt Niut lava may be classified as subalkaline and alkaline, and has some affinity with ocean-floor basalts in trace element compositions. They are unlike arc volcanics because they do not display characteristic Nb depletion. They are clearly unlike the Tertiary volcanic rocks of CWK and the Cretaceous volcanic rocks from WWK which have a composition typical of arc volcanics. Plagioclase is less anorthite-rich, and is not zoned; olivine occurs in the groundmass. This is in keeping with their eruption in post-orogenic time.

5. SUMMARY

5.1 IMPLICATIONS FOR REGIONAL GEOLOGY

Central West Kalimantan (CWK) is divisible into three main geological provinces (Indonesia-Australia Geological Mapping Project (IAGMP); Williams et al., 1986) (Figs 5.1 and 5.2). The differences in tectonic setting and geological history which distinguish the three main geological provinces is also reflected in the petrology and geochemistry of the younger Tertiary CWK volcanic rocks.

The southern province is composed of Cretaceous granitoids. The Tertiary volcanics of this province consist of basalts, andesites, dacites and rhyolites. The central province is composed of the Upper Cretaceous to Palaeocene Melawi sedimentary basin and Cretaceous marine sediments. The Tertiary volcanics of this province consist of dacites and rhyolites. Basalt rocks are absent from the central province. The northern province is composed of Mid-Tertiary Ketungau sedimentary basin. The Tertiary volcanics of this province consist of andesites, dacites and rare basalts.

Thompson et al. (1983) suggested that incompatible trace element enrichment seen in intraplate volcanics reflects assimilation/contamination by crustal rocks. The similar incompatible trace element enrichments seen in rocks analysed from the central province, and the absence of basalt suggests that central province magmatism has involved some form of crustal involvement.

The andesites and dacites from the northern province have high TiO_2 contents and spidergram patterns similar to ocean-island basalts (see Section 2.4). This suggests the northern province volcanics may be derived from a similar mantle source as ocean-island basalts. This suggests that the basement to the northern province may include a component of oceanic lithosphere.

The Tertiary subvolcanics from the southern province have the most siliceous character and the highest enrichment in K-type elements similar to orogenic subduction-related volcanics (Andean type). This suggests that the southern province has a relatively thick continental crust.

5.2 IMPLICATIONS FOR THE TECTONIC MODEL PRESENTLY USED FOR KALIMANTAN

The petrological data obtained here can be used to test many models for the tectonic evolution of West Kalimantan which have been proposed over the last 20 years.

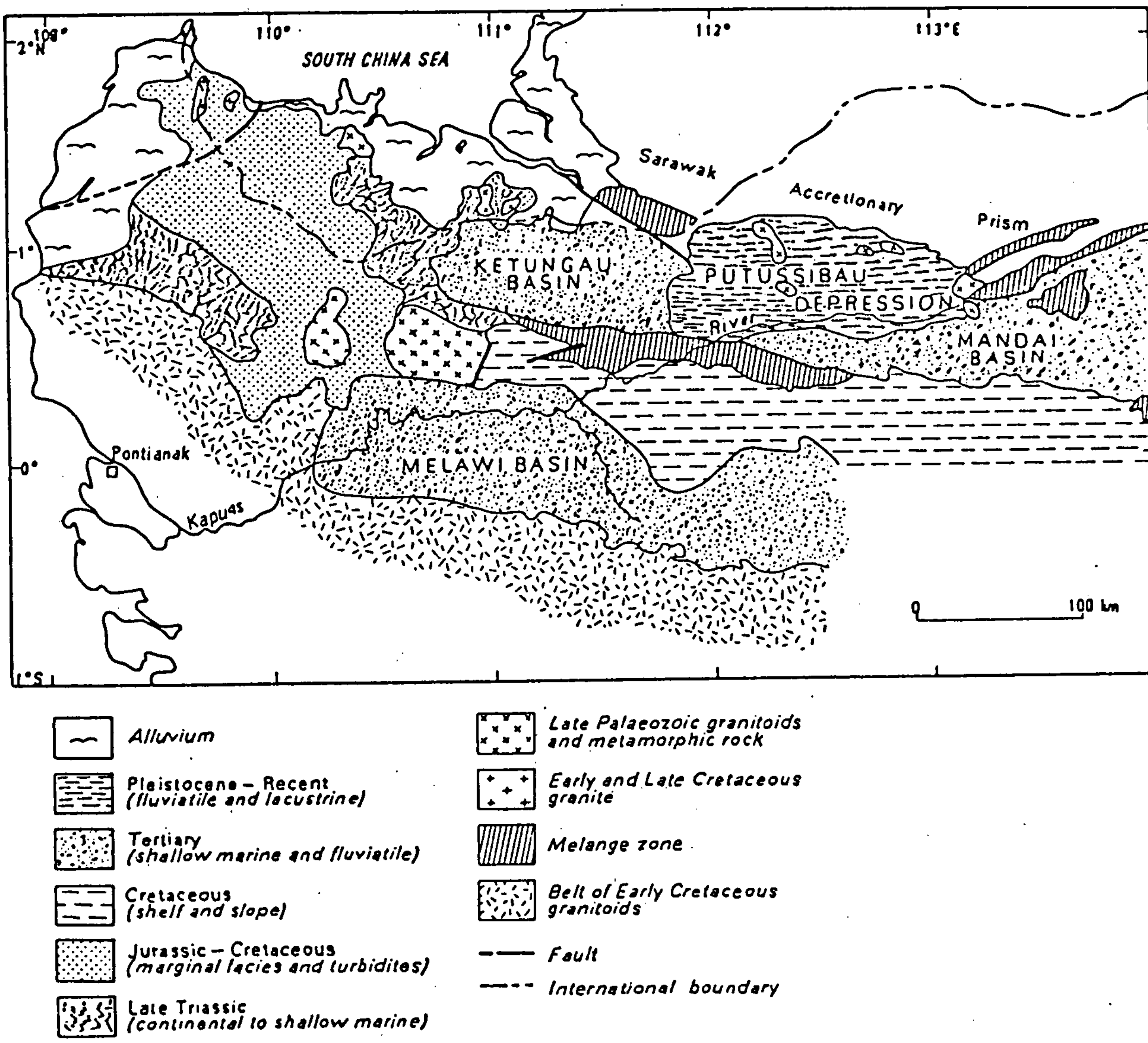


Fig. 5.1 The main tectonic elements in West Kalimantan.

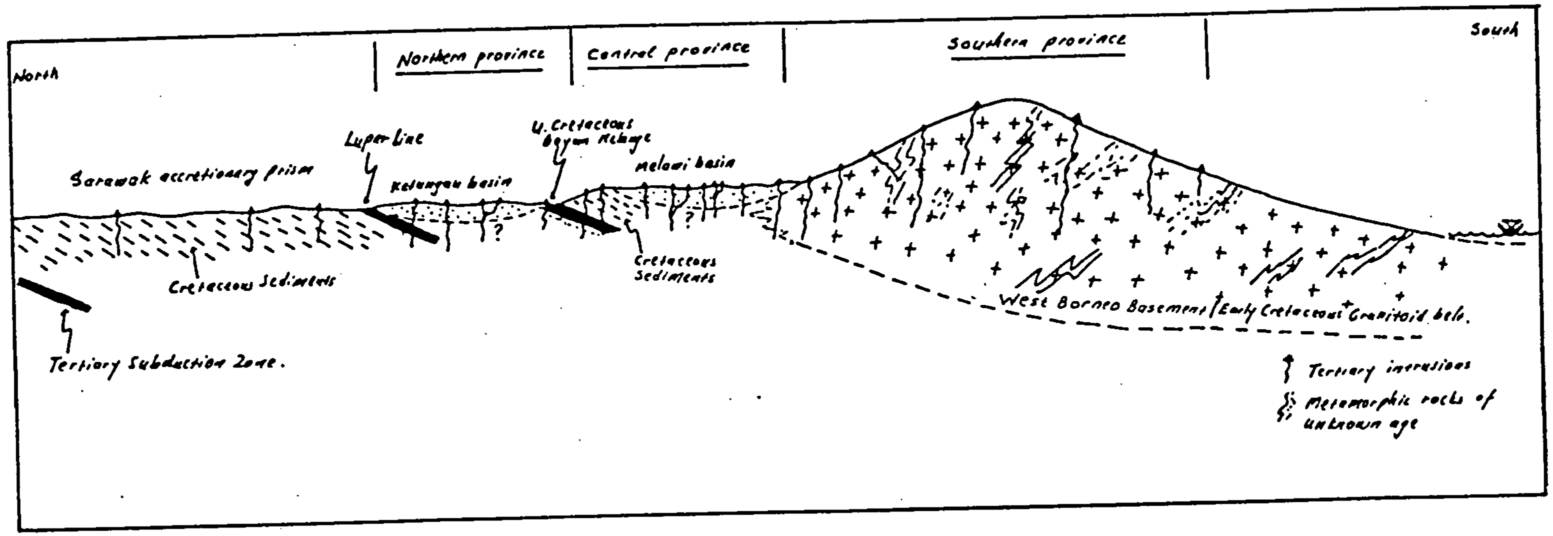


Fig. 5.2 Diagramatic cross-section of the Central West Kalimantan, to show the relation of the Tertiary intrusions with the country rocks. This section is taken from Fig. 1.2 from north to south at 111°E longitude

Katili (1975) and others proposed that there was Cretaceous subduction toward the south along the Lupar Line and the Boyan Melange (refer to Fig. 5.2). This is supported by the recognition of Cretaceous calcalkaline volcanics in the western part of West Kalimantan (WWK) (Section 3.4).

Geological mapping by the IAGMP suggests that there is a distinct unconformity between the Cretaceous basement and the Tertiary rocks in West Kalimantan. The Cretaceous basalts studied here have been metamorphosed to greenschist facies, in contrast to the Tertiary volcanic rocks. This difference in metamorphic grade implies a major erosional break in the early Tertiary.

The IAGMP also reported tuffs in the Upper Cretaceous sedimentary sequence in the Melawi Basin. This may be the result of volcanic activity during Cretaceous time from WWK. These tectonic models interpret the Melawi basin as a fore-arc environment in the Cretaceous (see Section 1.2.4).

Hamilton (1979) and others proposed a southeastward subduction during Tertiary time, active from the Palaeogene to the Miocene, beneath the Sarawak accretionary prism (refer to Fig. 5.1). This is supported by the petrological data presented here which demonstrate that the Tertiary volcanic rocks are similar to calcalkaline and arc tholeiitic suites.

The subduction events in West Kalimantan differ from normal island arcs (e.g. along the Java Trench, More et al., 1980). The total volume of volcanic material erupted over the 20 m.y. period is much smaller than these very active areas. One possible reason for this small amount of material is that the total amount of crust subducted at the arc was small. Taylor & Hayes (1983) reported the spreading rate in the South China Basin during mid-Oligocene through to early Miocene (32-17 m.y.) varied between 2.2 and 3.0 cm/yr, very slow compared with the rate of subduction at the Java Trench (7-7.5 cm/yr) (More et al., 1980). However, in Burma, where the rate of subduction is 0.8-1.0 cm/yr, very small amounts of volcanics are produced (More et al., 1980).

Holloway (1982) proposed that the subduction in West Borneo migrated northwards. The variation in K/Ar ages of the intrusions in the CWK suite apparently reflects this northward retreat as they range from 16 m.y. in the north to 65 m.y. in the south. As the locus of volcanism migrates the nature of the volcanic rocks changes, but this may reflect the nature of the crust as much as any changes in depth to Benioff zone.

Tjia (1980) proposed that West Kalimantan has been tectonically stable since early Tertiary times. In contrast, the result here demonstrates that the mid- to late-Tertiary volcanism in West Kalimantan is orogenic in character. It is therefore more likely that West Kalimantan was not stabilized before Mio-Pliocene time.

The intraplate magmatic signature of the Quaternary Mt Niut lavas shows that stabilization has now occurred and also shows that the Mt Niut activity was not related to subduction along the Java Trench. Although Katili (1971) suggested that Mt Niut activity was related to subduction along the Java Trench, the intraplate character of Mt Niut volcanics shows that unlike subduction-related rocks.

it was

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Appendix 1

K-Ar age of some Tertiary volcanic rocks from central West Kalimantan

Sample No	Material date	Age (m.y)	Locality	Co-ordinates
69482	Biotite	16.4 ± 0.1	Sintang	112°29'E, 0°26'N
69336	Hornblende	17.8 ± 0.7	"	112°00'E, 0°07'N
69334	Biotite	17.9 ± 0.2	"	111°44'E, 0°34'N
69363	Total rock	21.1 ± 0.2	Nangapinoh	111°46'E, 0°06'S
69362	,,	21.2 ± 0.3	Sintang	112°07'E, 0°14'N
69326	Hornblende	21.2 ± 0.3	"	111°20'E, 0°58'N
69340	,,	23.0 ± 0.7	"	112°07'E, 0°03'N
69307	,,	23.6 ± 0.6	"	
69345	,,	25.4 ± 0.7	"	111°46'E, 0°04'S
69347	,,	26.3 ± 1.6	"	111°55'E, 0°04'S
69481	,,	30.4 ± 0.9	Nangapinoh	111°53'E, 0°06'S
69306	Biotite	41.7 ± 0.5	Sintang	111°35'E, 0°46'S

Appendix 2

Microprobe analyses

Section A. The Teriary subvolcanic and volcanic rocks from central West Kalimantan
Section B. The Cretaceous subvolcanic and volcanic rocks from western part of West Kalimantan
Section C. The Quaternary lavas from Mt.Niut
Section D. The Neogene subvolcanic rocks from western part of South Sulawesi
Section E. Rock sample not referred to in this thesis

Note: Abbreviations are as follows

P	= phenocryst	Pr	= phenocryst rim
Pc	= ,, core	mp	= micro phenocryst
mpr	= micro phenocryst rim	mpc	= ,, ,, core
gr	= groundmass	I.pl	= iclusion in plagioclase
I.cpx	= inclusion in clinopyroxene	xlth	= xenolith
I.ol	= inclusion in olivine	I.chl	= inclusion in chlorite

Structural formula have been calculated on the basis of the following numbers of oxygens.

Clinopyroxene	= 6	Orthopyroxene	= 6	Amphybole	= 23
Biotite	= 22	Plagioclase	= 8	K-feldspar	= 8
Olivine	= 4	Magnetite	= 4	Ilmenite	= 3
Chrome spinel	= 32	Analcite	= 7	Phlogopite	= 22

Contents for appendix 2

A. Tertiary subvolcanic and volcanic rocks from Central West Kalimantan

Plagioclase

Rock type					Basalt				
Sample no.	69295				69293				
Type	mp	mp	Pr	Pc	mp	mp	p	p	p
SiO2	49.20	49.03	50.98	49.89	50.61	51.01	50.07	49.45	49.05
Al2O3	31.17	31.06	30.19	32.10	30.05	29.31	31.25	30.37	31.17
FeO	0.38	0.48	0.30	0.47	0.67	0.66	0.53	0.43	0.43
MgO	0.19	-	-	-	0.48	-	0.28	0.19	0.20
CaO	14.99	14.56	14.79	15.45	13.38	12.80	14.26	14.10	14.75
K2O	0.10	-	-	0.12	0.17	0.10	0.24	-	0.11
Na2O	2.84	2.83	2.73	2.67	3.51	3.81	3.39	3.01	2.97
Cr2O3	-	-	-	-	-	-	-	-	-
Total	98.87	98.08	100.00	100.70	98.85	97.69	100.03	97.56	98.68
Si	2.2755	2.2817	2.3192	2.2659	2.3342	2.3744	2.2893	2.3098	2.2732
Al	1.6990	1.7091	1.6723	1.7182	1.6332	1.6080	1.6841	1.6720	1.7025
Fe	0.0146	0.0186	0.0115	0.0179	0.0257	0.0256	0.0201	0.0169	0.0169
Mg	0.0129	-	-	-	0.0332	-	0.0190	0.0133	0.0137
Ca	0.7426	0.7267	0.7210	0.7518	0.6610	0.6384	0.6986	0.7057	0.7325
K	0.0057	-	-	0.0069	0.0097	0.0061	0.0140	-	0.0063
Na	0.2551	0.2553	0.2411	0.2353	0.3138	0.3442	0.3008	0.2728	0.2671
Cr	-	-	-	-	-	-	-	-	-
Total	5.0053	4.9914	4.9651	4.9960	5.0109	4.9967	5.0259	4.9905	5.0121
Ca	74.0	74.0	84.4	75.6	67.1	64.6	68.9	72.1	72.8
Na	25.4	26.0	15.6	23.7	31.9	34.8	29.7	27.9	26.6
K	0.6	0.0	0.0	0.7	1.0	0.6	1.4	0.0	0.6

	69292						69297	
	mp	Pc	Pr	mp	P	mp	Pr	Pc
	53.03	53.10	53.76	56.17	53.29	53.81	54.68	52.55
	29.94	28.99	28.30	27.08	29.18	28.94	29.21	29.91
	0.65	0.68	0.71	0.70	0.74	0.75	0.36	0.37
	-	-	-	-	-	-	-	-
	12.94	12.34	11.28	9.76	12.13	11.81	11.93	13.07
	0.27	0.22	0.27	0.39	0.28	0.28	0.21	0.12
	4.09	4.43	4.82	5.76	4.55	4.56	4.43	3.70
	-	-	-	-	-	-	-	-
	100.92	99.76	99.14	99.85	100.17	100.16	100.80	99.73
	2.3897	2.4180	2.4566	2.5374	2.4172	2.4367	2.4506	2.3892
	1.5907	1.5560	1.5239	1.4419	1.5598	1.5446	1.5427	1.6028
	0.0245	0.0257	0.0271	0.0266	0.0281	0.0285	0.0133	0.0140
	-	-	-	-	-	-	-	-
	0.6245	0.6021	0.5525	0.4722	0.5897	0.5729	0.5730	0.6365
	0.0153	0.0127	0.0157	0.0227	0.0161	0.0161	0.0117	0.0071
	0.3573	0.3915	0.4270	0.5042	0.4002	0.4006	0.3848	0.3264
	-	-	-	-	-	-	-	-
	5.0014	5.0060	5.0028	5.0050	5.0110	4.9993	4.9762	4.9760
	62.6	59.8	55.5	47.3	58.6	57.9	59.10	65.6
	35.8	38.9	42.9	50.5	39.8	40.5	39.69	33.6
	1.5	1.3	1.6	2.3	1.6	1.6	1.21	0.7

69297						69308		
Pr	Pc	mp	mp	Pr	Pc	Pr	Pc	P
55.92	53.27	52.93	56.35	54.09	53.27	53.84	54.38	54.10
27.83	29.04	29.65	27.90	29.42	30.18	29.47	28.91	29.09
0.34	0.23	0.30	0.23	0.26	0.30	0.66	0.49	0.37
-	-	-	-	-	-	-	-	-
10.19	11.92	12.78	10.25	12.06	12.96	12.58	12.15	12.38
0.18	0.14	0.15	0.23	0.17	0.23	0.27	0.40	0.29
5.13	4.06	3.75	5.32	4.30	3.89	4.03	4.20	4.02
-	-	-	-	-	-	-	-	-
99.58	98.66	99.57	100.27	100.29	100.84	100.86	100.52	100.26
2.5229	2.4370	2.4065	2.5256	2.4364	2.3947	2.4213	2.4492	2.4413
1.4796	1.5657	1.5887	1.4737	1.5618	1.5991	1.5619	1.5345	1.5469
0.0129	0.0090	0.0114	0.0085	0.0098	0.0113	0.0248	0.0184	0.0141
-	-	-	-	-	-	-	-	-
0.4924	0.5844	0.6227	0.4922	0.5821	0.6244	0.6062	0.5864	0.5986
0.0101	0.0079	0.0089	0.0129	0.0096	0.0133	0.0157	0.0228	0.0169
0.4490	0.3605	0.3309	0.4622	0.3754	0.3393	0.3512	0.3667	0.3518
-	-	-	-	-	-	-	-	-
4.9668	4.9643	4.9691	4.9751	4.9751	4.9820	4.9812	4.9781	4.9695
51.7	61.3	64.7	50.9	60.2	63.9	62.3	60.1	61.9
47.2	37.8	34.4	47.8	38.8	34.7	36.1	37.6	36.4
1.1	0.8	0.9	1.3	1.0	1.4	1.6	2.3	1.7

Type one andesite								
69308						69310		
gm	gm	Pr	Pr	Pc	Pc	Pr	Pc	Pr
57.49	55.59	52.48	53.54	53.20	53.69	56.14	53.72	53.15
27.16	28.21	30.01	28.90	29.32	29.40	27.50	29.03	29.01
0.88	0.62	0.46	0.95	0.45	0.47	0.70	0.43	0.34
-	-	-	0.23	0.19	-	-	-	-
9.72	11.19	13.44	12.24	12.65	12.71	10.16	12.07	12.28
0.55	0.43	0.20	0.31	0.30	0.29	0.39	0.28	0.30
5.53	4.56	3.28	4.03	3.88	3.71	4.85	4.11	3.86
-	-	-	-	-	-	-	-	-
101.35	100.60	99.88	100.20	99.98	100.27	99.27	99.65	98.93
2.5570	2.4949	2.3840	2.4264	2.4127	2.4248	2.5444	2.4388	2.4303
1.4237	1.4921	1.6067	1.5435	1.5672	1.5648	1.4450	1.5531	1.5633
0.0327	0.0235	0.0173	0.0362	0.0171	0.0178	0.0264	0.0162	0.0130
-	-	-	0.0155	0.0127	-	-	-	-
0.4634	0.5379	0.6542	0.5942	0.6145	0.6148	0.4932	0.5873	0.6016
0.0314	0.0246	0.0116	0.0179	0.0173	0.0164	0.0223	0.0165	0.0174
0.4771	0.3965	0.2891	0.3541	0.3416	0.3245	0.4260	0.3621	0.3421
-	-	-	-	-	-	-	-	-
4.9854	4.9695	4.9629	4.9877	4.9831	4.9632	4.9572	4.9739	4.9677
47.7	56.1	68.5	61.5	63.1	64.3	52.38	60.8	62.6
49.1	41.3	30.3	36.6	35.1	34.0	45.25	37.5	35.6
3.2	2.6	1.2	1.9	1.8	1.7	2.37	1.7	1.8

69310						69301		
Pc	Po	gr	gr	Pr	Pc	gr	Pr	Pc
55.38	59.49	57.40	55.64	55.11	54.39	58.82	50.59	58.76
29.47	26.54	25.98	28.39	29.25	29.90	25.19	32.16	25.78
0.53	0.44	1.54	1.39	0.60	0.49	0.80	0.47	0.66
-	-	0.86	0.43	-	-	-	-	-
11.81	8.92	10.24	10.81	12.05	12.49	6.84	15.26	7.96
0.40	0.49	0.32	0.29	0.33	0.36	0.79	0.21	0.69
4.36	5.83	5.07	4.93	4.41	4.19	6.30	2.55	6.25
-	-	-	-	-	-	-	-	-
101.95	101.71	101.41	101.88	101.75	101.82	98.76	101.25	100.09
2.4553	2.6179	2.5598	2.4754	2.4516	2.4210	2.6616	2.2816	2.6309
1.5398	1.3766	1.3657	1.4887	1.5338	1.5686	1.3434	1.7091	1.3607
0.0197	0.0164	0.0573	0.0517	0.0222	0.0183	0.0308	0.0179	0.0247
-	-	0.0568	0.0282	-	-	-	-	-
0.5612	0.4205	0.4895	0.5155	0.5744	0.5957	0.3317	0.7374	0.3817
0.0226	0.0276	0.0180	0.0166	0.0187	0.0205	0.0457	0.0122	0.0392
0.3751	0.4973	0.4385	0.4251	0.3802	0.3616	0.5524	0.2232	0.5423
-	-	-	-	-	-	-	-	-
4.9736	4.9562	4.9855	5.0011	4.9809	4.9857	4.9657	4.9814	0.9795
58.5	44.5	51.7	53.9	59.0	60.9	35.7	75.8	39.6
39.1	52.6	46.4	44.4	39.1	37.0	59.4	22.9	56.3
2.4	2.9	1.9	1.7	1.9	2.1	4.9	1.3	4.1

Type two andesite								
69301				69306				
mp	Pr	Pc	mp	Pr	Pr	Pc	Pr	Pc
50.60	49.73	49.22	54.87	61.83	57.16	49.98	49.80	48.75
28.00	32.40	32.93	28.66	25.37	28.35	32.72	32.72	32.42
0.62	0.46	0.36	0.62	-	-	0.25	0.24	-
-	-	-	-	-	-	-	-	-
10.69	15.44	16.16	11.49	6.69	10.24	15.69	15.96	15.73
0.34	0.11	0.11	0.23	0.33	0.34	0.19	0.11	-
4.97	2.41	2.06	4.43	7.36	5.39	2.31	2.50	2.17
-	-	-	-	-	-	-	-	-
100.20	100.55	100.84	100.30	101.59	101.67	101.15	101.33	99.08
2.5032	2.2596	2.2328	2.4705	2.7037	2.5258	2.2566	2.2479	2.2442
1.4855	1.7347	1.7609	1.5208	1.3076	1.4762	1.7409	1.7405	1.7590
0.0233	0.0176	0.0135	0.0234	-	-	0.0095	0.0089	-
-	-	-	-	-	-	-	-	-
0.5154	0.7515	0.7857	0.5543	0.3136	0.4934	0.7591	0.7718	0.7761
0.0193	0.0062	0.0061	0.0134	0.0185	0.0193	0.0110	0.0063	-
0.4338	0.2127	0.1815	0.3867	0.6243	0.4619	0.2025	0.2189	0.1941
-	-	-	-	-	-	-	-	-
4.9806	4.9824	4.9805	4.9691	4.9677	4.9766	4.9796	4.9944	4.9733
53.2	77.4	80.7	58.1	32.8	50.6	78.0	77.4	80.0
44.8	21.9	18.6	40.5	65.3	47.4	20.8	22.0	20.0
2.0	0.6	0.6	1.4	1.9	2.0	1.1	0.6	0.0

69306		69307					69299	
gr	gr	Pr	Pr	Pc	Pc	Pr	Pc	Pc
51.78	68.53	47.24	59.39	54.61	55.28	56.26	45.58	46.06
30.94	26.90	34.61	27.86	29.50	28.99	28.07	25.41	24.54
0.36	-	0.25	-	-	-	-	6.28	7.62
-	-	-	-	-	-	-	-	-
13.72	8.74	18.09	9.49	12.10	11.49	10.46	20.75	18.17
0.22	0.35	-	0.12	0.11	0.10	0.13	-	-
3.17	5.73	1.21	5.90	4.47	4.72	5.17	1.46	3.43
-	-	-	-	-	-	-	0.21	-
100.19	100.25	101.39	102.76	100.79	100.58	100.09	99.69	100.20
2.3474	2.6048	2.1422	2.5820	2.4441	2.4740	2.5223	2.2070	2.2317
1.6530	1.4109	1.8494	1.4278	1.5563	1.5288	1.4829	1.4498	1.4012
0.0137	-	0.0094	-	-	-	-	0.2542	0.3086
-	-	-	-	-	-	-	-	-
0.6665	0.4167	0.8788	0.4421	0.5802	0.5509	0.5023	1.0766	0.9431
0.0126	0.0198	-	0.0064	0.0061	0.0058	0.0076	-	-
0.2784	0.4947	0.1063	0.4977	0.3882	0.4098	0.4496	0.1369	0.3221
-	-	-	-	-	-	-	0.0080	-
4.9716	4.9469	4.9862	4.9561	4.9749	4.9694	4.9648	5.1325	5.2224
69.6	44.8	89.2	46.7	59.5	57.0	52.4	88.7	74.5
29.1	53.1	10.8	52.6	39.8	42.4	46.9	11.3	25.5
1.3	2.1	0.0	1.0	0.6	0.6	0.8	0.0	0.0

Basaltic andesite					Dacite			
69299					69334			
Pr	gr	gr	Pr	Pc	Pc	Pr	Pr	Pc
53.98	53.58	56.02	62.33	62.83	57.17	57.43	60.38	55.68
27.49	30.20	27.20	23.38	20.42	27.01	26.75	26.14	28.03
1.01	0.92	-	0.23	1.61	0.28	0.25	-	-
-	-	-	-	1.75	-	-	-	-
9.38	9.07	9.57	4.11	4.49	9.31	8.87	7.73	10.43
-	0.24	0.11	0.21	0.11	0.28	0.30	0.31	0.18
4.83	5.37	6.19	8.74	8.81	5.74	5.81	6.54	4.98
-	-	-	-	-	-			
97.73	99.38	99.09	99.00	100.01	99.79	99.41	101.08	99.31
2.4991	2.4299	2.5397	2.7826	2.8060	2.5686	2.5856	2.6569	2.5160
1.4999	1.6144	1.4536	1.2300	1.0747	1.4304	1.4195	1.3558	1.4929
0.0391	0.0349	-	0.0086	0.0602	0.0104	0.0095	-	-
-	-	-	-	0.1165	-	-	-	-
0.4651	0.4406	0.4651	0.1969	0.2149	0.4483	0.4280	0.3646	0.5052
0.0618	0.0136	0.0063	0.0117	0.0062	0.0161	0.0170	0.0172	0.0104
0.4334	0.4725	0.5437	0.7569	0.7625	0.5004	0.5069	0.5583	0.4363
-	-	-	-	-	-	-	-	-
4.9985	5.0059	5.0084	4.9867	5.0410	4.9744	4.9666	4.9529	4.9608
48.4	47.5	45.8	20.4	21.8	46.5	45.0	38.8	53.1
45.1	51.0	53.6	78.4	77.5	51.9	53.2	59.4	45.8
6.4	1.5	0.6	1.2	0.6	1.7	1.8	1.8	1.1

69328						69325		
gr	Pc	Pr	gr	Pc	Pr	Pr	Pc	gr
59.83	58.82	57.77	58.96	59.66	59.29	59.62	59.84	62.41
25.44	27.47	28.12	27.19	27.37	27.39	24.61	26.39	25.12
0.89	0.33	0.31	0.32	-	-	-	-	0.27
-	-	-	-	-	-	-	-	-
7.14	9.29	10.21	8.73	8.94	8.96	6.21	7.96	6.25
0.41	0.26	0.33	0.53	0.25	0.33	0.29	0.23	0.38
6.60	6.00	5.42	6.26	6.34	6.08	7.27	6.42	7.36
-	-	-	-	-	-	-	-	-
100.31	102.17	102.16	101.99	102.56	102.04	98.08	100.84	101.79
2.6638	2.5796	2.5405	2.5914	2.6227	2.5961	2.7003	2.6415	2.2706
1.3349	1.4197	1.4574	1.4084	1.3872	1.4134	1.3135	1.3728	1.2903
0.0332	0.0121	0.0115	0.0119	-	-	-	-	0.0100
-	-	-	-	-	-	-	-	-
0.3404	0.4367	0.4812	0.4110	0.3856	0.4205	0.3013	0.3765	0.2919
0.0233	0.0146	0.0182	0.0297	0.0129	0.0182	0.0166	0.0130	0.0209
0.5696	0.5104	0.4619	0.5333	0.5462	0.5163	0.6387	0.5493	0.6220
-	-	-	-	-	-	-	-	-
4.9652	4.9730	4.9708	4.9858	4.9632	4.9644	4.9769	4.9531	4.9557
36.5	45.4	50.1	42.2	40.8	44.0	31.5	40.1	31.2
61.0	53.1	48.0	54.8	57.8	54.1	66.8	58.5	66.5
2.5	1.5	1.9	3.1	1.4	1.9	1.7	1.4	2.2

69325	69337							
Pc	Pc	Pr	Pc	Pc	Pr	Pr	Pc	Pr
60.50	54.49	53.15	54.13	53.87	54.88	55.56	56.38	53.03
25.09	27.09	27.77	27.22	28.73	28.13	27.81	26.20	28.15
-	-	0.36	-	0.22	-	-	-	0.25
-	-	-	-	-	-	-	-	-
6.59	9.75	10.69	9.84	11.31	10.65	9.84	8.47	10.73
0.22	0.19	0.12	0.10	-	0.21	0.15	0.18	0.18
7.08	5.54	4.93	5.15	4.76	5.20	5.62	5.95	4.78
-	-	-	-	-	-	-	-	-
99.48	97.05	97.03	96.44	98.88	99.07	98.98	97.18	97.12
2.6976	2.5226	2.4720	2.5181	2.4565	2.4936	2.5202	2.5916	2.4625
1.3184	1.4781	1.5220	1.4922	1.5440	1.5062	1.4866	1.4196	1.5406
-	-	0.0139	-	0.0082	-	-	-	0.0098
-	-	-	-	-	-	-	-	-
0.3146	0.4834	0.5329	0.4903	0.5524	0.5184	0.4783	0.4171	0.5338
0.0127	0.0113	0.0074	0.0062	-	0.0123	0.0087	0.0106	0.0107
0.6122	0.4970	0.4450	0.4643	0.4206	0.4576	0.4940	0.5299	0.4302
-	-	-	-	-	-	-	-	-
4.9556	4.9924	4.9931	4.9710	4.9817	4.9882	4.9878	4.9688	4.9876
33.5	48.7	54.1	51.0	56.8	52.2	48.8	43.6	54.8
65.2	50.1	45.2	48.3	43.2	46.3	50.4	55.3	44.1
1.3	1.1	0.7	0.6	0.0	1.2	0.9	1.1	1.1

69336					69342			
Pc	Pr	gr	mp	Pr	Pr	gm	Pr	Pc
69.39	69.91	60.67	55.62	55.59	53.59	57.18	55.12	55.53
21.17	20.57	26.50	27.72	27.76	30.63	25.43	30.00	28.56
-	-	-	0.28	-	0.38	-	0.32	-
-	-	-	-	-	-	-	-	-
0.39	0.12	7.69	10.44	10.63	12.89	7.81	11.94	10.87
0.21	-	0.26	0.16	0.12	0.15	0.41	0.21	0.12
10.83	11.10	6.50	4.87	4.82	3.93	6.05	4.51	4.96
-	-	-	-	-	-	-	-	-
101.99	101.69	101.52	99.10	98.92	101.58	96.87	102.09	100.05
2.9645	2.9898	2.6537	2.5209	2.5211	2.3902	2.6320	2.4385	2.4946
1.0661	1.0366	1.3662	1.4810	1.4838	1.6099	1.3793	1.5639	1.5119
-	-	-	0.0108	-	0.0144	-	0.0120	-
-	-	-	-	-	-	-	-	-
0.0179	0.0053	0.3604	0.5071	0.5163	0.6158	0.3852	0.5658	0.5233
0.0114	-	0.0144	0.0091	0.0072	0.0087	0,0242	0.0117	0.0071
0.8967	0.9203	0.5513	0.4282	0.4241	0.3402	0.5397	0.3869	0.4322
-	-	-	-	-	-	-	-	-
4.9565	4.9520	4.9460	4.9572	4.9526	4.9792	4.9602	4.9788	4.9691
1.9	0.6	38.9	53.7	54.5	63.8	40.6	58.7	54.4
96.8	9.44	59.5	45.3	44.8	35.3	56.9	40.1	44.9
1.2	0.0	1.6	1.0	0.8	0.9	2.5	1.2	0.7

69342				69344				
Pr	Pc	Pr	Pc	Pr	Pc	Pr	Pc	Pc
54.49	53.92	56.24	54.91	58.10	58.78	58.16	54.68	58.09
29.78	28.76	28.84	28.65	28.14	26.95	27.34	30.03	27.17
0.45	0.25	-	-	0.23	-	-	-	-
-	-	-	-	-	-	-	-	-
11.93	11.25	10.84	11.09	9.48	8.83	9.26	12.45	7.80
0.16	0.17	0.19	0.14	0.54	0.57	0.44	0.20	0.26
4.27	4.77	4.90	4.65	5.48	5.95	5.89	4.14	6.28
-	-	-	-	-	-	-	-	-
101.09	99.12	101.02	99.45	101.98	101.09	101.09	101.50	99.61
2.4347	2.4555	2.5002	2.4823	2.5545	2.6009	2.5767	2.4313	2.5985
1.5684	1.5436	1.5111	1.5267	1.4581	1.4055	1.4277	1.5734	1.4326
0.0170	0.0094	-	-	0.0086	-	-	-	-
-	-	-	-	-	-	-	-	-
0.5712	0.5488	0.5264	0.5374	0.4465	0.4187	0.4394	0.5932	0.3740
0.0093	0.0098	0.0110	0.0081	0.0300	0.0321	0.0250	0.0111	0.0147
0.3700	0.4208	0.4220	0.4079	0.4673	0.5102	0.5060	0.3571	0.5450
-	-	-	-	-	-	-	-	-
4.9706	4.9880	4.9607	4.9623	4.9651	4.9675	4.9748	4.9661	4.9649
60.1	56.0	54.4	56.4	47.3	43.6	45.3	61.7	40.1
38.9	43.0	44.5	42.8	49.5	53.1	52.1	43.9	58.4
1.0	1.0	1.2	0.9	3.2	3.3	2.6	1.2	1.6

69344					69350			
Pc	Pr	gm	Pr	Pc	Pc	Pc	Pr	Pr
57.85	59.08	56.70	57.96	58.70	50.13	52.84	52.93	51.66
27.43	27.01	28.35	27.60	27.90	31.45	29.94	29.74	29.64
0.28	0.31	0.25	-	-	0.48	0.53	0.48	0.50
-	-	-	-	-	-	-	-	-
9.34	8.64	10.56	9.72	9.74	14.69	13.17	12.51	12.84
0.35	0.47	0.31	0.38	0.42	0.11	0.19	0.12	0.16
5.70	6.02	4.90	5.54	5.56	2.97	3.60	4.10	3.88
-	-	-	-	-	-	-	-	-
100.95	101.53	101.07	101.20	102.32	99.83	100.28	99.89	98.68
2.5683	2.6033	2.5201	2.5655	2.5686	2.2924	2.3912	2.4018	2.3784
1.4355	1.4024	1.4851	1.4396	1.4390	1.6949	1.5967	1.5906	1.6085
0.0105	0.0113	0.0094	-	-	0.0184	0.0202	0.0183	0.0193
-	-	-	-	-	-	-	-	-
0.4445	0.4079	0.5027	0.4612	0.4566	0.7196	0.6387	0.6084	0.6333
0.0198	0.0265	0.0176	0.0217	0.0236	0.0062	0.0112	0.0068	0.0092
0.4904	0.5146	0.4225	0.4751	0.4715	0.2623	0.3159	0.3607	0.3466
-	-	-	-	-	-	-	-	-
4.9690	4.9660	4.9573	4.9631	4.9594	4.9948	4.9738	4.9866	4.9952
46.6	43.0	53.3	48.1	48.0	72.8	66.1	62.3	64.0
51.4	54.2	44.8	49.6	49.5	26.6	32.7	37.0	35.0
2.1	2.8	1.9	2.3	2.5	0.6	1.2	0.7	0.9

					Rhyolite			
69350					69361			
Pr	glass	Pc	xlth	xlth	gr	gr	Pr	Pc
49.16	56.89	48.31	48.34	48.91	61.68	63.49	66.05	58.69
31.36	25.46	32.10	32.55	32.64	23.73	23.52	22.37	26.22
0.46	0.37	0.43	0.40	0.53	-	-	-	0.53
-	-	-	-	-	-	-	-	0.36
14.88	8.36	15.70	16.00	15.64	5.02	4.39	2.84	6.59
-	4.17	0.15	-	0.12	1.64	0.33	0.11	0.31
2.89	3.06	2.30	2.10	2.43	7.17	8.32	9.59	6.33
-	-	-	-	-	-	-	-	-
98.75	98.30	99.00	99.39	100.28	99.24	100.05	100.96	99.03
2.2747	2.6204	2.2355	2.2259	2.2339	2.7614	2.7979	2.8708	2.6359
1.7102	1.3824	1.7506	1.7664	1.7567	1.2523	1.2214	1.1459	1.3881
0.0178	0.0143	0.0168	0.0153	0.0204	-	-	-	0.0200
-	-	-	-	-	-	-	-	0.0243
0.7376	0.4125	0.7784	0.7895	0.7655	0.2408	0.2074	0.1324	0.3172
-	0.2447	0.0088	-	0.0068	0.0934	0.0186	0.0058	0.0175
0.2595	0.2730	0.2064	0.1875	0.2154	0.6226	0.7108	0.8083	0.5514
-	-	-	-	-	-	-	-	-
4.9998	4.9473	4.9967	4.9846	4.9987	4.9705	4.9561	4.9633	4.9544
74.0	44.3	78.3	80.8	77.5	25.2	22.1	14.0	35.8
26.0	29.4	20.8	19.2	21.8	65.1	75.9	85.4	62.2
0.0	26.3	0.9	0.0	0.7	9.8	2.0	0.6	2.0

69379					69368			
Pr	Pc	Pc	Pc	Pr	Pr	Pc	mp	gr
60.56	62.81	63.27	63.86	62.30	59.64	59.74	60.93	61.17
24.52	23.48	23.21	24.04	23.10	25.26	25.22	25.48	24.12
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
5.93	4.67	4.71	4.82	4.53	6.96	6.98	6.92	5.63
0.56	0.88	0.88	0.78	0.82	0.23	0.18	0.18	0.30
7.28	7.75	7.76	7.96	7.92	7.06	6.76	6.97	7.33
-	-	-	-	-	-	-	-	-
98.85	99.59	99.83	101.45	98.67	99.14	98.88	100.48	98.56
2.7181	2.7882	2.8009	2.7828	2.7921	2.6749	2.6817	2.6903	2.7444
1.2972	1.2285	1.2112	1.2345	1.2204	1.3350	1.3343	1.3256	1.2755
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
0.2850	0.2222	0.2234	0.2248	0.2177	0.3344	0.3356	0.3274	0.2705
0.0320	0.0499	0.0498	0.0434	0.0467	0.0132	0.0104	0.0100	0.0171
0.6338	0.6672	0.6663	0.6721	0.6884	0.6136	0.5886	0.5970	0.5855
-	-	-	-	-	-	-	-	-
4.9661	4.9560	4.9515	4.9576	4.9652	4.9710	4.9506	4.9503	4.9452
30.0	23.7	23.8	23.9	22.8	34.8	35.9	35.0	33.3
66.7	71.0	70.9	71.5	72.3	63.8	63.0	63.9	64.0
3.4	5.3	5.3	4.6	4.9	1.4	1.1	1.1	2.6

69368				69375			
Pr	Pc	Pc	Pr				
60.76	60.29	60.18	60.77	56.31	54.27	55.64	54.75
25.53	25.16	25.28	24.29	28.44	29.21	28.30	28.54
-	-	-	-	-	-	0.27	0.25
-	-	-	-	0.23	-	-	0.17
6.64	6.66	6.97	5.91	9.40	11.43	9.99	10.68
0.23	0.23	0.21	0.32	0.16	0.16	0.17	0.17
7.09	7.21	7.14	7.29	6.45	4.92	5.63	5.27
-	-	-	-	-	-	-	0.18
100.25	99.54	99.79	98.58	100.99	100.00	100.00	100.00
2.6887	2.6896	2.6809	2.7299	2.5075	2.4487	2.5035	2.4707
1.3315	1.3227	1.3274	1.2861	1.4924	1.5531	1.5007	1.5178
-	-	-	-	-	-	0.0101	0.0093
-	-	-	-	0.0150	-	-	0.0113
0.3147	0.3183	0.3328	0.2843	0.4482	0.5528	0.4815	0.5163
0.0132	0.0130	0.0119	0.0183	0.0091	0.0094	0.0095	0.0096
0.6080	0.6238	0.6169	0.6352	0.5570	0.4306	0.4912	0.4608
-	-	-	-	-	-	-	
4.9560	4.9674	4.9698	4.9538	5.0293	4.9946	4.9965	5.0023
33.6	33.3	34.6	30.3	44.2	55.7	49.0	52.3
65.0	65.3	64.2	67.7	54.9	43.4	50.0	46.7
1.4	1.4	1.2	2.0	0.9	1.0	1.0	1.0

K-feldspar

Rock type	Andesite		Dacite				Rhyolite	
Sample no.	69306		69328		69325		69365	
Type	gr	gr	gr	gr			P	P
SiO2	66.62	65.51	68.06	58.40	63.63	64.76	64.56	65.43
TiO2	0.20	0.34	-	-	-	-	-	-
Al2O3	19.09	18.82	20.77	18.75	18.40	18.50	18.30	18.61
FeO	-	-	0.60	4.84	-	-	-	-
MgO	-	-	-	1.69	-	-	-	-
CaO	0.25	0.33	1.82	2.10	-	-	-	-
K2O	14.05	14.65	4.81	4.69	15.42	16.16	16.16	15.23
Na2O	1.23	0.82	7.16	5.18	0.25	-	-	0.62
Total	100.43	100.48	103.21	95.64	97.69	99.43	99.01	99.89
Si	2.9877	2.9896	2.9384	2.8013	2.9968	3.0026	3.0068	3.0068
Ti	0.0069	0.0118	-	-	-	-	-	-
Al	1.0246	1.0123	1.0567	1.0603	1.0212	1.0111	1.0043	1.0082
Fe	-	-	0.0217	0.1941	-	-	-	-
Mg	-	-	-	0.1207	-	-	-	-
Ca	0.0120	0.0161	0.0843	0.1078	-	-	-	-
K	0.8158	0.8529	0.2647	0.2868	0.9265	0.9560	0.9599	0.8931
Na	0.1081	0.0724	0.5996	0.4818	0.0227	-	-	0.0550
Total	4.9551	4.9551	4.9654	5.0528	4.9671	4.9698	4.9710	4.9631
Ca	1.0	1.7	8.9	12.3	0.0	0.0	0.0	0.0
Na	11.6	7.7	63.2	55.0	2.4	0.0	0.0	0.0
K	87.2	90.6	27.9	32.7	97.6	100.0	100.00	94.2

69361			69368		
gr	gr	gr	gr	gr	
65.23	67.02	67.04	65.54	67.28	
0.68	-	-	-	-	
19.38	19.55	19.24	19.12	18.41	
-	-	-	-	-	
-	-	-	-	-	
-	0.91	-	0.25	0.16	
13.54	8.56	13.61	11.16	11.37	
1.67	4.31	1.94	3.19	2.85	
100.49	100.35	101.83	99.25	100.07	
2.9653	2.9919	3.0019	2.9901	3.0359	
0.0231	-	-	-	-	
1.0380	1.0285	1.0156	1.0280	0.9789	
-	-	-	-	-	
-	-	-	-	-	
-	0.0435	-	0.0120	0.0076	
0.7848	0.4872	0.7772	0.6495	0.6547	
0.1473	0.3728	0.1684	0.2821	0.2496	
4.9586	4.9239	4.9631	4.9617	4.9268	
0.0	4.8	0.0	1.3	0.8	
15.8	41.3	17.8	29.9	27.4	
84.2	53.9	82.2	68.8	71.8	

Clinopyroxene

Rock type	Basalt							
Sample No	69292							
Type	Pc	Pr	MP	Pr	Pc	Pr	Pr	Pc
SiO2	47.98	51.28	49.36	47.67	48.17	50.33	50.83	48.74
TiO2	1.97	1.13	1.67	2.11	2.34	1.26	1.16	1.77
Al2O3	5.23	2.99	4.36	5.24	5.35	3.47	3.16	5.21
Cr2O3	-	-	-	-	-	-	-	-
FeO	10.60	9.93	10.69	10.38	10.57	9.93	9.91	10.16
MnO	-	0.39	-	-	-	0.29	0.40	0.30
MgO	12.53	14.23	13.31	12.31	12.63	13.88	13.88	12.94
CaO	21.36	20.89	21.09	21.03	21.32	20.93	20.79	21.51
Na2O	-	0.32	0.46	0.49	0.45	0.32	-	0.61
Total	99.66	101.17	100.87	99.23	100.82	100.39	100.14	101.25
Si	1.8152	1.8980	1.8428	1.8123	1.8036	1.8797	1.8992	1.8152
Ti	0.0559	0.0315	0.0469	0.0604	0.0658	0.0353	0.0326	0.0495
Al	0.2333	0.1305	0.1916	0.2349	0.2360	0.1526	0.1391	0.2287
Cr	-	-	-	-	-	-	-	-
Fe	0.3355	0.3074	0.3317	0.3299	0.3309	0.3101	0.3096	0.3167
Mn	-	0.0123	-	-	-	0.0092	0.0127	0.0095
Mg	0.7064	0.7853	0.7409	0.6973	0.7048	0.7726	0.7731	0.7184
Ca	0.8659	0.8286	0.8436	0.8569	0.8552	0.8374	0.8323	0.8593
Na	-	0.0228	0.0336	0.0361	0.0324	0.0232	-	0.0439
Total	4.0122	4.0166	4.0313	4.0278	4.0288	4.0202	3.9986	4.0421
100Mg/(Mg+Fe)	67.8	71.9	69.1	67.9	68.0	71.4	71.4	69.4
Ca	45.4	43.1	44.0	45.5	45.2	43.6	43.5	45.4
Mg	37.0	40.9	38.7	37.0	37.3	40.2	40.4	37.9
Fe	17.6	16.0	17.3	17.5	17.5	16.2	16.2	16.7

69293				69295			
P	mp	mp	mp	mp	mp	mp	gr
46.99	46.56	45.87	46.45	49.31	49.18	49.11	52.96
1.87	2.26	2.14	2.01	1.27	1.08	1.02	-
6.03	6.28	5.84	5.31	3.26	3.51	3.49	0.18
-	0.25	-	-	-	0.33	0.20	-
13.62	12.59	13.00	12.86	11.08	8.98	7.96	24.44
0.23	0.28	0.28	0.25	0.30	-	-	0.56
11.24	10.85	10.48	10.86	14.50	14.54	14.20	19.22
19.32	20.93	20.75	20.71	18.58	19.85	20.49	2.45
0.56	0.49	0.41	0.45	0.27	-	-	-
99.86	100.49	98.71	98.92	98.56	97.47	96.48	99.81
1.7953	1.7710	1.7798	1.7967	1.8775	1.8790	1.8894	2.0059
0.0538	0.0647	0.0625	0.0585	0.0363	0.0309	0.0295	-
0.2714	0.2815	0.2669	0.2423	0.1464	0.1582	0.1581	0.0079
-	0.0074	-	-	-	0.0099	0.0062	-
0.4352	0.4005	0.4219	0.4161	0.3528	0.2870	0.2562	0.7742
0.0076	0.0090	0.0093	0.0081	0.0096	-	-	0.0179
0.6401	0.6149	0.6060	0.6263	0.8226	0.8283	0.8145	1.0848
0.7911	0.8528	0.8625	0.8585	0.7579	0.8126	0.8449	0.0994
0.4130	0.0359	0.0306	0.0341	0.0198	-	-	-
4.0358	4.0378	4.0395	4.0407	4.0229	4.0060	3.9989	3.9901
59.5	60.6	59.0	60.1	70.0	74.3	76.1	58.4
42.4	45.6	45.6	45.2	39.2	42.2	44.1	5.1
34.3	32.9	32.1	32.9	42.5	43.0	42.5	55.4
23.3	21.4	22.3	21.9	18.2	14.9	13.4	39.5

			69297			
mp	mp	I.pl	I.pl	I.pl	mp	mp
52.17	52.66	50.88	49.83	52.04	51.67	52.14
0.20	0.59	0.77	0.71	0.60	0.57	0.39
1.29	1.92	2.10	2.14	2.13	1.55	2.37
-	-	-	-	-	-	-
7.84	7.79	7.99	7.88	7.95	9.72	7.45
-	-	0.23	-	-	-	-
15.37	15.45	15.11	14.58	15.14	16.21	14.84
22.33	22.67	21.11	21.04	22.14	19.91	22.91
-	-	-	-	-	-	-
99.21	101.06	98.19	96.19	100.00	99.63	100.11
1.9526	1.9334	1.9243	1.9243	1.9312	1.9309	1.9316
0.0055	0.0162	0.0220	0.0206	0.0168	0.0160	0.0109
0.0570	0.0830	0.0935	0.0974	0.0932	0.0683	0.1035
-	-	-	-	-	-	-
0.2455	0.2391	0.2527	0.2546	0.2467	0.3038	0.2309
-	-	0.0073	-	-	-	-
0.8574	0.8456	0.8520	0.8391	0.8372	0.9026	0.8196
0.8954	0.8917	0.8552	0.8703	0.8803	0.7973	0.9093
-	-	-	-	-	-	-
4.0134	4.0089	4.0069	4.0064	4.0054	4.0190	4.0058
77.7	78.0	77.1	76.7	77.2	74.8	78.0
44.8	45.1	43.6	44.3	44.8	39.8	46.4
42.9	42.8	43.5	42.7	42.6	45.0	41.8
12.3	12.1	12.9	13.0	12.6	15.2	11.8

Andesite							
69299							
mp	Pr	Pr	Pr	Pc	gr	Pr	Pc
52.06	51.13	50.63	52.36	52.25	52.36	52.93	50.25
0.62	0.67	0.76	0.61	0.59	0.62	0.50	0.74
1.44	3.28	3.22	2.02	2.26	1.32	1.92	4.45
-	-	-	-	-	-	-	-
10.85	9.48	10.20	9.05	8.93	11.65	9.31	9.27
0.28	-	0.23	0.25	0.26	0.42	0.25	-
16.00	14.96	15.01	16.43	16.19	14.87	16.27	14.57
17.91	20.23	19.44	19.92	19.89	18.70	20.05	20.30
-	0.30	0.34	0.31	0.29	0.30	-	-
99.17	100.06	99.82	100.95	100.66	100.24	101.23	99.57
1.9528	1.9025	1.8946	1.9259	1.9257	1.9563	1.9398	1.8762
0.0175	0.0188	0.0213	0.0170	0.0163	0.0175	0.0137	0.0208
0.0638	0.1437	0.1419	0.0875	0.0982	0.0582	0.0828	0.1960
-	-	-	-	-	-	-	-
0.3405	0.2950	0.3193	0.2784	0.2752	0.3641	0.2854	0.2893
0.0089	-	0.0073	0.0077	0.0081	0.0132	0.0079	-
0.8947	0.8297	0.8369	0.9006	0.8893	0.8281	0.8885	0.8106
0.7196	0.8063	0.7793	0.7852	0.7855	0.7487	0.7871	0.8119
-	0.0220	0.0247	0.0223	0.0209	0.0217	-	-
3.9978	4.0179	4.0254	4.0245	4.0193	4.0079	4.0051	4.0049
72.4	73.8	72.4	76.4	76.4	69.5	75.7	73.7
36.8	41.8	40.3	40.0	40.3	38.6	40.1	42.5
45.8	43.0	43.2	45.9	45.6	42.7	45.3	42.4
17.4	15.3	16.5	14.2	14.1	18.8	14.6	15.1

69306						69310			
gr	gr	gr	gr	I.pl	I.pl	mp	mp	mp	mp
51.53	53.65	53.41	52.61	51.88	52.89	52.29	51.59	52.47	52.27
0.58	-	-	0.48	0.69	0.36	0.71	0.82	0.69	0.61
1.24	0.73	1.25	1.80	1.45	1.21	1.83	2.77	1.86	1.99
-	-	-	-	-	-	-	-	-	-
13.72	9.94	15.16	11.68	16.03	12.56	12.88	14.72	12.57	13.45
0.25	-	0.29	-	0.24	0.28	-	-	0.24	-
13.61	14.45	15.05	13.99	15.58	14.47	15.92	15.49	15.79	15.17
19.20	22.37	16.58	20.91	15.62	20.71	17.81	15.93	18.02	17.65
-	-	-	0.27	-	-	-	-	-	-
100.12	101.15	101.74	101.73	101.50	102.48	101.43	101.43	101.63	101.15
1.9487	1.9820	1.9765	1.9436	1.9342	1.9473	1.9312	1.9133	1.9337	1.9390
0.0164	-	-	0.0133	0.0194	0.0101	0.0197	0.0230	0.0191	0.0170
0.0553	0.0319	0.0544	0.0785	0.0639	0.0524	0.0795	0.1211	0.0807	0.0869
-	-	-	-	-	-	-	-	-	-
0.4338	0.3072	0.4692	0.3610	0.4997	0.3866	0.3977	0.4565	0.3874	0.4173
0.0081	-	0.0090	-	0.0074	0.0087	-	-	0.0075	-
0.7672	0.7958	0.8301	0.7702	0.8659	0.7943	0.8762	0.8563	0.8672	0.8387
0.7778	0.8853	0.6572	0.8275	0.62.39	0.8172	0.7048	0.6329	0.7113	0.7016
-	-	-	0.0192	-	-	-	-	-	-
4.0073	4.0021	3.9963	4.0133	4.0144	4.0164	4.0093	4.2232	4.0068	4.0005
63.9	72.2	63.9	68.1	63.4	67.3	68.8	65.2	69.1	66.8
39.3	44.5	33.6	42.25	31.4	40.9	35.6	32.5	36.2	35.8
38.8	40.0	42.4	39.32	43.5	39.8	44.3	44.0	44.1	42.8
21.9	15.4	24.0	18.43	25.1	19.3	20.1	23.5	19.7	21.3

69308						69301		
mp	mp	mp	gr	P	P	gr	mp	mp
49.44	50.43	50.10	50.57	51.09	49.64	51.99	50.47	50.78
1.44	1.19	1.34	1.09	0.95	1.45	0.47	1.06	0.88
3.83	3.15	3.52	3.13	2.88	4.18	0.66	3.33	2.78
0.27	0.32	0.31	0.33	0.49	0.29	-	-	-
11.64	10.44	11.59	9.81	10.43	11.38	12.93	10.26	9.43
0.29	-	0.24	-	-	0.26	0.33	-	0.24
14.93	14.94	14.43	15.06	16.17	15.25	15.75	15.33	15.99
17.99	19.16	18.29	19.46	18.29	17.79	16.49	19.88	20.23
-	0.25	0.29	-	-	-	-	0.28	0.37
99.82	99.87	100.01	99.46	100.31	100.25	98.62	100.60	101.13
1.8583	1.8871	1.8780	1.8939	1.8957	1.8531	1.9732	1.8760	1.8731
0.0408	0.0336	0.0376	0.0307	0.0265	0.0408	0.0135	0.0296	0.0243
0.1695	0.1381	0.1553	0.1381	0.1261	0.1840	0.0294	0.1458	0.1208
0.0079	0.0095	0.0092	0.0098	0.0144	0.0086	-	-	-
0.3658	0.3268	0.3634	0.3073	0.3237	0.3553	0.4105	0.3190	0.2909
0.0092	-	0.0075	-	-	0.0082	0.0106	-	0.0076
0.8362	0.8333	0.8060	0.8407	0.8941	0.8486	0.8910	0.8492	0.8789
0.7245	0.7680	0.7345	0.7809	0.7271	0.7113	0.6704	0.7919	0.7994
-	0.0182	0.0210	-	-	-	-	0.0199	0.0261
4.0122	4.0146	4.0126	4.0015	4.0076	4.0098	3.9986	4.0314	4.0348
69.6	71.8	68.9	73.2	73.4	70.5	68.5	72.7	75.1
37.6	39.8	38.6	40.5	37.4	37.1	34.0	40.4	40.6
43.4	43.2	42.3	43.6	46.0	44.3	45.2	43.3	44.6
19.0	16.9	19.1	15.9	16.6	18.6	20.8	16.3	14.8

Dacite								
69328					69344			
Pr	Pr	Pc	Pr	Pc	Pr	Pc	Pc	Pr
53.56	52.84	52.31	53.53	52.58	52.23	51.99	51.62	53.42
0.40	0.61	0.39	0.47	0.58	0.64	0.60	0.52	0.28
1.87	2.18	2.91	1.69	2.35	3.51	2.58	2.05	1.32
-	-	-	-	-	0.78	-	-	-
11.23	11.06	11.88	11.87	11.00	6.32	7.62	9.04	7.81
0.42	0.42	0.41	0.39	0.26	-	-	-	0.24
15.03	15.00	13.83	14.73	14.83	16.56	15.12	14.88	15.48
20.59	20.52	19.71	20.69	21.05	21.13	21.07	20.62	21.74
0.30	-	0.38	0.25	0.26	0.34	0.44	0.25	-
103.41	102.63	101.83	103.63	102.90	101.51	99.43	98.99	100.29
1.9414	1.9285	1.9285	1.9421	1.9177	1.8937	1.9332	1.9389	1.9700
0.0110	0.0168	0.0109	0.0129	0.0159	0.0173	0.0167	0.0148	0.0077
0.0798	0.0936	0.1266	0.0721	0.1008	0.1499	0.1132	0.0909	0.0574
-	-	-	-	-	0.0223	-	-	-
0.3405	0.3376	0.3662	0.3602	0.3355	0.1915	0.2371	0.2841	0.2410
0.0129	0.0130	0.0127	0.0121	0.0082	-	-	-	0.0074
0.8119	0.8158	0.7601	0.7965	0.8062	0.8950	0.8380	0.8331	0.8508
0.7996	0.8026	0.7786	0.8043	0.8225	0.8209	0.8393	0.8299	0.8592
0.0209	-	0.0270	0.0176	0.0182	0.0242	0.0319	0.0183	-
4.0181	4.0079	4.0107	4.0178	4.0250	4.0150	4.0094	4.0100	3.9936
70.5	70.7	67.5	68.9	70.6	82.4	77.9	74.6	77.9
41.0	41.0	40.9	41.0	41.9	43.0	43.8	42.6	44.0
41.6	41.7	39.9	40.6	41.0	46.9	43.8	42.8	43.6
17.4	17.3	19.2	18.4	17.1	10.1	12.4	14.6	12.4

Orthopyroxene

Rock type	Basalt						
Sample No			69297				
Type							
SiO2	53.25	53.39	51.99	52.76	54.89	53.37	53.63
TiO2	0.34	0.34	0.24	-	-	0.31	0.31
Al2O3	1.01	1.18	0.89	3.11	0.89	0.93	1.00
Cr2O3	-	-	-	-	-	-	-
FeO	18.19	19.17	19.01	14.72	14.77	20.66	20.20
MnO	0.22	0.46	0.38	0.26	-	0.53	0.54
MgO	25.48	25.26	24.13	27.35	28.83	24.53	24.43
CaO	1.73	1.48	1.47	0.50	0.60	1.49	1.39
K2O	-	-	-	1.02	-	-	-
Total	100.22	101.28	98.11	99.72	99.97	101.81	101.50
Si	1.9478	1.9408	1.9537	1.9129	1.9686	1.9440	1.9531
Ti	0.0094	0.0093	0.0068	-	-	0.0086	0.0086
Al	0.0437	0.0508	0.0394	0.1327	0.0347	0.0399	0.0431
Cr	-	-	-	-	-	-	-
Fe	0.5566	0.5828	0.5974	0.4464	0.4429	0.6293	0.6153
Mn	0.0069	0.0143	0.0121	0.0078	-	0.0162	0.0168
Mg	1.3891	1.3688	1.3513	1.4781	1.5408	1.3315	1.3261
Ca	0.0676	0.0575	0.0592	0.0193	0.0230	0.0580	0.0542
K	-	-	-	0.0470	-	-	-
100Mg/ Mg+Fe	71.4	70.1	69.3	76.8	77.7	67.9	68.3
Ca	3.4	2.9	3.0	1.0	1.1	2.9	2.7
Mg	69.0	68.1	67.3	76.0	76.8	66.0	66.6
Fe	27.6	29.0	29.8	23.0	22.1	31.2	30.8

Andesite								
69308				69310				
Pc	P	P	P	gr	Pr	Pc	Pc	Pc
54.65	54.13	54.04	54.47	52.85	51.62	54.45	54.39	51.58
0.32	0.35	0.45	0.43	0.50	0.39	0.34	0.26	0.63
1.73	2.03	2.38	2.06	1.00	1.31	0.99	0.99	1.57
-	-	-	-	-	-	-	-	-
14.61	14.64	14.87	14.88	19.26	21.26	20.29	18.51	21.96
0.27	0.24	-	0.28	0.31	0.46	0.36	0.24	0.40
27.24	27.05	27.04	27.09	24.26	22.22	24.45	26.01	22.46
2.20	2.43	2.27	2.30	2.09	2.04	2.10	1.86	1.90
-	-	-	-	-	-	-	-	-
101.01	100.88	101.05	101.50	100.27	99.30	102.98	102.26	100.50
1.9489	1.9361	1.9284	1.9369	1.9457	1.9405	1.9548	1.9500	1.9210
0.0087	0.0094	0.0121	0.0114	0.0138	0.0111	0.0092	0.0069	0.0177
0.0728	0.0857	0.1001	0.0862	0.0432	0.0579	0.0420	0.0418	0.0690
-	-	-	-	-	-	-	-	-
0.4357	0.4383	0.4437	0.4424	0.5931	0.6684	0.6093	0.5550	0.6839
0.0081	0.0073	-	0.0083	0.0097	0.0147	0.0109	0.0073	0.0126
1.4478	1.4420	1.4380	1.4356	1.3311	1.2450	1.3083	1.3897	1.2468
0.0839	0.0930	0.0869	0.0878	0.0823	0.0820	0.0807	0.0715	0.0758
-	-	-	-	-	-	-	-	-
4.0060	4.0117	4.0094	4.0086	4.0189	4.0195	4.0150	4.0222	4.0268
76.9	76.7	76.4	76.4	69.2	65.1	68.2	71.5	64.6
4.3	4.7	4.4	4.5	4.1	4.1	4.0	3.5	3.8
73.6	73.1	73.0	73.0	66.3	62.4	65.5	68.9	62.1
22.1	22.2	22.5	22.5	29.6	33.5	30.5	27.5	34.1

69306							69301	
mp	gr	Pc	P	gr	I.pl	I.pl	gr	mp
51.68	52.95	52.68	53.21	52.44	52.90	52.11	53.07	54.12
0.34	0.22	-	0.23	0.24	0.25	0.22	0.54	0.40
0.98	0.65	1.12	0.60	0.88	0.55	0.61	0.62	0.74
-	-	-	-	-	-	-	-	-
24.14	23.28	21.91	27.29	26.94	25.06	26.09	19.54	17.29
0.39	0.43	1.00	0.58	0.49	0.48	0.44	0.60	0.48
20.49	22.18	23.10	19.02	19.71	21.50	20.43	24.14	26.15
1.67	1.51	0.64	1.02	1.59	1.91	1.47	2.03	2.16
-	-	-	-	-	-	-	-	-
99.68	101.21	100.44	101.96	102.27	102.65	101.38	100.55	101.34
1.9570	1.9626	1.9556	1.9880	1.9568	1.9520	1.9560	1.9528	1.9526
0.0096	0.0060	-	0.0066	0.0067	0.0070	0.0062	0.0151	0.0107
0.0436	0.0282	0.0491	0.0265	0.0385	0.0238	0.0269	0.0268	0.0316
-	-	-	-	-	-	-	-	-
0.7646	0.7216	0.6802	0.8528	0.8405	0.7734	0.8191	0.6012	0.5215
0.0125	0.0135	0.0314	0.0183	0.0154	0.0150	0.0139	0.0188	0.0148
1.1564	1.2255	1.2780	1.0592	1.0960	1.1824	1.1428	1.3241	1.4061
0.0679	0.0599	0.0254	0.0408	0.0634	0.0755	0.0592	0.0800	0.0836
-	-	-	-	-	-	-	-	-
4.0116	4.0173	4.0198	3.9922	4.0173	4.0291	4.0242	4.0187	4.0209
60.2	62.9	65.3	55.4	56.6	60.5	58.3	68.8	72.9
3.4	3.0	1.3	2.1	3.2	3.7	2.9	4.0	4.2
58.1	61.1	64.4	54.2	54.8	58.2	56.5	66.0	69.9
38.4	36.0	34.3	43.7	42.0	38.1	40.5	30.0	25.9

		Dacite						
69301		69344						
gr	gr							
53.85	53.07	53.13	55.49	56.67	54.57	54.89	56.60	
0.42	0.36	0.20	0.34	1.70	1.53	3.74	2.60	
0.90	0.71	0.44	2.25	-	-	0.26	0.18	
-	-	-	0.40	0.22	-	-	0.68	
17.30	17.20	17.70	12.61	10.62	17.89	11.63	9.65	
0.54	0.45	0.27	-	-	0.45	-	-	
26.04	25.31	26.24	29.52	31.10	26.49	29.72	31.44	
2.12	2.78	1.12	1.42	1.46	0.65	1.22	1.16	
-	-	-	-	-	-	-	-	
101.25	100.40	101.10	102.04	101.77	101.57	101.77	102.21	
1.9457	1.9356	1.9845	1.9354	1.9607	1.9564	1.9106	1.9389	
0.0115	0.0099	0.0055	0.0090	-	-	0.0069	0.0046	
0.0415	0.0303	0.0185	0.0926	0.0692	0.0646	0.1533	0.1052	
-	-	-	0.0109	0.0061	-	-	0.0183	
0.5227	0.5245	0.5329	0.3678	0.3073	0.5363	0.3473	0.2768	
0.0164	0.0138	0.0082	-	-	0.0137	-	-	
1.4021	1.3762	1.4080	1.5348	1.6040	1.4155	1.5421	1.6079	
0.0822	0.1084	0.0431	0.0532	0.0543	0.0249	0.0457	0.0427	
-	-	-	-	-	-	-	-	
4.0221	4.0150	4.0008	4.0038	4.0016	4.0113	4.0059	3.9946	
72.8	72.4	72.5	80.7	83.9	72.5	81.6	85.3	
4.1	5.4	2.2	2.7	2.8	1.3	2.4	2.2	
69.9	68.5	71.0	78.5	81.6	71.6	79.7	83.4	
26.0	26.1	26.9	18.8	15.6	27.1	17.9	14.4	

69350			
53.84	54.41	52.70	54.26
-	-	-	-
1.46	1.81	2.89	1.82
-	-	-	-
18.71	18.87	19.19	17.89
0.38	0.41	0.58	0.51
25.34	25.35	24.69	26.58
0.92	0.99	0.59	0.75
-	-	-	-
100.64	101.84	100.64	101.81
1.9581	1.9549	1.9226	1.9430
-	-	-	-
0.0625	0.0767	0.1240	0.0770
-	-	-	-
0.5690	0.5669	0.5855	0.5358
0.0116	0.0124	0.0180	0.0155
0.0359	0.0380	0.0229	0.0287
1.3736	1.3577	0.0229	0.0287
-	-	-	-
4.0107	4.0067	4.0154	4.0185
70.7	70.5	69.6	72.6
1.8	1.9	1.2	1.4
69.4	69.2	68.8	71.5
28.8	28.9	30.0	27.0

Hornblende

Rock type	Basalt				Andesite			
Sample No	69297				69306			
Type	mp	mp	gr	mp				
SiO2	45.80	44.95	48.43	41.10	56.64	50.85	50.70	50.85
TiO2	1.69	1.42	0.93	2.97	0.42	0.23	0.20	0.39
Al2O3	8.24	8.33	7.13	9.53	4.19	5.28	5.16	4.86
Cr2O3	-	-	-	0.32	-	-	-	-
FeO	11.65	10.37	11.68	19.39	13.35	14.35	14.78	14.39
MnO	-	-	-	-	-	-	-	-
MgO	15.33	15.85	16.61	13.79	14.53	16.23	15.57	15.33
CaO	12.12	11.78	12.21	10.93	13.95	11.39	11.46	11.57
K2O	0.56	0.46	0.36	0.56	0.43	0.36	0.36	0.39
Na2O	1.19	1.38	1.01	1.50	0.71	0.84	0.91	0.78
Cl	0.14	0.13	0.14	0.15	0.11	0.10	0.14	0.13
Total	96.71	94.66	98.49	100.24	98.33	99.63	99.28	98.69
Si	6.7616	6.7434	6.9755	6.1300	7.3709	7.2734	7.2983	7.3485
Ti	0.1877	0.1607	0.1010	0.3331	0.0460	0.0246	0.0213	0.0423
Al	1.4341	1.4727	1.2100	1.6756	0.7196	0.8892	0.8749	0.8280
Cr	-	-	-	0.0383	-	-	-	-
Fe	1.4378	1.3007	1.4069	2.4188	1.6248	1.7166	1.7796	1.7392
Mn	-	-	-	-	-	-	-	-
Mg	3.3728	3.5436	3.5660	3.0670	3.1512	3.4593	3.3407	3.3019
Ca	1.9164	1.8939	1.8847	1.7464	2.1651	1.7456	1.7676	1.7906
K	0.1047	0.0888	0.0664	0.1072	0.0805	0.0655	0.0667	0.0717
Na	0.3417	0.4002	0.2819	0.4337	0.1997	0.2318	0.2544	0.2177
Cl	-	-	-	0.0383	0.0268	0.0253	0.0348	0.0310
Total	15.5915	15.6372	15.5260	15.9870	15.3846	15.4312	15.4382	15.3709
100Mg/(Mg+Fe)	70.1	73.1	71.7	55.9	66.0	66.8	65.2	65.5
Ca	28.5	28.1	27.5	24.1	31.2	25.2	25.7	26.2
Mg	50.1	52.6	52.0	42.4	45.4	50.0	48.5	48.3
Fe	21.4	19.3	20.5	33.4	23.4	24.8	25.8	25.5

							Dacite	
69307						69350		
Pr	Pc	Pr	Pc	Pr	Pc	P	P	
43.32	45.39	45.73	42.10	41.29	42.31	43.33	45.33	
1.45	0.64	1.16	0.93	1.22	0.69	2.46	2.38	
13.37	11.15	9.39	14.59	11.60	16.65	10.01	10.34	
-	-	-	-	-	-	-	-	
11.16	14.87	14.09	14.80	10.60	16.65	11.93	12.52	
-	0.28	-	-	-	0.33	-	-	
15.59	13.36	14.59	11.79	15.43	11.10	14.22	14.76	
11.48	10.15	10.44	10.63	11.08	10.13	10.98	11.49	
0.26	0.18	0.22	0.33	0.26	0.26	0.48	0.42	
2.10	1.37	1.46	1.70	2.25	1.55	1.88	1.86	
-	-	-	0.08	-	-	-	-	
98.72	97.40	97.08	96.95	96.35	96.52	95.29	99.10	
6.2464	6.6770	6.7389	6.2634	6.1021	6.3691	6.5085	6.5425	
0.1567	0.0711	0.1288	0.1036	0.1356	0.0783	0.2778	0.2579	
2.2714	1.9322	1.6316	2.5589	2.4757	2.3950	1.7724	1.7579	
-	-	-	-	-	-	-	-	
1.3453	1.8296	1.7361	1.8421	1.3103	2.0958	1.4987	1.7579	
-	0.0347	-	-	-	0.0414	-	-	
3.3503	2.9291	3.2042	2.6147	3.3996	2.4912	3.1842	3.1759	
1.7733	1.6001	1.6482	1.6943	1.7541	1.6331	1.7665	1.7766	
0.0472	0.0338	0.0412	0.0621	0.0491	0.0491	0.0928	0.0768	
0.5881	0.3898	0.4160	0.4906	0.6444	0.4527	0.5461	0.5205	
-	-	-	0.0192	-	-	-	-	
15.7786	15.4975	15.5450	15.6489	15.8710	15.6058	15.6469	15.6191	
71.3	61.6	64.9	58.7	72.2	54.3	68.0	67.8	
27.4	25.2	25.0	27.5	27.1	26.3	27.4	27.5	
51.8	46.1	48.6	42.5	52.6	40.1	49.4	49.1	
20.8	28.8	26.4	29.9	20.3	33.7	23.2	23.4	

69325					69337			
Pr	Pc	pr	Pc	mp	mp	Pr	Pr	Pc
46.17	43.54	53.34	44.89	45.91	43.93	44.10	44.57	45.22
0.68	0.86	0.22	1.20	1.15	1.21	1.47	1.36	1.14
11.09	13.37	3.76	11.06	11.47	11.98	12.10	12.13	11.09
-	-	-	-	-	-	-	-	-
14.24	16.14	15.91	13.93	7.28	10.24	9.32	9.56	8.51
-	0.34	0.23	-	-	-	-	-	-
14.19	11.99	20.56	14.46	17.39	15.29	15.67	15.69	16.15
10.55	10.72	3.98	11.03	11.65	10.72	11.61	11.51	11.40
0.20	0.43	0.10	0.31	0.30	0.31	0.33	0.35	0.26
1.53	1.63	0.61	1.68	1.86	1.70	2.12	2.06	1.94
-	-	-	-	-	-	-	-	-
98.67	99.01	98.71			95.37	96.91	71.78	95.70
6.6803	6.3783	7.5386	6.5355	6.5861	6.4960	6.4193	6.4647	6.6166
0.0745	0.0949	0.0236	0.1315	0.1245	0.1344	0.1610	0.1485	0.1249
1.8907	2.3081	0.6267	1.8983	1.9394	2.0874	2.1096	2.0737	1.9118
-	-	-	-	-	-	-	-	-
1.7233	1.9771	1.8802	1.6953	0.8736	1.2663	1.1345	1.1596	1.0419
-	0.0419	0.0274	-	-	-	-	-	-
3.0610	2.6183	4.3324	3.1365	3.7186	3.3697	3.3993	3.3921	3.5213
1.6362	1.6829	0.6027	1.7211	1.7910	1.6989	1.8110	1.7893	1.7866
0.0371	0.0804	0.0177	0.0571	0.0547	0.0592	0.0610	0.0649	0.0482
0.4303	0.4619	0.1679	0.4737	0.5179	0.4871	0.5992	0.5790	0.5505
-	-	-	-	-	-	-	-	-
15.5334	15.6437	15.2171	15.6490	15.6058	15.5989	15.6949	15.6718	15.6018
64.0	57.0	69.7	64.9	81.0	72.7	75.0	74.5	77.2
25.5	26.8	8.8	26.3	28.1	26.8	28.5	28.2	28.1
47.7	41.7	63.6	47.9	58.3	53.2	53.6	53.5	55.5
26.8	31.5	27.6	25.9	13.7	20.0	17.9	18.3	16.4

69336					69334			
P	P	P	mp	P				
45.72	45.93	45.10	45.21	45.31	50.02	51.49	53.44	49.85
1.27	1.48	1.41	1.31	1.25	0.89	0.70	1.07	0.85
10.84	11.58	10.69	10.18	10.45	4.05	3.66	5.00	3.87
-	-	-	-	-	-	-	-	-
12.19	10.69	10.27	9.95	10.42	11.13	12.36	12.60	10.53
-	-	-	-	-	0.53	0.35	0.47	0.56
15.49	16.23	15.33	15.83	15.57	16.88	16.91	17.45	16.95
11.29	11.62	11.14	11.42	11.26	11.30	11.44	12.63	11.35
0.23	0.25	0.22	0.27	0.23	0.39	0.31	0.44	0.35
1.60	1.66	1.59	1.38	1.36	0.67	0.59	0.79	0.73
-	-	-	-	-	-	-	-	-
98.63	99.45	95.76	95.55	95.86	95.87	97.82	103.90	95.03
6.5887	6.5240	6.6375	6.6634	6.6617	7.3533	7.4304	7.2794	7.3758
0.1376	0.1584	0.1559	0.1449	0.1383	0.0979	0.0764	0.1095	0.0950
1.8420	1.9389	1.8540	1.7683	1.8113	0.7017	0.6222	0.8027	0.0950
-	-	-	-	-	-	-	-	-
1.4689	1.2703	1.2640	1.2260	1.2806	1.3687	1.4911	1.4354	1.3024
-	-	-	-	-	0.0663	0.0433	0.0540	0.0698
3.3272	3.4355	3.3636	3.4786	3.4128	3.6975	3.6377	3.5420	3.7375
1.7429	1.7688	1.7571	1.8040	1.7740	1.7799	1.7695	1.8435	1.7989
0.0423	0.0462	0.0406	0.0504	0.0435	0.0736	0.0574	0.0771	0.0659
0.4482	0.4581	0.4540	0.3939	0.3874	0.1920	0.1656	0.2096	0.2104
-	-	-	-	-	-	-	-	-
15.5978	15.6001	15.5268	15.5296	15.5096	15.3307	15.2936	15.3531	15.3302
69.4	73.0	72.7	73.9	72.7	73.0	70.9	71.2	74.2
26.7	27.3	27.5	27.7	27.4	26.0	25.7	27.0	26.3
50.9	53.1	52.7	53.4	52.8	54.0	52.7	51.9	54.7
22.5	19.6	19.8	18.8	19.8	20.0	21.6	21.0	19.0

Rhyolite	
69379	
45.04	43.80
2.06	2.20
8.56	8.32
-	-
12.05	12.18
0.43	0.40
15.35	14.77
10.94	11.13
0.45	0.47
1.66	1.69
-	-
96.54	94.94
6.6731	6.6275
0.2292	0.2500
1.4943	1.4831
-	-
1.4933	1.5409
0.0541	0.0509
3.3886	3.3310
1.7364	1.8046
0.0859	0.0915
0.4769	0.4946
-	-
15.6319	15.6740
69.4	68.4
26.2	27.0
51.2	49.9
22.6	23.1

Biotite

Rock type	Basalt	Andesite				Dacite	
Spl. No	69292	69306				69334	
Type							
SiO2	35.07	36.31	37.57	37.97	37.30	36.94	40.07
TiO2	5.36	5.51	4.12	4.71	4.54	4.12	4.59
Al2O3	13.52	13.28	13.47	14.63	13.74	13.23	13.86
FeO	18.47	18.40	17.30	18.69	25.36	15.02	15.90
MnO	0.24	-	-	-	-	-	-
MgO	13.80	12.92	13.81	12.92	7.11	14.92	16.11
CaO	0.21	-	-	-	-	-	-
K2O	6.46	8.67	9.09	9.40	9.23	9.23	9.88
Na2O	0.65	-	-	-	-	-	-
Cl	-	0.22	0.31	0.31	0.31	0.29	0.31
Total	93.79	95.30	95.68	98.63	97.58	93.74	100.72
Si	5.3835	5.5262	5.6608	5.5770	5.7221	5.6376	5.6819
Ti	0.6186	0.6306	0.4668	0.5208	0.5239	0.4728	0.4899
Al	2.4457	2.3814	2.3924	2.5333	2.4839	2.3792	2.3155
Fe	2.3716	2.3422	2.1798	2.2956	5.2535	1.9170	1.8850
Mn	0.0325	-	-	-	-	-	-
Mg	3.1583	2.9304	3.1023	2.8280	1.6249	3.3944	3.4042
Ca	0.0352	-	-	-	-	-	-
K	1.2642	1.6830	1.7479	1.7616	1.8071	1.7976	1.7875
Na	0.1948	-	-	-	-	-	-
Cl	-	0.0568	0.0792	0.0765	0.0795	0.0754	0.0743
Total	15.5044	15.5507	15.6292	15.5927	15.4948	15.6740	15.6383
100Mg/ Mg+Fe	57.1	55.6	58.7	55.2	33.3	63.9	64.4
Ca	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Mg	56.8	55.6	58.7	55.2	33.3	63.9	64.4
Fe	42.6	44.1	41.3	44.8	66.7	36.1	35.6

			Rhyolite					
69334			69379				69368	
			P	Pr		P		
37.39	37.77	36.99	36.73	35.25	35.05	37.05	33.32	36.22
4.39	4.18	4.35	4.20	4.06	4.00	4.18	2.17	2.29
13.00	12.71	12.83	13.75	13.43	13.00	14.24	18.91	19.32
15.30	14.60	15.04	15.38	15.73	15.60	16.06	16.47	19.87
-	-	-	0.48	0.36	0.34	0.42	-	-
14.92	15.63	15.03	14.57	14.17	13.73	15.17	9.14	10.01
-	-	-	-	-	-	-	0.40	-
9.08	9.18	9.25	8.63	8.37	8.49	8.60	5.89	8.04
-	-	-	0.27	0.25	0.26	0.50	-	-
0.25	-	-	0.12	0.12	0.17	0.12	0.12	0.08
94.62	94.37	93.79	94.13	91.75	90.63	96.34	86.42	95.82
5.6574	5.7050	5.6482	5.5789	5.5189	5.5656	5.5103	5.4336	5.4313
0.4992	0.4752	0.4992	0.4799	0.4786	0.4774	0.4670	0.2662	0.2582
2.3182	2.2619	2.3089	2.4617	2.4778	2.4317	2.4961	3.6340	3.4149
1.9355	1.8444	1.9208	1.9533	2.0599	2.0710	1.9971	2.2454	2.4923
0.0321	-	-	0.0612	0.0472	0.0455	0.0525	-	-
3.3653	3.5179	3.4204	3.2993	3.3069	3.2495	3.3633	2.2211	2.2375
-	-	-	-	-	-	-	0.0706	-
1.7528	1.7683	1.8009	1.6730	1.6717	1.7199	1.6312	1.2242	1.5374
-	-	-	0.0786	0.0766	0.0807	0.1450	-	-
0.0759	0.0765	0.0762	0.0304	0.0318	0.0452	0.0310	0.0343	0.0194
15.6364	15.6493	15.6746	15.6164	15.6694	15.6865	15.6936	15.1294	15.3910
63.5	65.6	64.0	62.8	61.6	61.1	62.7	49.7	47.3
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0
63.5	65.6	64.0	62.8	61.6	61.1	62.7	49.0	47.3
36.5	34.4	36.0	37.2	38.4	38.9	37.3	49.5	52.7

Magnetite

Rock type	Basalt							
Sample No.	69292			69295			69297	
Type	mp	mp	I.cpx	gr	gr	gr		
SiO2	-	1.71	1.20	-	-	-	0.32	0.38
TiO2	27.71	13.66	14.29	12.12	11.93	14.92	4.12	4.24
Al2O3	1.68	1.50	3.29	1.18	1.66	1.27	2.34	2.00
Cr2O3	-	-	-	0.74	0.97	0.40	1.12	1.05
Fe2O3	11.11	38.81	35.07	-	39.63	35.60	55.55	54.15
FeO	53.30	42.57	40.65	76.28	39.60	42.28	34.67	33.86
MnO	2.68	1.45	1.59	1.21	1.29	1.64	-	-
MgO	-	-	-	-	-	-	0.39	0.40
CaO	-	1.41	1.02	-	-	-	-	-
Na2O	-	-	0.54	-	-	-	-	-
Total	96.48	98.12	97.65	91.52	95.08	96.10	98.51	96.29
Si	-	0.0651	0.0453	-	-	-	0.0124	0.0150
Ti	0.8012	0.3899	0.4045	0.4209	0.3553	0.4397	0.1185	0.1249
Al	0.0761	0.0672	0.1458	0.0645	0.0775	0.0585	0.1053	0.0923
Cr	-	-	-	0.0272	0.0305	0.0123	0.0339	0.0326
Fe3+	0.3216	1.0028	0.9937	-	1.1814	1.0497	1.5989	1.5951
Fe2+	1.7141	1.3513	1.2797	2.9671	1.3121	1.3856	1.1090	1.1085
Mn	0.0872	0.0466	0.0508	0.0475	0.0434	0.0543	-	-
Mg	-	-	-	-	-	-	0.0222	0.0233
Ca	-	0.0573	0.0413	-	-	-	-	0.0083
Na	-	-	0.0391	-	-	-	-	-
Total	3.0000	3.0001	3.0001	3.5302	3.0001	3.0001	3.0002	3.0002

						Andesite		
69297		69307			69301			
		gr	gr	gr				
0.29	0.30	-	-	1.47	1.55	0.64	0.55	1.15
3.94	2.60	5.03	5.23	4.34	15.43	18.06	16.18	16.67
2.48	1.72	2.70	3.76	2.04	1.68	1.14	1.55	1.07
0.99	0.87	0.27	-	0.21	-	-	-	-
53.67	57.20	54.77	54.07	55.55	30.56	29.92	33.70	31.01
33.10	31.86	34.10	33.80	34.77	45.27	46.68	45.46	45.97
-	-	0.30	-	0.73	1.10	1.29	1.21	1.19
0.60	0.49	0.75	1.46	1.06	-	-	-	-
-	-	-	-	0.34	-	0.24	-	0.20
-	-	-	-	-	-	-	-	-
95.09	95.04	97.93	98.33	100.51	95.59	97.97	98.64	97.24
0.0116	0.0118	-	-	0.0544	0.0604	0.0246	0.0210	0.0441
0.1172	0.0777	0.1450	0.1485	0.1212	0.4525	0.5192	0.4624	0.4825
0.1157	0.0805	0.1222	0.1672	0.0892	0.0773	0.0515	0.0695	0.0486
0.0310	0.0275	0.0083	-	0.0062	-	-	-	-
1.5957	1.7130	1.5795	1.5357	1.5532	0.8969	0.8607	0.9637	0.8982
1.0938	1.0604	1.0929	1.0669	1.0805	1.4767	1.4925	1.4447	1.4798
-	-	0.0098	-	0.0231	0.0364	0.0417	0.0388	0.0389
0.0353	0.0293	0.0426	0.0819	0.0589	-	-	-	-
-	-	-	-	0.0135	-	0.0098	-	0.0081
-	-	-	-	-	-	-	-	-
3.0002	3.0002	3.0002	3.0002	3.0002	3.0001	3.0001	3.0001	3.0001

69299		69306			69310				
gr	mp								
0.68	1.54	0.19	0.39	-	0.85	0.83	0.84	0.65	
2.08	0.42	6.20	8.94	0.53	15.27	19.22	17.07	18.41	
1.87	0.31	1.70	2.06	0.80	3.26	1.61	1.52	3.21	
-	-	-	-	-	0.69	1.50	2.21	0.76	
58.13	60.87	54.56	57.90	64.91	29.83	24.16	27.77	26.21	
30.29	31.04	37.35	30.56	30.73	43.77	47.32	45.39	47.28	
-	-	-	-	-	1.13	1.26	1.33	1.32	
1.44	0.56	-	-	-	0.36	0.32	0.34	0.27	
-	-	-	0.15	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	
94.49	94.57	100.00	100.00	96.96	95.16	96.15	96.47	98.11	
0.027		0.0072	0.0209	-	0.0330	0.0334	0.0324	0.0246	
0.0620	0.0125	0.1768	0.3612	0.0156	0.4459	0.5557	0.4957	0.5215	
0.0873	0.0148	0.0761	0.0652	0.0373	0.1490	0.0734	0.0694	0.1423	
-	-	-	-	-	0.0213	0.0457	0.0676	0.0225	
1.7344	1.8364	1.5561	1.1706	1.9313	0.8717	0.7028	0.8068	0.7429	
1.0044	1.0412	1.1837	1.3733	1.0159	1.4215	1.5294	1.4655	1.4893	
-	-	-	-	-	0.0370	0.0413	0.0434	0.0420	
0.0850	0.0335	-	-	-	0.0206	0.0185	0.0193	0.0149	
-	-	-	0.0088	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	
3.0002	3.0002	2.9999	3.0000	3.0002	3.0001	3.0001	3.0001	3.0001	

					Dacite				
69342					69344				
gr	gr	gr	gr	gr			mp	gr	
0.77	0.56	0.56	0.23	6.70	1.09	-	-	-	
10.12	5.89	7.76	6.70	1.79	2.43	0.91	1.12	9.32	
3.65	3.99	3.75	5.41	2.23	1.05	1.02	0.80	0.60	
-	-	-	-	-	0.24	0.26	0.34	-	
42.34	49.17	37.79	48.00	40.82	59.84	65.11	65.19	47.61	
39.32	34.74	33.24	35.24	38.81	32.64	30.87	31.14	37.66	
0.43	0.38	0.27	-	-	-	-	-	-	
1.07	0.85	0.80	1.56	-	0.76	0.51	0.52	0.92	
-	0.19	-	-	0.31	0.60	-	-	0.31	
-	-	-	-	-	-	-	-	-	
97.69	95.77	84.16	97.14	90.67	98.66	98.68	99.11	96.41	
0.0290	0.0216	0.0245	0.0085	0.2711	0.0417	-	-	-	
0.2877	0.1715	0.2557	0.2406	0.1064	0.0699	0.0263	0.0324	0.2731	
0.1625	0.1820	0.1935	0.2406	0.1064	0.0475	0.0465	0.0361	0.0275	
-	-	-	-	-	0.0027	0.0079	0.0105	-	
1.2042	1.4317	1.2461	1.3620	1.2423	1.7220	1.8930	1.8886	1.3961	
1.2429	1.1241	1.2181	1.1111	1.3125	1.0439	0.9975	1.0026	1.2272	
0.0136	0.0124	0.0101	-	-	-	-	-	-	
0.0604	0.0492	0.0522	0.0877	-	0.0435	0.0291	0.0301	0.0532	
-	0.0077	-	-	0.0133	-	-	-	0.0130	
3.0001	3.0002	3.0001	3.0001	3.0001	3.0002	3.0002	3.0002	3.0000	

69336				69328				69334	
				gr	gr	gr	gr		
1.70	1.29	2.85	0.97	0.50	-	0.99	0.63	0.23	0.35
4.29	2.87	3.36	5.62	16.64	18.48	19.63	16.22	-	-
1.23	1.03	1.18	0.89	1.98	2.00	1.37	2.31	0.21	0.28
-	-	-	-	-	-	-	-	0.22	0.28
51.52	55.90	51.69	51.18	33.08	30.12	26.00	32.80	65.58	67.50
34.14	33.41	34.39	35.47	41.27	41.66	43.15	41.39	30.33	31.55
-	-	-	-	5.55	6.46	6.18	5.16	-	-
0.26	0.57	2.01	0.49	-	-	-	-	-	-
0.96	0.57	2.01	0.49	0.40	-	0.71	0.35	-	-
-	-	-	-	-	-	-	-	-	-
94.11	95.07	95.49	94.62	99.42	98.73	98.03	98.86	96.57	99.96
0.0681	0.0515	0.1118	0.0390	0.0187	-	0.0376	0.0239	0.0093	0.0136
0.1288	0.0861	0.0989	0.1691	0.4699	0.5263	0.5604	0.4596	-	-
0.0577	0.0482	0.0545	0.0420	0.0878	0.0893	0.0613	0.1027	0.0099	0.0125
-	-	-	-	-	-	-	-	0.0069	0.0084
1.5485	1.6764	1.5239	1.5416	0.9350	0.8581	0.7428	0.9303	1.9646	1.9517
1.1405	1.1134	1.1268	1.1875	1.2964	1.3191	1.3702	1.3046	1.0096	1.0139
-	-	-	-	0.1764	0.2073	0.1989	0.1649	-	-
0.0154	-	-	-	-	-	-	-	-	-
0.0412	0.0245	0.0842	0.0209	0.0159	-	0.0289	0.0141	-	-
-	-	-	-	-	-	-	-	-	-
3.0002	3.0002	3.0002	3.0002	3.0001	3.0001	3.0001	3.0001	3.0002	3.0002

Rhyolite										
69361	69368			69375		69379				
gr	gr	gr	gr			gr	gr	mp		
-	0.30	0.23	-	1.54	-	2.83	0.59	0.42		
2.14	2.58	2.60	2.51	25.65	27.73	3.80	3.85	3.67		
-	4.50	4.24	4.32	2.79	0.54	3.90	3.00	2.37		
-	-	-	-	-	-	-	-	-		
58.26	56.44	56.30	-	-	-	49.00	54.32	57.48		
29.08	32.98	32.68	84.52	54.61	59.29	28.91	31.87	31.57		
0.49	0.48	0.32	0.48	1.69	1.75	2.31	1.48	2.18		
-	0.27	0.32	-	-	-	1.70	0.86	0.77		
0.38	-	-	-	0.24	0.20	-	-	-		
-	-	-	-	-	-	0.71	-	-		
90.35	97.55	96.69	91.83	87.01	89.51	93.14	95.96	98.45		
-	0.0115	0.0091	-	0.0652	-	0.1100	0.0228	0.0159		
0.0684	0.0744	0.0757	0.0916	0.8170	0.8879	0.1110	0.1128	0.1054		
-	0.2029	0.1930	0.2467	0.1394	0.0272	0.1784	0.1376	0.1065		
-	-	-	-	-	-	-	-	-		
1.8630	1.6253	1.6374	-	-	-	1.4332	1.5911	1.6508		
1.0336	1.0553	1.0563	3.4269	1.9346	2.1111	0.9396	1.0375	1.0076		
0.0177	0.0156	0.0104	0.0196	0.0605	0.0630	0.0760	0.0487	0.0704		
-	0.0153	0.0183	-	-	-	0.0983	0.0497	0.0435		
0.0174	-	-	-	0.0108	0.0093	-	-	-		
-	-	-	-	-	-	0.0536	-	-		
3.0002	3.0002	3.0002	3.0002	3.0685	3.0985	3.0002	3.0002	3.0002		

Ilmenite

Rock type	Basalt				Andesite			
Sample No	69297				69306			
Type								
SiO2	0.33	0.21	0.32	0.24	0.19	0.27	2.35	0.29
TiO2	46.28	45.77	48.03	43.90	52.09	52.26	50.00	51.04
Al2O3	0.36	0.38	0.29	0.26	-	0.31	0.25	-
Cr2O3	-	-	-	-	-	-	-	-
Fe2O3	11.73	13.15	6.35	13.30	-	-	0.43	0.55
FeO	38.10	38.52	39.39	37.22	44.64	44.02	43.55	44.10
MnO	0.37	0.52	0.80	0.47	0.56	0.65	0.58	0.49
MgO	1.73	1.23	1.74	1.16	1.04	1.37	1.56	0.84
CaO	0.36	0.13	0.20	-	-	0.15	0.66	0.13
SO3	-	-	-	-	-	-	-	-
Total	99.25	99.92	97.12	96.55	98.29	99.47	99.51	96.89
Si	0.0084	0.0053	0.0081	0.0062	0.0048	0.0068	0.0583	0.0075
Ti	0.8754	0.8647	0.9262	0.8596	0.9974	0.9846	0.9330	0.9924
Al	0.0106	0.0114	0.0089	0.0081	-	0.0092	0.0073	-
Cr	-	-	-	-	-	-	-	-
Fe3+	0.2220	0.2487	0.1225	0.2605	-	0 0081	0.0102	-
Fe2+	0.8014	0.8094	0.8448	0.8104	0.9506	0.9222	0.9037	0.9535
Mn	0.0078	0.0110	0.0173	0.0103	0.0121	0.0137	0.0122	0.0107
Mg	0.0647	0.0460	0.0666	0.0449	0.0391	0.0512	0.0576	0.0325
Ca	0.0098	0.0035	0.0055	-	-	0.0041	0.0177	0.0036
S	-	-	-	-	-	-	-	-
Total	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0002

Dacite								
69342				69344				
0.60	0.47	0.61	0.57	-	-	-	-	-
43.85	41.39	41.15	45.93	0.29	0.18	-	-	-
0.42	0.43	0.39	0.39	42.77	41.69	37.50	37.37	37.65
-	-	-	-	-	-	-	-	-
10.52	11.11	9.62	10.97	19.89	21.07	29.71	29.36	29.29
35.11	33.93	32.96	37.74	34.26	33.46	30.08	30.66	30.82
0.87	0.87	0.73	1.09	0.59	0.42	0.34	-	-
2.33	1.67	2.15	1.76	2.51	2.39	0.85	0.65	1.70
-	-	0.15	-	-	-	-	-	-
-	-	-	-	0.28	0.22	-	-	-
	89.85	87.77	98.45	100.59	99.42	99.48	99.04	99.47
0.0159	0.0130	0.0171	0.0145	-	-	-	-	-
0.8727	0.8640	0.8741	0.8751	0.0084	0.0055	-	-	-
0.0132	0.0139	0.0131	0.0118	0.7985	0.7889	0.7162	0.7178	0.7199
-	-	-	-	-	-	-	-	-
0.2096	0.2321	0.2045	0.2092	0.3715	0.3990	0.5677	0.5643	0.5604
0.7772	0.7876	0.7786	0.7996	0.7112	0.7041	0.6388	0.6551	0.6554
0.0195	0.0204	0.0176	0.0233	0.0124	0.0090	0.0073	0.0628	0.0645
0.0920	0.0689	0.0905	0.0665	-	-	-	-	-
-	-	0.0044	-	0.0050	0.0038	-	-	-
-	-	-	-	-	-	-	-	-
2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0001	2.0001	2.0001

69328		69334	
gr	gr		
2.10	-	0.22	0.34
46.34	49.51	47.51	45.83
0.47	-	-	-
-	-	-	-
6.27	9.63	7.28	10.94
38.71	41.66	37.82	36.18
1.46	0.94	5.10	5.36
1.15	1.07	-	-
1.51	-	-	-
-	-	-	-
97.38	102.81	97.93	98.64
0.0530	-	0.0057	0.0086
0.8805	0.9114	0.9236	0.8857
0.0140	-	-	-
-	-	-	-
0.1192	0.1774	0.1416	0.2115
0.8179	0.8527	0.8175	0.7776
0.0313	0.0195	0.1116	0.1166
0.0434	0.0391	-	-
0.0408	-	-	-
-	-	-	-
2.0000	2.0000	2.0000	2.0000

Chrome spinel

Rock type	Basalt			
Sample No.	69293			
Type	I.chl	I.chl	I.chl	I.chl
TiO2	0.35	0.33	0.40	0.42
Al2O3	42.93	43.74	40.56	40.98
Cr2O3	20.20	19.53	23.08	22.66
Fe2O3	5.80	7.17	7.42	6.82
FeO	11.55	11.20	12.27	12.64
MgO	17.68	18.02	17.37	17.27
NiO	-	0.34	0.35	-
CaO	-	0.20	-	-
Total	98.50	100.52	101.45	100.79
Ti	0.0592	0.0549	0.0658	0.0698
Al	11.3271	11.3150	10.5875	10.7342
Cr	3.5752	3.3886	4.0410	3.9823
Fe3+	0.9765	1.1838	1.2371	1.1412
Fe2+	2.1620	2.0563	2.2732	2.3499
Mg	5.9001	5.8950	5.7338	5.7229
Ni	-	0.0595	0.0618	-
Ca	-	0.0469	-	-
Total	24.0001	24.0001	24.0001	24.0001
100Mg/Mg+Fe2+	73.2	74.1	71.6	70.9
100Cr/Cr+Al	24.0	23.0	27.6	27.1

B. The Cretaceous subvolcanic and volcanic rocks from western part of West Kalimantan

Plagioclase

Rock type	Basalt							
Sample No	69381				69382			
Type	mp	mp	mp	gr	mp	Pc	Pr	gr
SiO2	54.35	53.80	50.07	52.80	49.89	45.85	47.06	50.71
Al2O3	29.05	28.99	32.29	28.79	30.89	33.57	33.10	30.72
Cr2O3	-	-	-	-	-	-	-	-
FeO	0.31	0.30	0.25	0.56	0.23	0.27	-	-
MgO	-	-	-	-	-	-	-	-
CaO	11.37	11.42	15.12	12.16	14.09	17.39	16.64	13.49
K2O	0.13	-	-	-	-	-	-	-
Na2O	4.85	4.90	2.96	4.33	3.44	1.44	1.97	3.60
Total	100.17	99.41	100.68	98.64	98.77	98.53	98.77	98.53
Si	2.4525	2.4441	2.2694	2.4250	2.3033	2.1412	2.1842	2.3359
Al	1.5449	1.5523	1.7248	1.5584	1.6809	1.8475	1.8103	1.6677
Cr	-	-	-	-	-	-	-	-
Fe	0.0117	0.0114	0.0096	0.0216	0.0090	0.0107	-	-
Mg	-	-	-	-	-	-	-	-
Ca	0.5497	0.5559	0.7342	0.5981	0.6968	0.8702	0.8275	0.6659
K	0.0076	-	-	-	-	-	-	-
Na	0.4247	0.4318	0.2601	0.3853	0.3083	0.1307	0.1769	0.3215
Total	4.9911	4.9955	4.9981	4.9884	5.0063	5.0003	4.9990	4.9909
Ca	69.5	70.0	73.8	60.8	69.3	86.9	82.4	67.4
Na	29.7	30.0	26.2	39.2	30.7	13.1	17.6	32.6
K	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0

69383					69384			
gr	Pr	P	Pc	P	mp	mp	mp	mp
56.06	45.69	45.03	45.11	51.22	50.44	47.23	50.31	48.54
27.92	34.47	35.56	35.38	30.79	30.81	31.79	31.11	31.19
-	-	0.22	-	-	-	-	-	-
0.44	0.41	0.37	0.30	0.27	1.05	0.84	1.50	0.61
-	-	-	-	-	0.35	0.21	0.24	-
9.57	18.11	19.03	19.06	13.45	14.10	15.86	12.98	15.13
0.29	-	-	-	0.15	-	0.13	1.03	0.10
5.73	1.32	0.80	1.04	3.68	3.25	2.19	2.83	2.70
100.00	100.00	100.99	100.89	99.56	100.00	98.25	100.00	98.26
2.5220	2.1086	2.0626	2.0687	2.3390	2.3059	2.2113	2.3059	2.2628
1.4802	1.8750	1.9198	1.9123	1.6574	1.6599	1.7538	1.6805	1.7134
-	-	0.0080	-	-	-	-	-	-
0.0165	0.0159	0.0140	0.0115	0.0102	0.0401	0.0330	0.0576	0.0238
0.4611	0.8955	0.9338	0.9364	0.6581	0.0237	0.0148	0.0164	-
0.0167	-	-	-	0.0087	-	0.0078	0.0600	0.0059
0.4996	0.1177	0.0706	0.0924	0.3262	0.6908	0.7956	0.6375	0.7554
4.9959	5.0127	5.0088	5.0213	4.9997	5.0080	5.0147	5.0096	5.0052
47.2	88.4	93.0	91.0	66.3	70.6	79.4	67.2	75.2
51.1	11.6	7.0	9.0	32.8	29.4	19.8	26.5	24.3
1.7	0.0	0.0	0.0	0.9	0.0	0.8	6.3	0.6

Andesite				
69391				
P	P	P	P	P
50.11	46.61	48.18	49.61	48.32
30.67	32.60	32.46	32.10	31.88
-	-	-	-	-
0.50	0.74	0.71	0.41	0.36
-	-	-	-	-
14.23	16.42	16.14	15.00	15.24
0.15	-	0.11	0.12	-
3.08	1.87	2.40	2.76	2.77
98.74	98.25	100.00	100.00	98.56
2.3147	2.1821	2.2150	2.2662	2.2434
1.6699	1.7987	1.7584	1.7282	1.7444
-	-	-	-	-
0.0192	0.0291	0.0273	0.0155	0.0140
-	-	-	-	-
0.7042	0.8235	0.7949	0.7340	0.7579
0.0087	-	0.0066	0.0071	-
0.2761	0.1700	0.2136	0.2443	0.2493
4.9927	5.0035	5.0159	4.9953	5.0090
71.2	82.9	78.3	74.5	75.2
27.9	17.1	21.0	24.8	24.8
0.9	-	0.7	0.7	-

Clinopyroxene

Rock type	Basalt						
Sample No	69381				69384		
Type	Pc	Pr	Pc	Pr	Pc	Pr	Pc
SiO2	51.59	51.36	52.23	50.37	50.13	51.33	52.84
TiO2	0.74	0.53	0.78	0.79	0.58	0.52	0.33
Al2O3	3.08	1.75	2.98	3.04	5.20	5.06	2.07
Cr2O3	0.35	0.44	0.32	0.47	-	0.59	-
FeO	8.11	7.85	8.24	7.90	6.86	6.05	9.72
MnO	-	-	-	0.25	-	-	0.34
MgO	15.18	15.93	15.57	14.84	15.02	15.76	14.92
CaO	20.87	21.05	21.63	21.90	21.91	21.96	21.27
Na2O	-	0.33	-	-	-	-	-
Total	99.92	99.24	101.75	99.57	99.68	101.28	101.47
Si	1.9116	1.9222	1.9044	1.8857	1.8577	1.8645	1.9419
Ti	0.0207	0.0150	0.0214	0.0224	0.0162	0.0141	0.0091
Al	0.1347	0.0771	0.1281	0.1343	0.2269	0.2168	0.0895
Cr	0.0101	0.0129	0.0092	0.0139	-	0.0170	-
Fe	0.2515	0.2457	0.2513	0.2472	0.2126	0.1839	0.2986
Mn	-	-	-	0.0082	-	-	0.0105
Mg	0.8382	0.8889	0.8462	0.8278	0.8295	0.8535	0.8173
Ca	0.8286	0.8439	0.8450	0.8785	0.8698	0.8546	0.8374
Na	-	0.0241	-	-	-	-	-
Total	3.9953	4.0299	4.0056	4.0178	4.0127	4.0044	4.0043
100Mg/Mg+Fe	76.9	78.3	77.1	77.4	79.6	82.3	73.2
Ca	43.2	42.7	43.5	45.0	45.5	45.2	42.9
Mg	43.7	44.9	43.6	42.4	43.4	45.1	41.8
Fe	13.1	12.4	12.9	12.7	11.1	9.7	15.3

			Andesite					
69384			69391					
Pr	Pc	Pr	P	Pc	P	mp	Pr	P
49.24	50.50	51.97	51.53	47.76	52.24	52.87	51.31	51.85
0.70	0.66	0.57	0.42	0.30	0.35	0.54	0.34	0.38
5.75	5.08	4.62	2.19	3.05	2.02	1.86	3.71	1.93
0.68	-	0.21	-	-	-	-	0.52	-
6.14	7.67	7.01	10.74	9.50	9.74	10.65	8.73	10.96
-	-	-	0.29	-	-	0.37	0.35	0.30
14.83	15.05	15.71	14.28	13.87	15.22	14.94	13.69	14.99
21.53	21.43	22.56	20.04	23.38	20.77	20.63	22.33	20.12
-	-	-	-	0.34	-	-	-	-
98.87	100.39	102.65	99.49	98.20	100.35	101.86	100.98	100.53
1.8373	1.8613	1.8711	1.9379	1.8443	1.9387	1.9410	1.8977	1.9323
0.0196	0.0183	0.0153	0.0120	0.0088	0.0099	0.0150	0.0094	0.0106
0.2528	0.2208	0.1960	0.0969	0.1388	0.0885	0.0805	0.1616	0.0847
0.0202	-	0.0061	-	-	-	-	0.0152	-
0.1915	0.2364	0.2111	0.3379	0.3068	0.3023	0.3270	0.2700	0.3415
-	-	-	0.0094	-	-	0.0115	0.0109	0.0095
0.8245	0.8268	0.8428	0.8004	0.7985	0.8417	0.8173	0.7548	0.8329
0.8607	0.8463	0.8702	0.8073	0.9672	0.8259	0.8114	0.8850	0.8032
-	-	-	-	0.0256	-	-	-	-
4.0066	4.0099	4.0125	4.0017	4.0902	4.0071	4.0037	4.0045	4.0147
81.1	77.8	80.0	70.3	72.2	73.6	71.4	73.7	70.9
45.9	44.3	45.2	41.5	46.7	41.9	41.5	46.3	40.6
43.9	43.3	43.8	41.1	38.5	42.7	41.8	39.5	42.1
10.2	12.4	11.0	17.4	14.8	15.3	16.7	14.1	17.3

Actinolite

Rock type	Basalt						
Sample No	69381		69382		69383		
Type	mp		mp	mp			P
SiO2	54.48	53.60	52.81	51.29	50.11	50.24	50.10
TiO2	0.33	0.37	0.18	0.25	0.74	0.66	0.88
Al2O3	4.86	3.87	3.30	4.84	5.33	5.15	5.14
FeO	8.50	9.50	14.23	13.90	12.14	11.92	11.77
MnO	-	-	0.30	-	0.24	0.36	0.44
MgO	19.81	18.71	15.64	14.98	15.69	15.68	15.96
CaO	10.28	11.65	10.78	11.23	12.17	12.09	12.05
Na2O	-	-	-	0.41	0.25	0.38	0.43
Cl	-	-	-	-	0.21	0.15	0.15
Total	98.25	97.70	97.24	96.90	97.19	96.93	97.21
Si	7.5628	7.5667	7.6518	7.4710	7.2956	7.3253	7.2868
Ti	0.0340	0.0395	0.0193	0.0276	0.0813	0.0721	0.0962
Al	0.7950	0.6442	0.5636	0.8307	0.9142	0.8857	0.8808
Fe	0.9863	1.1214	1.2749	1.6939	1.4785	1.4535	1.4311
Mn	-	-	0.0370	-	0.0290	0.0447	0.0538
Mg	4.0991	3.9379	3.3766	3.2525	3.4048	3.4082	3.4606
Ca	1.5283	1.7622	1.6739	1.7529	1.8985	1.8890	1.8780
Na	-	-	-	0.1150	0.0718	0.1073	0.1217
Cl	-	-	-	-	0.0507	0.0371	0.0359
Total	15.0056	15.0718	15.0471	15.1435	15.2806	15.2778	15.3015
100Mg/Mg+Fe	80.6	77.8	66.2	65.8	69.7	70.1	70.7
Ca	23.1	25.8	24.7	26.2	28.0	28.0	27.7
Mg	62.0	57.7	49.8	48.6	50.2	50.5	51.1
Fe	14.9	16.4	25.5	25.3	21.8	21.5	21.1

Magnetite

Rock type	Basalt						
Sample No	69381			69382	69383		
Type				mp	gr	gr	gr
SiO2	-	-	0.48	-	-	-	-
TiO2	0.62	0.52	16.45	-	1.26	0.19	0.33
Al2O3	0.48	0.39	1.23	-	0.35	0.35	0.44
Cr2O3	-	-	-	0.62	-	-	-
Fe2O3	65.99	66.15	33.28	65.62	63.26	65.08	63.40
FeO	30.61	30.99	43.37	29.83	30.99	29.88	29.45
MnO	-	-	0.54	-	-	-	-
MgO	0.30	-	1.49	-	-	-	-
Total	98.00	98.06	96.82	96.06	95.86	95.50	93.62
Si	-	-	0.0184	-	-	-	-
Ti	0.0181	0.0154	0.4740	-	0.0380	0.0057	0.0103
Al	0.0221	0.0180	0.0553	-	0.0166	0.0165	0.0215
Cr	-	-	-	0.0195	-	-	-
Fe3+	1.9416	1.9511	0.9598	1.9804	1.9073	1.9719	1.9579
Fe2+	1.0009	1.0158	1.3900	1.0003	1.0383	1.0061	1.0106
Mn	-	-	0.0174	-	-	-	-
Mg	0.0175	-	0.0852	-	-	-	-
Total	3.0002	3.0002	3.0001	3.0002	3.0002	3.0002	3.0002

Andesite	
69391	
0.23	-
0.59	0.58
2.07	1.09
0.32	-
-	-
86.46	87.00
-	-
0.43	-
90.09	88.67
0.0116	-
0.0225	0.0230
0.1244	0.1291
0.0129	-
-	-
3.6928	2.8690
-	-
0.0327	-
3.8970	3.9428

Ilmenite

Rock type	Basalt			
Sample No	69381			
Type	mp		mp	mp	P

Type	mp		mp	mp	P
SiO2	0.61	-	-	-	-
TiO2	44.72	49.08	42.24	44.89	44.77
Al2O3	-	-	0.28	-	-
Fe2O3	13.15	7.44	19.43	14.77	15.73
FeO	35.12	37.54	34.13	36.27	35.10
MnO	0.54	0.90	0.41	0.39	0.32
MgO	2.96	3.19	1.98	2.08	2.71
Total	97.10	98.14	98.57	98.38	98.64
Si	0.0155	-	-	-	-
Ti	0.8583	0.9296	0.8099	0.8587	0.8505
Al	-	-	0.0083	-	-
Fe3+	0.2525	0.1409	0.3719	0.2827	0.2991
Fe2+	0.7495	0.7906	0.7261	0.7715	0.7415
Mn	0.0116	0.0192	0.0089	0.0081	0.0069
Mg	0.1127	0.1197	0.0750	0.0788	0.1020
Total	2.0000	2.0000	2.0000	2.0000	2.0000

Biotite

Rock type	Basalt			
Sample No	69383			
Type				
SiO2	36.18	36.12	37.08	38.06
TiO2	3.91	4.17	4.28	3.90
Al2O3	13.95	14.67	14.06	14.43
FeO	16.45	16.68	17.42	19.39
MgO	13.47	14.13	13.62	12.64
CaO	0.34	0.25	0.21	0.28
K2O	8.79	8.30	9.18	9.39
Cl	0.44	0.44	0.41	0.43
Total	93.54	94.77	96.27	98.52
Si	5.5768	5.4799	5.5720	5.6258
Ti	0.4537	0.4755	0.4838	0.4332
Al	2.5348	2.6226	2.4898	2.5142
Fe	2.1211	2.1165	2.1896	2.3970
Mg	3.0947	3.1940	3.0500	2.7846
Ca	0.0568	0.0412	0.0338	0.0441
K	1.7281	1.6067	1.7604	1.7697
Cl	0.1153	0.1131	0.1051	0.1083
Total	15.6813	15.6496	15.6845	15.6769
100Mg/Mg+Fe	59.3	60.1	58.2	53.7
Ca	1.1	0.8	0.6	0.8
Mg	58.7	59.7	57.8	53.3
Fe	40.2	39.5	41.5	45.9

C. Quaternary lava from Mt.Niut

Plagioclase

Rock type					Basaltic andesite			
Sample No	69399				69397			
Type	mp	mp	mp	mp	mp	mp	mp	mp
SiO2	54.59	54.26	54.46	53.01	51.90	53.26	53.32	56.34
TiO2	-	-	-	0.16	-	-	-	0.17
Al2O3	29.10	28.98	29.07	28.29	28.93	29.08	28.89	26.58
Cr2O3	-	-	-	-	-	0.19	0.19	-
FeO	0.52	0.66	0.54	0.59	0.39	0.40	0.50	0.58
CaO	11.68	11.83	11.98	11.77	12.27	12.38	11.80	9.58
K2O	0.35	0.38	0.30	0.33	0.16	0.24	0.20	0.29
Na2O	4.79	4.60	4.69	4.48	4.48	4.71	4.71	5.78
Total	101.02	100.71	101.03	98.64	98.13	100.26	99.61	
Si	2.4475	2.4430	2.4430	2.4382	2.4021	2.4145	2.4278	2.5542
Ti	-	-	-	0.0057	-	-	-	0.0058
Al	1.5378	1.5379	1.5367	1.5331	1.5777	1.5536	1.5502	1.4203
Cr	-	-	-	-	-	0.0069	0.0069	-
Fe	0.0194	0.0250	0.0204	0.0227	0.0150	0.0152	0.0189	0.0219
Ca	0.5609	0.5707	0.5761	0.5801	0.6083	0.6011	0.5759	0.4653
K	0.0199	0.0216	0.0170	0.0196	0.0094	0.0136	0.0118	0.0166
Na	0.4160	0.4013	0.4075	0.3998	0.4022	0.4143	0.4160	0.5082
Total	5.0015	4.9995	5.0008	4.9992	5.0148	5.0192	5.0074	4.9922
Ca	56.3	57.4	57.6	58.0	59.6	58.4	57.4	47.0
Na	41.7	40.4	40.7	40.0	39.4	40.3	41.4	51.3
K	2.0	2.2	1.7	2.0	0.9	1.3	1.2	1.7

69396						
gr	Pr	Pc	P	gr	Pr	Pc
56.78	54.72	55.43	54.63	54.92	54.93	54.70
0.17	-	-	-	-	-	-
27.37	28.32	28.44	28.30	27.93	28.48	28.84
-	-	-	-	-	-	-
0.69	-	0.30	0.24	0.65	-	0.25
0.23	-	-	-	0.20	-	-
10.20	11.00	10.99	11.17	11.11	11.25	11.48
0.33	0.35	0.37	0.35	0.20	0.15	0.16
5.43	4.81	5.06	4.67	4.77	4.86	4.76
101.21	99.21	100.59	99.36	99.79	99.67	100.19
2.5303	2.4848	2.4867	2.4803	2.4861	2.4819	2.4640
0.0055	-	-	-	-	-	-
1.4373	1.5156	1.5041	1.5141	1.04903	1.5162	1.5308
-	-	-	-	-	-	-
0.0258	-	0.0114	0.0092	0.0247	-	0.0095
0.0156	-	-	-	0.0134	-	-
0.4872	0.5351	0.5282	0.5435	0.5390	0.5447	0.5540
0.0187	0.0200	0.0210	0.0200	0.0114	0.0085	0.0094
0.4690	0.4238	0.4405	0.4111	0.4189	0.4257	0.4153
4.9894	4.9783	4.9919	4.9782	4.9838	4.9771	4.9829
50.0	54.7	53.4	55.8	55.6	55.6	56.6
48.1	43.3	44.5	42.2	43.2	43.5	42.4
1.9	2.0	2.1	2.1	1.2	0.9	1.0

Sanidine

	Trachybasalt			
	69395			
SiO2	56.96	64.37	64.27	64.44
TiO2	0.22	0.31	0.38	0.16
Al2O3	18.90	18.47	18.64	18.67
FeO	10.78	-	0.34	-
MgO	2.51	-	-	-
CaO	0.26	0.28	-	0.22
K2O	9.77	16.58	16.37	10.82
Na2O	0.61	-	-	3.50
Total	100.00	100.00	100.00	97.81
Si	2.7202	2.9815	2.9757	2.9858
Ti	0.0077	0.0108	0.0131	0.0056
Al	1.0638	1.0080	1.0172	1.0194
Fe	0.4304	-	0.0132	-
Mg	0.1789	-	-	-
Ca	0.0132	0.0138	-	0.0108
K	0.5950	0.9794	0.9667	0.6397
Na	0.0568	-	-	0.3147
Total	5.0660	4.9934	4.9859	4.9760
Ca	2.0	1.4	0.0	1.1
Na	8.5	0.0	0.0	32.6
K	89.5	98.6	100.0	66.3

Clinopyroxene

Rock type					Basaltic andesite		
Sample No	69399				69397		
Type	mp	mp	mp	mp	mp	mp	mp
SiO2	49.68	49.61	50.22	48.66	50.61	49.44	49.11
TiO2	1.99	1.89	1.52	1.85	1.44	1.82	1.63
Al2O3	2.12	1.93	1.81	1.88	4.96	2.27	2.50
Cr2O3	0.32	-	-	-	-	-	0.26
FeO	13.06	12.85	14.56	15.82	14.31	13.52	11.89
MnO	0.27	0.29	0.30	0.29	-	0.36	-
MgO	12.55	12.74	12.22	10.60	10.97	13.01	12.34
CaO	19.44	19.40	19.17	19.01	14.81	17.57	19.54
Na2O	0.38	0.25	-	0.30	1.34	-	-
Total	99.81	98.97	99.80	98.41	98.44	97.99	97..27
Si	1.8865	1.8979	1.9180	1.8988	1.9263	1.9081	1.9052
Ti	0.0569	0.0543	0.0435	0.0543	0.0412	0.0529	0.0475
Al	0.0949	0.0871	0.0813	0.0864	0.2227	0.1035	0.1143
Cr	0.0096	-	-	-	-	-	0.0080
Fe2+	0.4159	0.4120	0.4650	0.5175	0.4553	0.4362	0.3857
Mn	0.0086	0.0095	0.0097	0.0097	-	0.0117	-
Mg	0.7101	0.7265	0.6958	0.6168	0.6224	0.7481	0.7132
Ca	0.7909	0.7952	0.7845	0.7947	0.6039	0.7267	0.8122
Na	0.0280	0.0186	-	0.0230	0.0989	-	-
Total	4.0123	4.0090	3.9978	4.0101	3.9706	3.9873	3.9861
Mg/(Mg+Fe)	63.1	63.9	59.9	54.4	57.8	63.2	64.9
Ca	42.3	41.1	40.3	41.2	35.9	38.0	42.5
Mg	37.1	37.6	35.8	32.0	37.0	39.1	37.3
Fe	20.6	21.3	23.9	26.8	27.1	22.8	20.2

Trachybasalt				
69395				
47.53	47.38	50.34	48.96	49.17
2.23	2.12	0.91	2.17	2.12
4.97	4.59	2.49	4.58	4.64
-	-	-	-	-
11.13	10.94	11.46	11.10	11.12
0.25	-	0.34	-	-
12.87	13.13	15.24	13.28	13.68
19.50	19.63	17.99	20.52	20.76
0.34	0.38	-	0.30	0.26
99.01	98.16	98.78	100.90	101.76
1.8133	1.8203	1.9077	1.8288	1.8218
0.0639	0.0613	0.0261	0.0609	0.0592
0.2234	0.2077	0.1112	0.2018	0.2028
-	-	-	-	-
0.3610	0.3516	0.3633	0.3467	0.3446
0.0081	-	0.0109	-	-
0.7316	0.7517	0.8611	0.7392	0.7558
0.7970	0.8079	0.7305	0.8213	0.8243
0.0254	0.0280	-	0.0216	0.0184
4.0238	4.0286	4.0106	4.0202	4.0268
67.0	68.1	70.3	68.1	68.7
42.2	42.3	37.4	43.1	42.8
38.7	39.3	44.1	38.8	39.3
19.1	18.4	18.6	18.2	17.9

Orthopyroxene

Sample No	69396					
Type	Pr	Pc	mp	P	Pr	Pc
SiO2	53.89	54.01	54.83	53.16	53.04	53.85
TiO2	0.29	0.34	0.33	0.17	0.41	0.27
Al2O3	0.64	3.05	0.89	1.71	1.13	2.94
Cr2O3	0.28	0.30	0.30	-	0.40	0.26
FeO	17.95	13.20	18.51	13.02	17.78	13.21
MnO	0.26	-	0.26	-	0.23	-
MgO	25.06	27.97	25.26	27.46	24.86	27.74
CaO	2.05	1.78	2.13	1.61	2.15	1.74
Total	100.43	100.65	102.50	97.13	100.00	100.00
Si	1.9659	1.9186	1.9615	1.9550	1.9454	1.9250
Ti	0.0081	0.0090	0.0089	0.0048	0.0113	0.0072
Al	0.0276	0.1275	0.0375	0.0740	0.0487	0.1237
Cr	0.0081	0.0084	0.0084	-	0.0115	0.0073
Fe	0.5475	0.3921	0.5537	0.4005	0.5454	0.3948
Mn	0.0080	-	0.0078	-	0.0071	-
Mg	1.3628	1.4810	1.3471	1.5054	1.3593	1.4778
Ca	0.0081	0.0678	0.0817	0.0635	0.0844	0.0667
Total	4.0081	4.0044	4.0066	4.0032	4.0131	4.0023
100Mg/Mg+Fe	71.3	79.1	70.9	79.0	71.4	78.9
Ca	4.0	3.5	4.1	3.2	4.2	3.4
Mg	68.5	76.3	68.0	76.4	68.3	76.2
Fe	27.5	20.2	27.9	20.3	27.4	20.4

Olivine

Rock type	Basaltic andesite							
Sample No	69399							
Type	Pc	mpc	mpr	mpr	Pc	Pr	Pc	Pr
SiO2	38.23	35.62	32.65	32.54	38.01	35.86	38.02	36.19
Al2O3	-	0.43	0.47	-	-	-	-	-
FeO	21.43	33.77	52.60	47.31	21.26	31.20	20.96	30.10
MnO	0.27	0.51	0.93	0.77	0.31	0.35	0.22	0.43
MgO	39.90	29.36	13.00	17.82	39.85	31.82	39.66	33.08
CaO	0.17	0.31	0.35	0.29	0.15	0.22	-	0.14
NiO	-	-	-	-	0.41	-	-	-
Total	100.00	100.00	100.00	98.72	100.00	99.44	98.86	99.93
Si	0.9912	0.9843	0.9996	0.9849	0.9876	0.9841	0.9948	0.9823
Al	-	0.0141	0.0169	-	-	-	-	-
Fe	0.4647	0.7803	1.3466	1.1974	0.4619	0.7159	0.4587	0.6832
Mn	0.0060	0.0120	0.0241	0.0196	0.0068	0.0080	0.0048	0.0100
Mg	1.5420		0.5931	0.8039	0.5433	1.3015	1.5469	1.3383
Ca	0.0048	0.0090	0.0116	0.0093	0.0041	0.0063	-	0.0040
Ni	-	0.0141	0.0169	-	-	-	-	-
Total	3.0088	3.0086	2.9919	3.0151	3.0123	3.0159	3.0052	3.0177
100Mg/Mg+Fe	76.8	60.8	30.6	40.2	77.0	64.5	77.1	66.2
Ca	0.2	0.5	0.6	0.5	0.2	0.3	0.0	0.2
Mg	76.7	60.5	30.4	40.6	76.8	64.3	77.1	66.1
Fe	23.1	39.0	69.0	59.6	23.0	35.4	22.9	33.7

69397							69396	
mp	Pc	Pr	mp	P	Pc	Pr		gr
36.85	38.87	38.15	35.43	39.45	37.68	37.06	35.61	35.92
-	-	-	0.31	-	-	-	-	-
33.60	23.38	27.40	35.51	24.23	22.65	25.71	29.86	30.64
0.32	-	0.23	0.30	0.33	0.28	0.27	0.39	0.30
30.70	39.58	36.58	26.54	40.28	39.04	36.80	32.09	32.67
0.24	-	-	0.66	0.15	-	0.15	0.23	0.23
-	-	-	-	-	0.35	-	-	-
101.71	101.83	102.37	98.74	104.44	100.00	100.00	98.18	99.76
0.9953	0.9949	0.9914	1.0009	0.9885	0.9851	0.9827	0.9850	0.9796
-	-	-	0.0102	-	-	-	-	-
0.7590	0.5005	0.5954	0.8387	0.5076	0.4951	0.5701	0.6908	0.6989
0.0074	-	0.0050	0.0071	0.0070	0.0062	0.0061	0.0092	0.0070
1.2358	1.5098	1.4168	1.1172	1.5042	1.5212	1.4541	1.3232	1.3282
0.0070	-	-	0.0199	0.0041	-	0.0043	0.0068	0.0067
-	-	-	-	-	0.0073	-	-	-
3.0046	3.0051	3.0086	2.9940	3.0114	3.0149	3.0173	3.0150	3.0203
62.0	75.1	70.4	57.1	74.8	75.4	71.8	65.7	65.5
0.4	0.0	0.0	1.0	0.2	0.0	0.2	0.3	0.3
61.7	75.1	70.4	56.5	74.6	75.4	71.7	65.5	65.3
37.9	24.9	29.6	42.5	25.2	24.6	28.1	34.2	34.4

		69396	
36.42	35.70	35.84	35.49
0.46	-	-	2.02
30.42	30.56	29.69	29.74
0.31	0.39	0.33	0.40
32.22	32.74	32.37	32.13
0.18	0.30	0.22	0.21
-	0.32	-	-
100.00	100.01	98.45	99.99
0.9872	0.9737	0.9869	0.9600
0.0147	-	-	0.0644
0.6896	69.70	0.6836	0.6728
0.0071	0.0090	0.0076	0.0091
1.3017	1.3309	1.3285	1.2952
0.0051	0.0088	0.0064	0.0062
-	0.0090	-	-
3.0054	3.0263	3.0130	3.0078
65.4	65.6	66.0	65.8
0.3	0.4	0.3	0.3
65.2	65.3	65.8	65.6
34.5	34.2	33.9	34.1

Magnetite

Rock type	Basaltic andesite					
Sample No	69399				69397	
Type	gr	gr	gr	gr	gr	gr
SiO2	-	-	0.60	0.29	-	0.54
TiO2	26.38	24.54	26.35	26.01	22.66	24.13
Al2O3	0.91	1.10	2.76	2.37	10.05	2.11
Cr2O3	-	-	0.25	-	-	-
Fe2O3	15.43	19.67	13.89	17.06	22.11	17.20
FeO	53.90	52.53	55.31	54.53	49.15	51.73
MnO	0.36	0.41	0.54	0.49	0.39	0.35
MgO	0.36	0.41	0.72	0.88	1.06	1.03
CaO	-	-	-	0.18	-	-
Total	97.46	98.74	100.41	101.79	96.42	97.09
Si	-	-	0.0219	0.0105	-	0.0204
Ti	0.7578	0.6964	0.7241	0.7070	0.6559	0.6874
Al	0.0409	0.0487	0.1189	0.1008	0.0477	0.0943
Cr	-	-	0.0071	-	-	-
Fe3+	0.4436	0.5584	0.3819	0.4642	0.6405	0.4902
Fe2+	1.7218	1.6574	1.6904	1.6485	1.5822	1.6385
Mn	0.0156	0.0159	0.0166	0.0149	0.0129	0.0111
Mg	0.0204	0.0233	0.0391	0.0473	0.0609	0.0582
Ca	-	-	-	0.0069	-	-
Total	3.0000	3.0001	3.0000	3.0000	3.0001	3.0001

Cr-Spinel

Sample No			69399		
Type	I.ol	I.ol	I.pl	I.ol	gr
TiO2	1.77	1.57	16.92	24.23	22.23
Al2O3	26.27	26.55	2.40	1.67	2.67
Cr2O3	33.19	33.32	18.29	10.06	13.54
Fe2O3	6.01	6.41	15.71	9.47	9.82
FeO	22.06	21.87	45.20	49.66	45.80
MnO	-	-	-	0.37	0.46
MgO	10.29	10.28	1.48	2.08	2.10
Total	100.00	100.00	100.00	97.51	99.36
Ti	0.0410	0.0364	0.4663	0.6817	0.6112
Al	0.9691	0.9653	0.1035	0.0722	0.1152
Cr	0.8090	0.8127	0.5301	0.2976	0.3922
Fe3+	0.1395	0.1489	0.4335	0.2666	0.2700
Fe	0.5688	0.5641	1.3857	1.5540	1.4826
Mg	0.4727	0.4727	0.0808	0.1160	0.1145
Total	3.0000	3.0000	3.0000	3.0000	3.0000
100Mg/Mg+Fe2+	45.0	45.6	5.5	6.9	7.16
100Cr/Cr+Al	46.0	45.7	83.7	80.5	77.3

Al-Spinel

Sample No			69396			
Type	I.pl	I.pl	I.pl	I.pl	I.pl	I.pl
TiO2	0.31	0.57	0.40	0.54	0.37	0.63
Al2O3	58.90	61.72	62.40	60.82	61.15	61.13
Cr2O3	0.49	0.26	0.56	-	0.49	0.71
Fe2O3	1.57	0.96	1.35	0.43	0.81	0.79
FeO	16.56	18.42	17.52	18.11	17.45	17.50
MnO	-	-	0.26	-	-	-
MgO	14.85	14.96	15.61	14.54	15.11	15.38
Total	92.68	96.89	98.10	94.44	95.39	96.14
Ti	0.0530	0.0921	0.0639	0.0888	0.0611	0.1022
Al	15.5407	15.6149	15.5601	15.7492	15.6588	15.5439
Cr	0.0873	0.0439	0.0943	-	0.0845	0.1281
Fe3+	0.2637	0.1546	0.2154	0.0708	0.1320	0.1281
Fe2+	3.1000	3.3064	3.0992	3.3278	3.1714	3.1572
Mn	-	-	0.0457	-	-	-
Mg	4.9554	4.7881	4.9214	4.7634	4.8921	4.9474
Total	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000
100Mg/Mg+Fe2+	61.5	59.2	61.4	58.9	60.7	61.0

Glassy groundmass

Sample No	69399	69396	69397
SiO2	63.01	56.90	63.21
TiO2	1.30	2.54	3.11
Al2O3	16.19	13.63	16.75
Cr2O3	-	0.05	-
FeO	5.53	10.56	5.48
MnO	-	0.06	-
MgO	0.56	2.42	-
CaO	4.12	7.96	3.75
Na2O	4.07	3.77	5.29
K2O	4.37	1.40	1.86
P2O5	0.59	0.31	0.26
SO3	0.27	0.36	0.26
Total	100.00	100.00	100.00

Glass inclusion in olivine and plagioclase

	In olivine	In plagioclase
Sample No	69397	69396
SiO2	75.05	56.70
TiO2	-	2.39
Al2O3	1.01	14.14
FeO	-	10.85
MgO	4.22	3.02
CaO	7.09	7.14
K2O	1.24	1.26
Na2O	11.39	3.80
P2O5	-	0.24
SO3	0.45	0.17
Total	100.00	99.82

D. Neogene subvolcanic rocks from western part of South Sulawesi
Plagioclase

Rock type	Trachyandesite							
Sample No	65973					65978		
Type	Pr	Pr	Pc	Pc	mp	Pc	Pr	Pr
SiO2	62.08	58.23	57.02	56.53	58.68	55.59	57.28	55.35
TiO2	0.32	0.26	-	-	-	-	-	-
Al2O3	23.83	26.72	27.26	27.41	25.35	28.95	27.01	28.45
FeO	-	-	-	-	0.23	0.30	-	0.26
CaO	5.96	8.88	9.70	9.43	7.81	11.31	11.31	11.16
K2O	1.02	0.92	0.84	0.87	1.15	0.59	0.81	0.62
Na2O	6.99	5.25	4.89	4.60	5.41	4.20	4.67	4.46
Total	100.21	100.26	99.70	98.84	98.64	100.95	99.69	100.30
Si	2.7532	2.6008	2.5643	2.5604	2.6564	2.4818	2.5747	2.4890
Ti	0.0120	0.0098	-	-	-	-	-	-
Al	1.2458	1.4068	1.4447	1.4630	1.3526	1.5235	1.4307	1.5079
Fe	-	-	-	-	0.0085	0.0111	-	0.0098
Ca	0.2834	0.4248	0.4672	0.4576	0.3790	0.5410	0.4777	0.5380
K	0.0578	0.0522	0.0481	0.0503	0.0663	0.0339	0.0466	0.0354
Na	0.6013	0.4549	0.4259	0.4039	0.4752	0.3639	0.4070	0.3892
Total	4.9535	4.9493	4.9503	4.9351	4.9380	4.9553	4.9368	4.9693
Ca	30.1	46.5	49.6	50.2	41.2	57.6	51.3	55.9
Na	63.8	48.8	45.2	44.3	51.6	38.8	43.7	40.4
K	6.1	5.6	5.1	5.5	7.2	3.6	5.0	3.7

			Dacite			
65978			65971			
Pc	Pr	Pc	Pr	Pr	Pc	
52.95	55.30	56.76	59.62	59.18	60.71	
-	-	-	-	-	-	
29.98	28.22	27.21	26.32	25.43	26.16	
0.32	0.26	0.36	-	-	-	
13.07	10.90	9.48	7.46	7.11	7.13	
0.34	0.53	0.86	0.13	0.11	0.10	
3.21	4.24	4.91	7.13	7.06	6.98	
99.88	99.45	99.58	100.65	98.89	101.07	
2.4001	2.5017	2.5597	2.6362	2.6621	2.6666	
-	-	-	-	-	-	
1.6014	1.5048	1.4465	1.3730	1.3483	1.3543	
0.0120	0.0097	0.0135	-	-	-	
0.6345	0.5285	0.4579	0.3538	0.3427	0.3353	
0.0199	0.0306	0.0497	0.0072	0.0060	0.0057	
0.2824	0.3719	0.4292	0.6117	0.6153	0.5942	
4.9503	4.9472	4.9565	4.9843	4.9744	4.9561	
67.7	56.8	48.9	36.4	35.5	35.9	
30.1	39.9	45.8	62.9	63.8	63.5	
2.1	3.3	5.3	0.7	0.6	0.6	

Sanidine

Rock type	Lamprophyre				Trachyandesite			
Sample No	65968				65973		65978	
Type	gr	gr	gr	gr	gr	gr	gr	gr
SiO2	65.32	64.74	64.79	65.32	63.18	65.81	64.85	67.31
TiO2	0.18	-	-	-	-	-	0.96	-
Al2O3	20.20	20.01	19.82	19.70	22.25	19.11	19.48	19.51
FeO	-	0.24	0.25	0.28	0.54	-	-	-
CaO	1.04	1.34	0.99	0.86	0.68	0.76	0.86	0.83
K2O	9.33	8.81	8.79	10.06	11.17	9.64	9.15	9.43
Na2O	4.28	4.55	4.71	4.03	2.18	3.70	3.58	4.14
Total	100.35	99.68	99.36	100.25	100.00	99.02	98.88	101.23
Si	2.9384	2.9341	2.9438	2.9532	2.8699	2.9921	2.9511	2.9910
Ti	0.0062	-	-	-	-	-	0.0327	-
Al	1.0708	1.0687	1.0616	1.0496	1.1911	1.0242	1.0445	1.0219
Fe	-	0.0090	0.0094	0.0105	0.0205	-	-	-
Ca	0.0499	0.0650	0.0483	0.0418	0.0332	0.0371	0.0421	0.0397
K	0.5356	0.5092	0.5095	0.5802	0.6473	0.5589	0.4312	0.5346
Na	0.3735	0.4001	0.4153	0.3536	0.1922	0.3257	0.3160	0.3564
Total	4.9745	4.9862	4.9878	4.9889	4.9542	4.9381	4.9175	4.9436
Ca	5.2	6.7	5.0	4.3	3.8	4.0	4.7	4.3
Na	38.9	41.1	42.7	36.2	22.0	35.3	35.5	38.3
K	55.9	52.3	52.4	59.5	74.2	60.6	59.7	57.4

Clinopyroxene

Rock Type	Lamprophyre							
Sample No	65968							
Type	Pr	Pc	Pr	Pc	Pr	Pc	Pr	Pc
SiO2	49.79	52.30	49.66	52.18	51.79	51.33	50.90	51.58
TiO2	0.66	0.35	0.73	0.41	0.53	0.37	0.72	0.35
Al2O3	4.48	2.92	4.77	2.98	3.19	3.51	4.80	2.81
Cr2O3	0.98	0.81	1.23	0.69	-	-	-	-
FeO	4.42	3.85	4.11	4.02	6.17	10.27	6.65	12.73
MnO	-	-	-	-	-	0.39	-	0.39
MgO	15.41	16.90	15.13	16.95	15.28	11.40	14.27	10.16
CaO	23.88	23.73	23.57	23.60	23.76	22.92	23.95	21.28
Na2O	-	-	-	-	-	1.09	0.29	1.76
Total	99.62	100.85	99.21	100.84	100.71	101.28	101.58	101.60
Si	1.8452	1.9012	1.8443	1.8977	1.9016	1.9136	1.8606	1.9374
Ti	0.0183	0.0096	0.0205	0.0113	0.0146	0.0102	0.0198	0.0099
Al	0.1955	0.1249	0.2087	0.1277	0.1381	0.1543	0.2067	0.1243
Cr	0.0288	0.0232	0.0360	0.0199	-	-	-	-
Fe	0.1371	0.1169	0.1278	0.1223	0.1893	0.3202	0.2033	0.3999
Mn	-	-	-	-	-	0.0790	0.0203	0.1281
Mg	0.8513	0.9154	0.8377	0.9188	0.8363	0.6333	0.7774	0.5691
Ca	0.9483	0.9241	0.9378	0.9194	0.9348	0.9155	0.9382	0.8563
Na	-	-	-	-	-	0.0790	-	0.0296
Total	4.0244	4.0152	4.0128	4.0172	4.0147	4.0385	4.0263	4.0546
100Mg/Mg+Fe 2+	86.1	88.7	86.8	88.2	81.5	66.4	79.3	58.7
Ca	49.0	47.2	49.3	46.9	47.7	49.0	48.9	46.9
Mg	44.0	46.8	44.0	46.9	42.7	33.9	40.5	31.2
Fe	7.1	6.0	6.7	6.2	9.7	17.1	10.6	21.9

Trachyandesite							
65973						65978	
Pr	Pc	mp	mp	Pr	Pc	gr	P
51.98	50.32	54.27	53.17	50.60	50.57	53.39	52.63
0.19	0.22	-	-	0.18	0.19	0.25	0.20
2.71	3.32	1.02	1.03	2.17	3.39	2.43	2.84
-	-	0.22	0.71	-	-	-	-
8.06	10.95	2.70	3.41	8.96	9.20	8.75	8.81
-	0.44	-	-	0.39	-	-	0.25
13.65	11.29	17.77	17.76	12.72	12.70	15.39	14.16
23.71	23.02	23.62	22.70	22.89	23.33	22.26	23.02
0.26	0.46	-	-	-	-	-	0.29
100.54	100.03	99.60	98.79	97.92	99.37	102.47	102.20
1.9281	1.9071	1.9976	1.9613	1.9383	1.9079	1.9350	1.9230
0.0053	0.0064	-	-	0.0053	0.0053	0.0067	0.0055
0.1183	0.1485	0.0439	0.0448	0.0982	0.1507	0.1039	0.1221
-	-	0.0064	0.0208	-	-	-	-
0.2499	0.3471	0.0822	0.1052	0.2870	0.2902	0.2653	0.2694
-	0.0140	-	-	0.0126	-	-	0.0078
0.7546	0.6376	0.9650	0.9766	0.7265	0.7144	0.8313	0.7712
0.9422	0.9346	0.9222	0.8972	0.9394	0.9429	0.8642	0.9011
0.0183	0.0338	-	-	-	-	-	0.0208
4.0167	4.0292	3.9972	4.0059	4.0073	4.0114	4.0064	4.0209
75.1	64.7	92.2	90.3	71.7	71.1	75.8	74.1
48.4	48.7	46.8	45.3	48.1	48.4	44.1	46.4
38.8	33.2	49.0	49.4	37.2	36.7	42.4	39.7
12.8	18.1	4.2	5.3	14.7	14.9	13.5	13.9

65978				
P	Pr	Pc	Pr	Pc
54.65	54.05	52.96	51.87	50.17
-	-	-	0.24	0.24
1.18	1.24	2.34	2.16	3.66
-	-	-	-	-
5.32	6.92	7.84	7.68	9.36
-	-	-	0.33	0.25
17.00	16.07	14.95	14.75	13.26
23.29	23.34	22.77	22.54	22.04
-	-	-	-	-
101.44	101.62	100.87	99.53	98.97
1.9740	1.9650	1.9459	1.9360	1.8981
-	-	-	0.0068	0.0067
0.0501	0.0529	0.1013	0.0949	0.1630
-	-	-	-	-
0.1606	0.2104	0.2410	0.2396	0.2962
-	-	-	-	-
0.9150	0.8709	0.8186	0.8205	0.7476
0.9013	0.9093	0.8965	0.9013	0.8932
-	-	-	0.0211	0.0181
4.0010	4.0085	4.0034	4.0202	4.0228
85.1	80.5	77.3	77.4	71.6
45.6	45.7	45.8	46.0	46.1
46.3	43.8	41.8	41.8	38.6
8.1	10.6	12.3	12.2	15.3

Hornblende

Rock type	Lamprophyre				Trachyandesite		
Sample No	65968				65973		
Type	Pr	Pc	Pc	Pr	mp	mp	P
SiO2	40.60	40.77	41.03	40.85	39.53	39.60	38.85
TiO2	2.11	2.06	2.08	2.32	1.55	1.27	1.88
Al2O3	13.53	14.01	13.84	13.66	13.78	14.10	12.52
FeO	13.64	13.75	12.87	10.72	17.66	17.01	18.73
MgO	12.79	12.76	13.21	14.34	10.01	10.36	9.09
CaO	12.26	12.32	12.33	12.37	11.85	11.92	11.76
K2O	1.81	1.91	1.84	1.75	1.92	1.83	2.36
Na2O	1.90	1.97	2.18	1.93	1.66	1.71	1.34
Cl	-	-	-	-	0.15	0.12	0.18
Total	98.65	99.53	99.38	97.95	98.11	97.91	96.71
Si	6.0285	6.0013	6.0235	6.0259	6.0227	6.0201	6.0678
Ti	0.2359	0.2277	0.2298	0.2573	0.1777	0.1448	0.2203
Al	2.3667	2.4314	2.3958	2.3752	2.4744	2.5257	2.3037
Fe	1.6942	1.6924	1.5806	1.3228	2.2500	2.1627	2.4467
Mg	2.8308	2.7992	2.8925	3.1520	2.2728	2.3467	2.1148
Ca	1.9507	1.9433	1.9408	1.9548	1.9335	1.9418	1.9676
K	0.3432	0.3582	0.3440	0.3287	0.3732	0.3557	0.4708
Na	0.5473	0.5611	0.6202	0.5532	0.4892	0.5050	0.4071
Cl	-	-	-	-	0.0396	0.0313	0.0472
Total	15.9974	16.0147	16.0289	15.9700	16.0330	16.0338	16.0460
100Mg/(Mg+Fe)	62.6	62.3	64.7	70.4	50.3	52.0	46.4
Ca	30.1	30.2	30.3	30.4	29.9	30.1	30.1
Mg	43.7	43.5	45.1	49.0	35.2	36.4	32.4
Fe	26.2	26.3	24.6	20.6	34.8	33.5	37.5

65978		
Pr	Pc	Pc
42.33	42.66	42.22
1.57	1.54	1.77
12.69	13.07	13.21
12.64	12.93	13.46
14.14	14.17	14.25
12.10	12.30	12.05
1.58	1.62	1.64
1.88	1.85	1.99
-	0.08	0.14
98.93	100.23	100.73
6.2048	6.1833	6.1140
0.1736	0.1673	0.1926
2.1921	2.2320	2.2541
1.5498	1.5677	1.6294
3.0904	3.0619	3.0760
1.8998	1.9104	1.8700
0.2955	0.3000	0.3026
0.5346	0.5207	0.5576
-	0.0193	0.0349
15.9404	15.9628	16.0312
66.6	66.1	65.4
29.0	29.2	28.4
47.3	46.8	46.8
23.7	24.0	24.8

Biotite

Rock type	Lamprophyre		Trachyandesite				
Sample No	65968		65973			65978	
Type	mp	mp		Pr	Pc	Pc	Pr
SiO2	33.40	33.39	34.95	36.50	37.63	37.15	37.45
TiO2	7.05	7.27	3.63	3.85	3.91	3.51	3.48
Al2O3	15.55	15.81	14.47	15.03	14.42	15.09	15.44
FeO	14.34	12.07	16.73	12.19	11.98	15.14	14.95
MnO	0.24	-	-	-	-	-	-
MgO	14.11	15.44	14.45	16.88	17.36	16.50	16.34
CaO	0.15	-	-	-	-	-	-
K2O	7.78	7.75	8.74	9.01	8.94	9.17	9.06
Na2O	0.45	0.72	-	0.48	0.31	0.39	0.35
Cl	-	-	0.18	0.15	0.23	0.18	0.16
Total	93.07	92.45	0.18	0.15	0.23	97.13	97.22
Si	5.1140	5.0862	5.4129	5.4649	5.5729	5.4589	5.4781
Ti	0.8114	0.8331	0.4229	0.4338	0.4359	0.3881	0.3824
Al	2.8064	2.8391	2.6419	2.6530	2.5171	2.6123	2.6617
Fe	1.8363	1.5378	2.1665	1.5265	1.4839	1.8603	1.8284
Mn	0.0316	-	-	-	-	-	-
Mg	3.2203	3.5050	3.3357	3.7670	3.8335	3.6125	3.5634
Ca	0.0245	-	-	-	-	-	-
K	1.5191	1.5068	1.7265	1.7200	1.6893	1.7189	1.6902
Na	0.1344	0.2126	-	0.1389	0.0887	0.1102	0.0986
Cl	-	-	0.0462	0.0371	0.0575	0.0455	0.0391
Total	15.4980	15.5207	15.7525	15.7411	15.6789	15.8067	15.7419
100Mg/(Mg+Fe)	63.7	69.5	60.6	71.2	72.1	66.0	66.1
Ca	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Mg	63.4	69.5	60.0	71.2	72.1	66.0	66.1
Fe	36.1	30.5	39.4	28.8	27.9	34.0	33.9

Phlogopite

Sample No	65968			
Type	mp	mp	Pr	P
SiO2	36.49	36.79	37.23	36.91
TiO2	2.56	3.53	3.06	2.79
Al2O3	18.35	16.80	16.79	16.12
Cr2O3	-	0.19	1.62	1.13
FeO	6.99	9.47	6.29	6.02
MgO	21.82	19.83	21.46	20.97
CaO	-	0.19	-	-
K2O	8.13	8.77	9.56	9.35
Na2O	0.41	0.59	0.28	0.27
Total	94.75	96.16	96.30	93.57
Si	5.2392	5.3012	5.3088	5.3996
Ti	0.2763	0.3825	0.3281	0.3067
Al	3.1054	2.8538	2.8210	2.7800
Cr	-	0.0220	0.1829	0.1306
Fe	0.8400	1.1415	0.7500	0.7371
Mg	4.6699	4.2592	4.5608	4.5737
Ca	-	0.0291	-	-
K	1.4886	1.6121	1.7397	1.7447
Na	0.1129	0.1659	0.0788	0.0763
Total	15.7323	15.7673	15.7701	15.7487
100Mg/(Mg+Fe)	84.8	78.9	85.9	86.1
Ca	0.0	0.5	0.0	0.0
Mg	84.8	78.4	85.9	86.1
Fe	15.2	21.0	14.1	13.9

Magnetite

Rock type	Lamprophyre			Trachyandesite					
Sample No	65968			65973			65978		
Type	gr	gr	gr	gr	gr	gr	mp	gr	gr
SiO2	0.56	0.46	0.36	0.79	-	-	1.23	2.57	1.82
TiO2	7.66	7.53	7.37	3.49	2.91	2.56	6.31	6.00	4.29
Al2O3	2.32	2.08	1.92	1.44	1.06	0.90	2.79	1.70	3.74
Cr2O3	-	-	-	0.32	0.25	0.24	-	-	0.22
Fe2O3	49.07	51.34	51.50	56.84	60.18	60.96	50.15	48.34	49.61
FeO	35.10	35.79	35.62	33.10	31.48	31.58	37.47	39.56	36.15
MnO	1.93	1.73	1.66	0.55	0.56	0.55	0.35	0.32	-
MgO	0.87	0.93	0.76	0.71	0.64	0.36	0.56	-	0.55
CaO	0.18	-	-	-	-	-	-	-	-
Total	97.70	99.86	99.20	97.23	97.10	97.14	98.86	98.51	96.37
Si	0.0216	0.0171	0.0138	0.0306	-	-	0.0464	0.0980	0.0698
Ti	0.2202	0.2124	0.2098	0.1020	0.0857	0.0755	0.1791	0.1718	0.1241
Al	0.1045	0.0919	0.0858	0.0657	0.0488	0.0415	0.1242	0.0761	0.1694
Cr	-	-	-	0.0097	0.0079	0.0074	-	-	0.0068
Fe3+	1.4118	1.4491	1.4670	1.6595	1.7717	1.8001	1.4247	1.3843	1.4359
Fe2+	1.1223	1.1224	1.1276	1.0740	1.0299	1.0363	1.1829	1.2598	1.1627
Mn	0.0626	0.0550	0.0531	0.0180	0.0187	0.0181	0.0113	0.0102	-
Mg	0.0497	0.0522	0.0430	0.0408	0.0374	0.0213	0.0316	-	0.0315
Ca	0.0074	-	-	-	-	-	-	-	-
Total	3.0002	3.0002	3.0002	3.0002	3.0002	3.0002	3.0001	3.0001	3.0001

Analcite

Sample No	65968	
SiO2	49.83	51.35
Al2O3	26.44	24.60
CaO	1.34	0.79
K2O	0.28	0.22
Na2O	12.29	12.67
Total	90.17	89.63
Si	2.1811	2.2541
Al	1.3640	1.2728
Ca	0.0628	0.0373
K	0.0154	0.0123
Na	1.0426	1.0781
Total	4.6659	4.6546
Ca	5.6	3.3
Na	93.0	95.6
K	1.4	1.1

Appendix 3

Sample catalogue

Section A. The Tertiary subvolcanic and volcanic rocks from central West Kalimantan
Section B. The Cretaceous subvolcanic and volcanic rocks from western part of West Kalimantan
Section C. The Quaternary lavas from Mt.Niut
Section D. The Neogene subvolcanic rocks from western part of South Sulawesi

Note: Abbreviation are as follows

S = sungai = river
Spl= sample
TS = thin section
pl = plagioclase
opx= orthopyroxene
il = ilmenite
hb = hornblende
san= sanidine
spl= spinel
ph = phlogopite
Mt = bukit = mount
P.Sibau = putussibau
HS = hand specimen
cpx = clinopyroxene
mt = magnetite
bt = biotite
qtz = quartz
act = actinolite
ol = olivine

Appendix 3

A. Tertiary subvolcanic and volcanic rocks from Central West Kalimantan

Basalt

U.TAS No 1	Field No 2	Preparation 3	Occurence 4	Composition 5	1:250000 Map 6	Coordinate 7 o ´E, o ´
69292	84DT151B	TS, HS	dyke	pl,cpx,mt,bt	Nangapinoh	112 22E, 0 51S
69293	84DT152A	TS, HS	,,	pl,cpx,mt,spl,ol	,,	,,
69294	84PW39D	TS, HS	,,	pl,cpx,mt	,,	111 42E, 0 58S
69295	84UM08	TS, HS	,,	pl,cpx,mt	,,	111 23E, 0 55S
69296	84IU97B	TS, HS	,,	pl,cpx,mt	,,	111 58E, 0 42S
69297	83PW118A	TS, HS	plug	pl,cpx,opx,il,mt,hb	,,	111 25E, 0 55N
69298	83P108B	TS, HS	,,	pl,cpx,opx,mt,il	,,	111 35E, 0 48N

Andesite

1	2	3	4	5	6	7
69299	84PP30A	TS, HS	dyke	pl,cpx,mt	Nangapinoh	111 22E, 0 58S
69300	84BH96A	TS	plug	pl,cpx,opx,mt	,,	111 17E, 0 24S
69301	84BH96C	TS, HS	,,	pl,cpx,opx,mt	,,	,,
69302	84BH96D	TS, HS	,,	pl,opx	,,	,,
69303	84IU95B	TS, HS	dyke	pl,hb,mt	,,	112 00E, 0 43S
69304	84PW89B	TS, HS	,,	pl,hb	,,	111 17E, 0 52S
69305	84UM07B	TS, HS	,,	pl	,,	111 23E, 0 55S
69306	83CP206B	TS, HS	plug	pl,cpx,opx,hb,bt mt,il	Sintang	111 35E, 0 46S
69307	83PW81B	TS, HS	plug	pl, hb,qtz	,,	
69308	83DS79A	TS, HS	plug	pl,opx,cpx	,,	111 40E, 0 55S
69309	83HZ113D	TS,	plug	pl,hb,mt.qtz	,,	111 07E, 0 58N
69310	83PW110A	TS, HS	plug	pl, opx,cpx,mt	,,	111 17E, 0 57N

Dacite

1	2	3	4	5	6	7
69311	83DT29C	TS, HS	plug	pl,hb,qtz	Sintang	111 50E, 0 03N
69312	83PW112B	TS, HS	,,	pl,hb,qtz	,,	112 21E, 0 04N
69313	83PW107A	TS, HS	,,	pl,qtz,mt	,,	112 22E, 0 03N
69314	83CP193A	TS,	,,	pl,hb,qtz	,,	112 10E, 0 15N
69315	83SN81A	TS, HS	,,	pl,qtz	,,	112 15E, 0 07N
69316	83PR57A	TS, HS	,,	pl,hb,qtz	,,	112 10E, 0 04N
69317	83KH81B	TS,	,,	pl,qtz	,,	112 11E, 0 19N
69318	83SN90B	TS	,,	pl,hb,qtz,cpx	,,	112 18E, 0 07N
69319	83DT27A	TS, HS	,,	pl,qtz,bt	,,	111 46E, 0 04N
69320	83AM77C	TS, HS	,,	pl,hb,qtz,san	,,	111 58E, 0 03N
69321	83DT54A	TS, HS	,,	pl,qtz,san,hb	,,	111 44E, 0 07N
69322	83CP143A	TS,	,,	pl,hb,cpx,qtz	,,	112 08E, 0 10N
69323	83SS82C	TS, HS	,,	pl,qtz	,,	111 45E, 0 06N

69324	83DS46C	TS, HS	,,	pl,hb,qtz,bt,cpx,opx	,,	111 56E, 0 04N
69325	83AM76A	TS, HS	,,	pl,hb,,qtz,bt	,,	111 50E, 0 07N
69326	83SS127A	TS, HS	,,	pl,hb,mt,il	,,	111 20E, 0 58N
69327	83DT53B	TS, HS	,,	pl,qtz	,,	111 44E, 0 07N
69328	83PW108A	TS, HS	,,	pl,cpx,mt,il,qtz	,,	111 17E, 0 55N
69329	83BH264A	TS, HS	,,	pl,qtz,hb,san	Putusibau	112 45E, 0 26N
69330	83PW118B	TS	?	?metamorphic	Sintang	111 25E, 0 55N
69331	83PW121B	TS, HS	,,	pl,cpx,qtz	,,	111 42E, 0 41N
69332	83BH192C	TS, HS	,,	pl,hb	,,	112 22E, 0 23N
69333	83BH203A	TS, HS	,,	pl,qtz	,,	112 21E, 0 17N
69334	83CP274A	TS, HS	,,	pl,hb,bt,qtz,mt	,,	111 44E, 0 34N
69335	83RH119A	TS, HS	,,	pl,qtz	,,	111 41E, 0 57N
69336	83PR77B	TS, HS	,,	pl,hb,qtz,mt	,,	112 00E, 0 07N
69337	83DS71B	TS, HS	,,	pl,hb,qtz	,,	111 52E, 0 19N
69338	83AM77A	TS, HS	,,	pl,hb,qtz	,,	111 56E, 0 03N
69339	83CP145A	TS, HS	,,	pl,cpx,opx,qtz,mt,il	,,	112 07E, 0 10N
69340	83PR68B	TS, HS	,,	pl,hb,il,mt	,,	112 07E, 0 03N
69341	83BH200A	TS, HS	lava	pl,qtz,san	,,	112 23E, 0 06N
69342	84AM225A	TS, HS	plug	pl,mt,il,qtz	Nangapinoh	111 07E, 0 11S
69343	84IU86B	TS, HS	,,	pl,qtz,hb	,,	112 34E, 0 03S
69344	84FK66A	TS, HS	,,	pl,opx,cpx,mt,il,qtz	,,	111 16E, 0 15S
69345	83DT28A	TS, HS	,,	pl,hb,qtz,bt	Sintang	111 46E, 0 04S
69346	83CP179B	TS, HS	,,	pl,hb,qtz	,,	111 51E, 0 04S
69347	83PW79C	TS, HS	,,	pl,hb,,bt,qtz,opx	,,	111 55E, 0 04S
69348	83IU92A	TS,	,,	pl,qtz,mt,il	Nangapinoh	112 32E, 0 03S
69349	84IU89A	TS, HS	,,	pl	,,	112 34E, 0 03S
69350	84IU112C	TS, HS	,,	pl,hb,opx,mt	,,	111 10E, 0 31S
69351	84FK37A	TS, HS	,,	pl,qtz,bt,hb	,,	112 05E, 0 52S
69352	84UM07C	TS, HS	,,	pl,hb	,,	111 23E, 0 57S
69353	84AM100E	TS, HS	,,	pl,cpx,hb,qtz	,,	112 04E, 0 45S
69354	84UM76A	TS, HS	,,	pl	,,	111 16E, 0 49S
69355	84DT330A	TS, HS	,,	pl,qtz	,,	111 31E, 0 23S
69481	83AM79B		,,		,,	111 53E, 0 06S

Rhyolite

1	2	3	4	5	6	7
69356	83P84A	TS, HS	plug	pl,qtz.san	Sintang	112 30E, 0 17N
69357	83PW78A	TS, HS	,,	pl,qtz,san	,,	111 52E, 0 07N
69358	83SS95B	TS, HS	,,	pl,hb,bt,qtz	,,	112 00E, 0 19N
69359	83HZ81A	TS, HS	,,	pl	,,	112 19E, 0 20N
69360	83AM64A	TS,	,,	pl	,,	111 16E, 0 03N
69361	83P01A	TS, HS	,,	pl,qtz,san,mt	,,	111 37E, 0 04N
69362	83SS108A	TS,	,,	pl,qtz,san	,,	112 07E, 0 14N
69363	83CP180A	TS, HS	,,	pl,qtz,san,mt	Nangapinoh	111 46E, 0 06S
69364	84AM214B	TS, HS	,,	pl,qtz,bt	,,	111 07E, 0 16S
69365	84PW92A	TS, HS	,,	pl,or,arf,qtz	,,	111 17E, 0 52S
69366	84IU161A	TS, HS	,,	pl,qtz,bt,san,mt	,,	110 29E, 0 58S
69367	84IU01A	TS, HS	,,	pl,qtz,san,bt	,,	111 36E, 0 07S
69368	84SN10A	TS, HS	,,	pl,bt,gr,cor,qtz,san	,,	111 30E, 0 28S
69369	84UM22	TS, HS	,,	pl,qtz,san	,,	111 29E, 0 56S
69370	84PW39C	TS, HS	,,	pl,san,qtz	,,	111 44E, 0 59S
69371	84IU157A	TS	,,	pl,san,qtz,bt,hb	Nangataman	110 30E, 0 55S
69372	84PR97A	TS, HS	,,	pl,qtz,hb	Nangapinoh	111 25E, 0 50S
69373	84PP26A	TS, HS	,,	pl,qtz	,,	111 23E, 0 60S
69374	83HZ48A	TS, HS	,,	pl,san,bt,qtz	,,	111 38E, 0 18S
69375	84IU112B	TS, HS	,,	pl,hb,qtz,mt	,,	111 10E, 0 31S
69482	83BH137A	TS	,,	pl,bt,qtz	Sintang	112 29E, 0 26N

Tuffs

1	2	3	4	5	6	7
69376	84UM129A	TS, HS	plug	pl,san,bt,mt,il,qtz	Ketapang	110 20E, 1 01S
69377	84UM133A	TS, HS	,,	pl,san,bt,hb,qtz	,,	,,
69378	84UM127A	TS, HS	,,	pl,san,qtz	,,	,,
69379	84UM131A	TS, HS	,,	pl,san,bt,qtz,mt	,,	,,
69380	84PP120A	TS, HS	,,	san,qtz	T. Manjul	111 19E, 1 15S

B. Cretaceous subvolcanic and volcanic rocks
from western part of West Kalimantan

U.Tas No	Field No	Preparation	Occurence	Rock type	Composition	1:250000 Map	General location
69381	85ER92B	TS, HS	dyke	basalt	pl,cpx,mt, il,qtz	Singkawang	Road Singkawang-Pontianak
69382	85YN210A	TS, HS	dyke	,,	pl,bt,qtz, act,hb	,,	P.Lemukutan
69383	85PW157A	TS, HS		,,	pl,act,bt,hb	,,	G.Poteng
69384	85YN270B	TS, HS		,,	pl,cpx	,,	Kp.Sebomat
69385	85ER143A	TS, HS		andesite	pl,act	,,	Kp.Bagu
69386	85SS84A	TS, HS		,,	pl	,, SESW	Road Pontianak -S.Penyuh
69387	85SS58A	TS, HS		,,	pl	Sanggau SWNW	Road Ngabang - Anjungan
69388	85ER112A	TS, HS		,,	pl,hb	Singkawang	Road Pontanak-Singkawang
69389	85NS158B	TS, HS	tuff	andesite	pl,opx,cpx	Sanggau NWSW	7.7km SE of Kp.Darit
69390	85SS68A	TS, HS	tuff	,,	pl,qtz,mt	Singkawang NCNE	Road Singkawa-Mempawrah
69391	85NS164A	TS, HS	tuff	,,	pl,cpx,hb,mt	Singkawang	G.Sebayung
69392	85YN234A	TS, HS		dacite	pl,hb,mt	,,	P.Baru
69393	85NS205A	TS, HS		,,	pl,cpx,qtz	,,	1 km SE of Kp. Selayang
69394	85SS54A	TS, HS		,,	pl,qtz,bt	Sanggau SWNW	Road Ngabang - Anjungan

C. Quaternary lavas from Mt. Niut

U.Tas No	Field No	Preparation	Composition	Rock type	1:250000 Map	General location
69395	85SR164A	TS, HS	pl,cpx,or,mt	basalt	Seluas	S.Landak South of Riam
69396	85SR145A	TS, HS	pl,ol,opx, spl	Basaltic andesite	,,	,,
69397	85PW106A	TS, HS	pl,ol,cpx	,,	Sanggau NWNE	S.Pade
69398	85PW103A	TS, HS	pl,ol,cpx	,,	,,	,,
69399	85RS109A	TS, HS	pl,ol,cpx, spl,mt	,,	Seluas SWSE	Road Ledo - Seluas

D. Neogen subvolcanic rocks from western part of South Sulawesi

U.Tas No	Prepa-ration	Composition	Rock type	1:250000 Map	General location
65968	TS, HS	cpx,bt,hb,mt, san,ph	lamprophyre	Pangkajene	2.5 km SW of Kp.Banga-bange
65978	TS, HS	pl,cpx,san,hb, qtz,bt,mt	trachy ande site	,,	2.25 km W of Kp.Wanua-waru
65973	TS, HS	pl,cpx,san,hb, bt,qtz,mt	,, ,,	,, ,,	2 km SW of Kp. Tabo-tabo
65971	TS, HS	pl,hb,qtz	Dacite	,,	3 km W of Kp.Tjamming
69400	TS, HS	pl,hb,bt,san, qtz,mt	trachy daci te	,,	S.Pattetejang area 7 km SE of Kp.Tabotabo
69401	TS, HS	pl,hb,bt,san,qtz	,,	,,	750m NE of sample 65978
69402	TS, HS	pl,hb,bt,san,qtz	,,	,,	1 km SE of sample 65978

E. Rock sample not referred to in this thesis

U.Tas No	Field No	Prepa-ration	Occu-rence	Rock type	1:250000 Map
69403	83SS138A	HS	dyke	Dacite	Sintang
69404	83AM77B	,,	,,	,,	,,
69405	83HZ49A	,,	,,	,,	,,
69406	83SN68B	,,	,,	,,	,,
69407	83CP188A	,,	,,	,,	,,
69408	84PW77B	,,	,,	,,	Nangapinoh
69409	83AM122C	,,	,,	,,	Sintang
69410	83HZ95C	,,	,,	,,	,,
69411	83DT38A	,,	,,	,,	,,
69412	83SN111C	,,	block	,,	,,
69413	83P76A	,,	dyke	,,	,,
69414	83UM74A	,,	,,	,,	Nangapinoh
69415	83AM81A	,,	,,	,,	Sintang
69416	83DS50A	,,	plug	,,	,,
69417	83SS107B	,,	dyke	,,	,,
69418	83PW105B	,,	,,	,,	,,
69419	83PW107A	,,	,,	,,	,,
69420	83AM99A	,,	,,	,,	,,
69421	83P56A	,,	block	,,	,,
69422	84UM12A	,,	dyke	,,	Nangapinoh
69423	83AM122B	,,	,,	,,	Sintang
69424	83BH190G	,,	block	,,	,,
69425	83HZ100A	,,	dyke	,,	,,
69426	83RH82C	,,	,,	,,	,,
69427	84ER109A	,,	,,	,,	Nangapinoh
69428	84PW94A	,,	,,	,,	,,
69429	83HZ102F	,,	,,	,,	Sintang
69430	83P54A	,,	block	,,	,,
69431	84SN04A	,,	dyke	,,	Nangapinoh

69432	83HZ92A	,,	,,	,,	Sintang
69433	83HZ98B	,,	,,	,,	,,
69434	84PW89D	,,	,,	,,	Nangapinoh
69435	83PR83C	,,	,,	,,	Sintang
69436	84PW43B	,,	,,	,,	Nangapinoh
69437	83HZ93A	,,	,,	,,	Sintang
69438	83SN69C	,,	,,	,,	,,
69439	83DT29B	,,	,,	,,	,,
69440	83ST10	,,	plug	Granite	Sarawak
69441	83DS71A	,,	dyke	Dacite	Sintang
69442	83PR67A	,,	,,	,,	,,
69443	84UM13	,,	,,	,,	Nangapinoh
69444	83SN69B	,,	,,	,,	Sintang
69445	83RH59A	,,	,,	,,	,,
69446	83DS67D	,,	,,	,,	,,
69447	84PR97A	,,	,,	,,	,,
69448	83PW83A	,,	,,	,,	,,
69449	83DS72	,,	,,	,,	,,
69450	83AM100A	,,	,,	,,	,,
69451	84IU93A	,,	,,	,,	,,
69452	83P62A	,,	,,	,,	,,
69453	83BH112A	,,	,,	,,	,,
69454	84IU92A	,,	,,	,,	Nangapinoh
69455	84P50A	,,	block	,,	Sintang
69456	8?PW157A	,,			
69457	83BH126B	,,	,,	,,	Putusibau
69458	84RH90A	,,	plug	,,	Sintang
69459	83P109B	,,	,,	Basalt	Sintang
69460	83SN118A	,,	,,	Dacite	,,
69461	83DT31B	,,	,,	,,	,,
69462	84IU160A	,,	plug	Rhyolite	Nangataman
69463	83RH81A	,,	,,	,,	Sintang
69464	83CP188B	,,	,,	,,	,,
69465	83SS77A	,,	,,	,,	,,
69466	83HZ85A	,,	,,	,,	,,
69467	84PW39B	,,	,,	,,	Nangapinoh
69468	84IU159A	,,	,,	,,	Nangataman
69469	83SN114D	,,	dyke	Andesite	Sintang
69470	84PW88A	,,	,,	,,	Nangapinoh
69471	84PW56A	HS,TS	,,	,,	,,
69472	83CP205A	HS,TS		Metamor-phic rx	Sintang
69473	83HZ113F	HS,TS		,,	,,
69474	84FK46A	HS,TS		,,	Nangapinoh
69475	83PW80B	HS,TS		Sediment	Sintang
69476	83CP268A	HS		,,	,,
69477	83SS92A	HS,TS		,,	,,
69478	83CP286A	HS		,,	,,
69479	83AM67B	HS		,,	,,
69480	83CP206C	HS,TS		,,	,,
69483	83PW120A	HS	dyke	Dacite	,,
69484	83BH126C	HS	block	,,	,,
69485	83SS115A	HS	dyke	,,	,,
69486	84PW95A	HS	,,	,,	Nangapinoh

Appendix 4

PRELIMINARY PETROLOGICAL DATA OF NEOGENE SUBVOLCANIC ROCKS FROM THE WESTERN PART OF SOUTH SULAWESI

Introduction

The rocks from the western part of South Sulawesi (WSS) (Fig. 1) are relatively potassium-rich (except sample 65971), with K_2O/Na_2O values ranging from 0.44-1.54. The TAS system (Fig. 1.5) classified the WWS rocks as phonotephrites, trachyandesites, trachydacites and dacites. They fall within the general field of volcanic rocks of the absarokite, banakite, high-K andesites, high-K dacites and dacites as defined by Gill (1982) and Peccerillo & Taylor (1976). These rocks are apparently associated with the Mio-Pliocene strike-slip faulting in South Sulawesi (Sukamto, 1978; Tjia, 1981; van Leeuwin, 1981; Berry & Grady, in press), although Hamilton (1979) suggested a subduction zone to the east of this area. The rocks intrude different types of country rocks, including the Cretaceous metamorphic complex and the overlying Cretaceous sandstone and Tertiary sediments. Many of these rocks intrude along the Late Tertiary wrench faults (Berry & Grady, in press).

Petrography and Mineralogy

The petrography of the WSS rocks is summarized in Table 1 and modal analyses are presented in Table 2.

The most distinctive petrographic characteristic within the WSS rocks is their richness in hornblende, biotite and K-feldspar. The phonotephrite or lamprophyre is holocrystalline and subporphyritic in texture, with amygdales filled by carbonate and analcite. The rock contains phenocrysts of clinopyroxene, hornblende and phlogopite, set in a holocrystalline groundmass of clinopyroxene, hornblende, biotite, K-feldspar and titanomagnetite. Apatite occurs as large grains included in hornblende and the groundmass. Euhedal and subhedral clinopyroxene crystals (maximum 1.2 x 0.75 mm) of diopsidic and salitic composition (Fig. 2) are zoned with a green core and grey to colourless rims. They range from the subalkaline to the alkaline compositional fields on SiO_2-Al_2O_3 and Al_z-TiO_2 diagrams (Fig. 3a,b). Some crystals show reversed zoning from cores of Mg value 66 to rims of Mg value 81, whereas others have cores of Mg value 82 and rims of Mg value 79. Plots of Al_2O_3 and TiO_2 versus Mg values (Fig. 4a,b) also suggest that not all of the clinopyroxene crystallized from the same melt. Magnesio-hastingsite grains (Leake, 1978) are euhedal to subhedral, light green to brownish green and zoned. Their compositions lie near

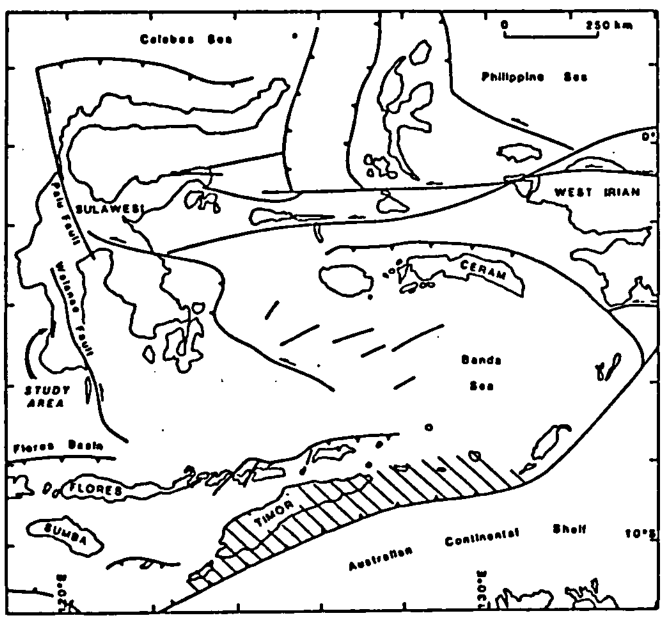

Fig. 1 Tectonic map of eastern Indonesia
The study area is shown by an arrow.

TABLE 1 SUMMARY OF PETROGRAPHY

ROCK TYPE	Phenocryst											Groundmass										
	pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol	ph	pl	san	qtz	cpx	opx	hbl	biot	mg	il	ol	ph
Lamprophyre	-	-	-	+	-	-	-	-	-	-	+	-	+	-	+	-	+	+	+	-	-	-
Trachy andesite	+	-	-	+	-	+	+	-	-	-	-	+	+	+	+	-	+	+	+	+	-	-
Trahcy dacite	+	-	+	-	-	+	+	-	-	-	-	+	+	+	-	-	+	+	+	+	-	-
Dacite	+	-	+	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	+	-	-	-

Explanation

ph = phlogopite, sec = secondary, vesic = vesicular.
Other abbreviation as in Table 2.1 and 2.2.

TABLE 2 MODAL COMPOSITION

Rock type	Spl.no.	cpx	hbl	biot/ph	pl	gr/sec	mg	san	vesic+zeolith	qtz
Phonoteprite	65968	20.68	0.63	9.57	-	34.29	5.76	22.49	6.58	-
Trachyandesite	65973	9.43	3.54	3.58	9.16	69.27	2.41	as gr	-	2.60
,,	65978	8.17	0.49	3.50	10.42	73.63	3.50	as gr	-	0.29

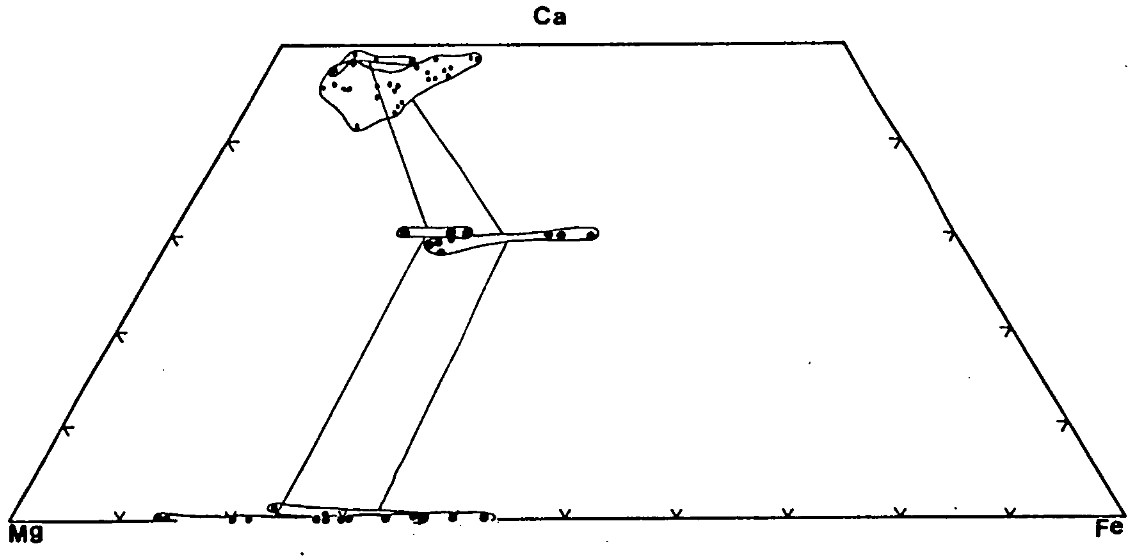

Fig. 2 Compositional variations of clinopyroxene, hornblende, biotie and phlogopite of the lamprophyre and trachyandesites. Tie lines join compositional fields of coexisting phases.

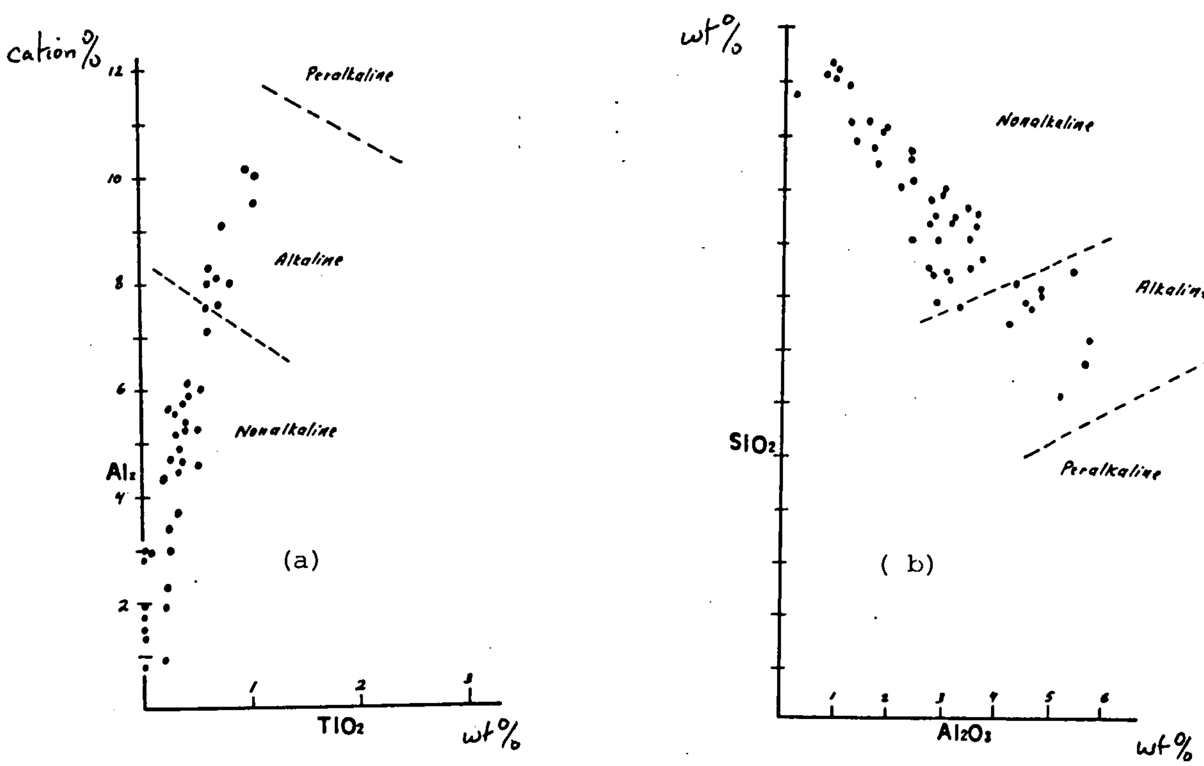

Fig. 3 Plots of Al_2O_3 versus SiO_2 (a) and TiO_2 versus Al_z (b) contents of clinopyroxene of the lamprophyre and trachyandesites.

Al_z = (100 x tetrahedral Al) /2
per 6 $O^=$

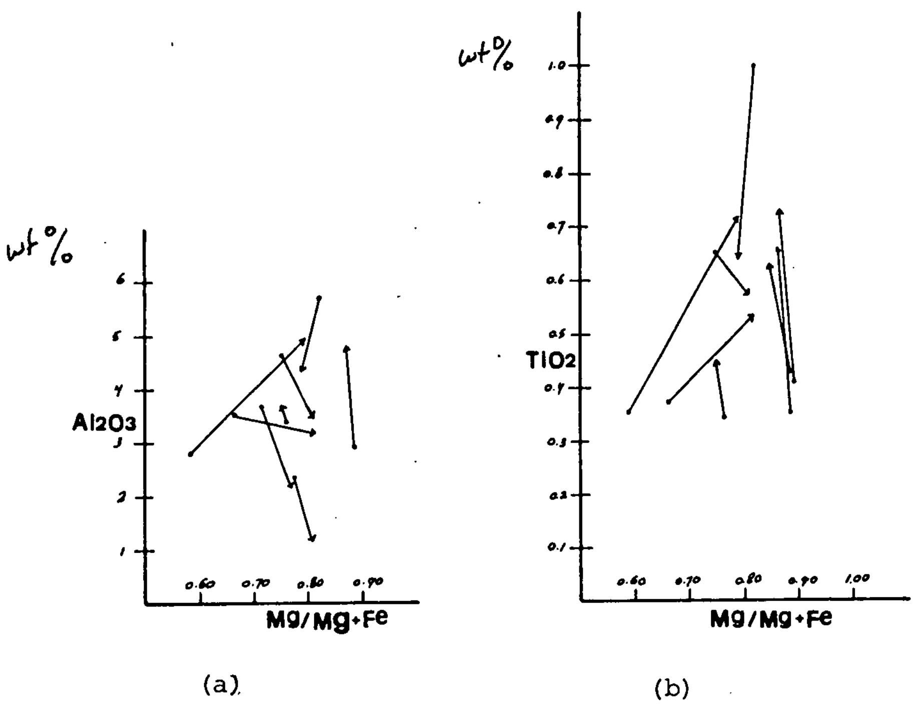

Fig. 4 Plot of Mg/Mg+Fe versus Al_2O_3 (a) and Mg/Mg+Fe versus TiO_2 (b) contents of clinopyroxene of the lamprophyre and trachyandesites. Tie lines join the core (dots) and rim (arrow) of the same phenocryst.

$Ca_{30}Mg_{44}Fe_{26}$, and Mg values range from 62.3-70.4 (Fig. 2, Appendix 2) and are rich in TiO_2 (2.3 wt%). This is a primitive magmatic hornblende. The phlogopite crystals (maximum 0.6 x 0.9 mm) are subhedral and zoned, with dark brown cores and brown rims. Their Mg values range up to 86 (Fig. 2, Appendix 2). The TiO_2 and Al_2O_3 contents range up to 3.5 and 18 wt%, respectively. The biotite grains contain TiO_2 and Al_2O_3 range up to 7.3 wt% and 16 wt%, respectively. Their compositional variations are $Ca_{0.0}Mg_{69}Ca_{31}$, with up to Mg value 70 (Fig. 2, Appendix 2). Titanomagnetite forms anhedral grains (see Appendix 2). K-feldspar is restricted to the groundmass, where it occurs as long prisms and needlès. Their compositional variations are shown in Fig. 5 and Appendix 2. Analcite compositions are also given in Appendix 2.

The trachyandesites and trachydacites contain phenocrysts of plagioclase, clinopyroxene, hornblende, biotite, Fe-Ti oxides and quartz. These minerals, together with sanidine, also make up the groundmass. One leucite xenocryst was found in sample 65978. The plagioclase (maximum 3.6 x 1.1 mm) is euhedral to subhedral, zoned, containing inclusions of clinopyoxene. The plagioclase zoned phenocrysts are composed of An_{50-68} cores to An_{30-57} rims, while the groundmass is $An_{32.3}$ (Fig. 5, Appendix 2). Phenocrysts of magnesio-hastingsite (Leake, 1978) up to 2.35 x 1 mm in size, are subhedral and green in colour. They range in composition (Fig. 2, Appendix 2) from $Ca_{29}Mg_{47}Fe_{24}$ to $Ca_{30}Mg_{35}Fe_{35}$ (Mg value 46-66).

The clinopyroxene grains (maximum 0.25 x 1.1 mm) are subhedral with resorbed rims, and compositionally zoned. They range in composition (Fig. 2) from $Ca_{45}Mg_{49}Fe_6$ to $Ca_{48}Mg_{34}Fe_{18}$. The clinopyroxene falls on the non-alkaline field of the SiO_2-Al_2O_3 and Al_z-TiO_2 plots (Fig. 3a,b). The zonation is reversed (Mg value 80.5 (core) to 77.3 (rim)) and normal (Mg value 89.0 (core) to 75.2 (rim)). Plots of the TiO_2 and Al_2O_3 versus Mg value (Fig. 4a,b) of the clinopyroxenes shows that they are derived from different sources. The biotites (1.1 x 0.25 mm) are subhedral, brown and have reaction rims against magnetite. They contain inclusions of apatite and magnetite. The opaques are mostly magnetite and titanomagnetite with scarce ilmenite and pyrite. The magnetite compositional variations are shown in Appendix 2. The K-feldspars are elongated prisms and needles. Their compositional variations are shown in Fig. 5 and Appendix 2.

The dacites consist of phenocrysts of plagioclase and quartz, set in a groundmass of plagioclase, quartz and magnetite. The plagioclase phenocrysts are zoned, ranging in composition from An_{35} to An_{49} (Fig. 5, Appendix 2).

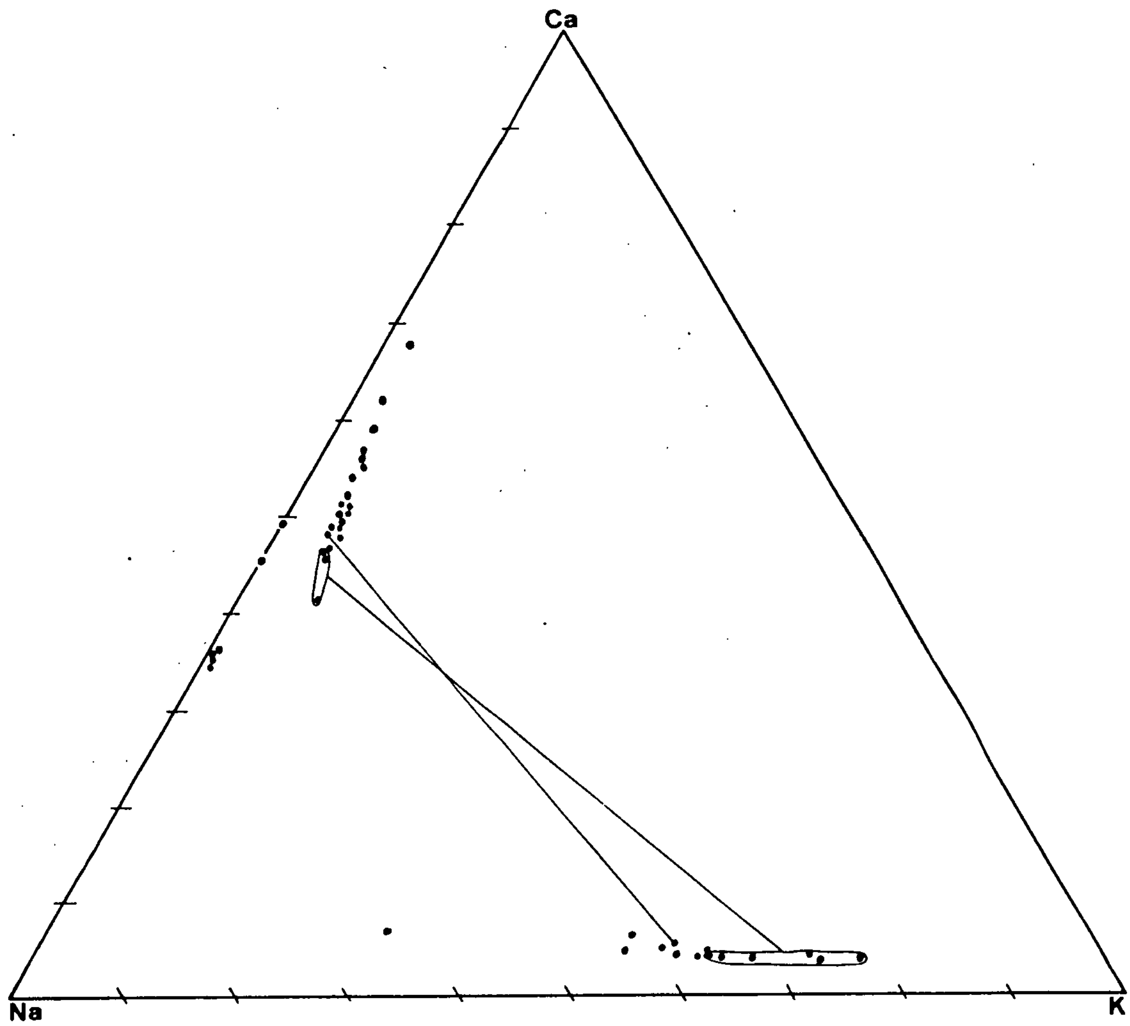

Fig. 5 Compositional variation of the feldspar from trachyandesite and dacites. Tie lines connect compositional fields of coexisting phases.

Major Elements

The CIPW norm calculations of the rocks are presented in Table 3. The lamprophyre is highly undersaturated up to 12.96% nepheline normative, 9.70% olivine normative, 22.46% diopside normative, and 1.78% apatite normative. It is classified as alkaline (Yoder & Tilley, 1962). The trachytes are quartz and hypersthene normative. All the rocks (except 65971) are extremely high orthoclase normative and low anorthite normative, compared with the rocks from West Kalimantan. The dacite (65971) has CIPW norm characteristics similar to the dacite from West Kalimantan.

The chemical characteristics of the rocks are presented in Table 3. The rocks (except 65971) are extremely high in K_2O (2.16-5.51 wt%) and low TiO_2 (0.31-1.02 wt%). They are also extremely high in loss of ignition (LOI) which is up to 4.88 wt%. Their Mg value ranges from 31.25 to 60.17, suggesting very evolved rocks. The lamprophyre has the highest Mg value, and high contents of FeO (7.72 wt%), MgO (5.87 wt%), CaO (8.93 wt%) and P_2O_5 (0.75 wt%). These types of rocks have been reported by Foden & Varne (1981) from G. Soromundi and G. Sanganges, East Indonesia.

On the AFM diagram, the WWS rocks fall in the calcalkaline field (Fig. 6).

Trace Elements and REE

Trace element analyses, including REE data, are given in Table 4. The rocks are high in Nd, La, Ba, Ce, Sr and Rb, compared with the rocks from West Kalimantan. Two samples (65968 and 65973) are extremely high in Zr (363 and 354 ppm, respectively) and Nb (42 and 21 ppm, respectively) contents. Sample 65973 has a high Y (72 ppm) content. K/Rb values of the WSS rocks range from 221 to 984. Relative to chondrite (Fig. 7a,b), enrichment decreases successively from low field strength to high field strength elements, but a marked trough occurs at Nb and Ti, and for two samples (65968 and 65973) also at Sr. Sample 65971 has extreme enrichment in Sr. It has different trace element characteristics from the others. It is from a different suite.

The REE patterns of the three representative samples (Fig. 8), show a distinct LREE enrichment. The trachytes are almost unfractionated HREE (Dy-Yb), while the lamprophyre has highly fractionated HREE. The rocks have a negative Eu anomaly, most pronounced in the trachytes. The REE abundance and distribution patterns of WSS are comparable to many similar calcalkaline rocks (Taylor et al., 1969; Thorpe et al., 1976) and the similar rocks from east Sunda Arc (Foden & Varne, 1981). Their pattern is also rather similar to the andesites and dacites from the southern region of CWK (see Section 2.5).

Table 3

Major element analyses and CIPW norms.

	65968	69402	65978	65973	69400	69401	65971
SiO_2	48.31	55.19	56.38	58.80	60.12	61.55	65.93
TiO_2	0.97	0.61	0.60	0.44	0.58	0.57	0.30
Al_2O_3	15.43	11.63	15.78	15.81	17.14	15.84	16.59
Fe_2O_3	7.34	6.23	7.31	5.34	5.25	5.06	2.77
MnO	0.17	0.10	0.13	0.11	0.08	0.11	0.05
MgO	5.58	4.16	2.72	2.43	2.74	1.26	2.07
CaO	8.49	5.12	6.07	5.72	4.03	4.79	3.96
Na_2O	4.40	2.05	3.57	3.49	4.79	3.31	4.85
K_2O	3.68	4.08	4.34	5.39	2.10	3.46	0.31
P_2O_5	0.71	0.31	0.51	0.31	0.20	0.24	0.10
LOI	4.88	10.19	2.85	2.90	2.41	3.37	2.87
Total	99.96	99.67	100.26	100.74	99.44	99.56	99.80
Q	-	10.52	1.76	2.88	9.08	15.56	23.66
C	-	-	-	-	0.14	-	1.32
Or	21.75	24.11	25.65	31.89	12.41	20.45	1.83
Ab	13.30	17.34	30.21	29.53	40.53	28.01	41.04
An	11.49	10.48	14.22	11.56	18.69	18.15	18.99
Ne	12.96	-	-	-	-	-	-
Di	21.21	10.57	10.52	12.30	-	3.43	-
Hy	-	13.10	11.02	6.91	13.39	7.77	8.64
Ol	9.16	-	-	-	-	-	-
Mt	1.06	0.90	1.06	0.77	0.76	0.73	0.40
Il	1.84	1.16	1.14	0.84	1.10	1.08	0.57
Ap	1.68	0.73	1.20	0.73	0.47	0.57	0.24
Mg value	60.17	57.32	42.16	46.36	52.27	31.25	57.04

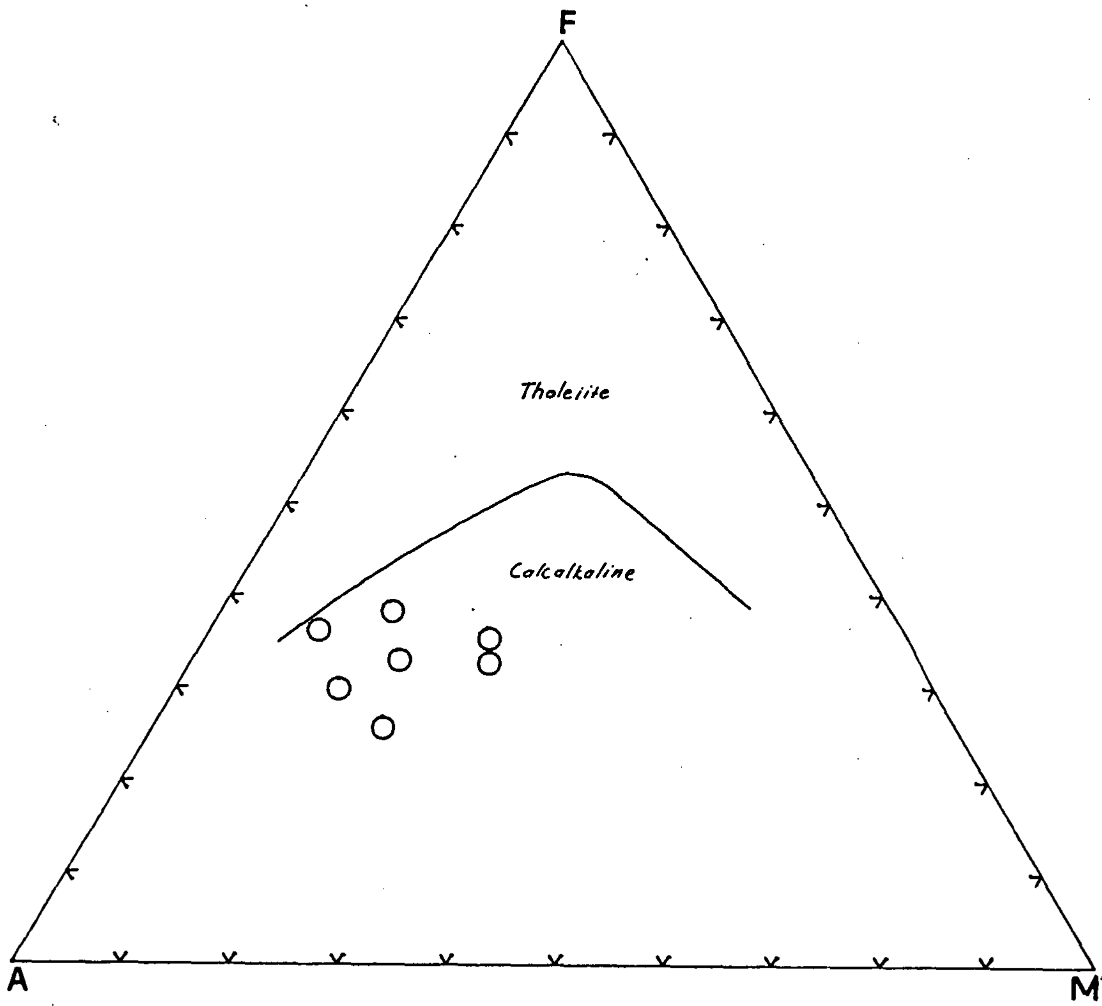

Fig. 6 AFM diagram: $A = K_2O+Na_2O$, $F = FeO$, and $M = MgO$.

Table 4

Trace element analyses.

	65968	69402	65978	65973	69400	69401	65971
Rb	98	116	149	207	29	111	3
Ba	2621	1098	1236	1526	375	960	168
Sr	746	726	971	1115	881	772	644
La	127	22	39	92	17	30	3
Ce	241	49	81	172	41	56	5
Pr	24.30	5.78		19			
Nd	89	24	34	72	23	25	4
Sm	15	5.38		13.60			
Eu	3.52	1.35		2.79			
Gd	10.80	5		12.20			
Dy	7	4.14		9.76			
Er	3.39	2.35		5.90			
Yb	2.58	2.23		5.25			
Y	38	24	31	72	15	24	4
Zr	363	83	185	354	124	124	47
Nb	42	4	9	30	2	5	1
Sc	15	20	18	14	14	13	11
V	181	162	165	113	121	98	90
Cr	192	190	37	106	13	5	66
Ni	80	132	17	54	30	8	27

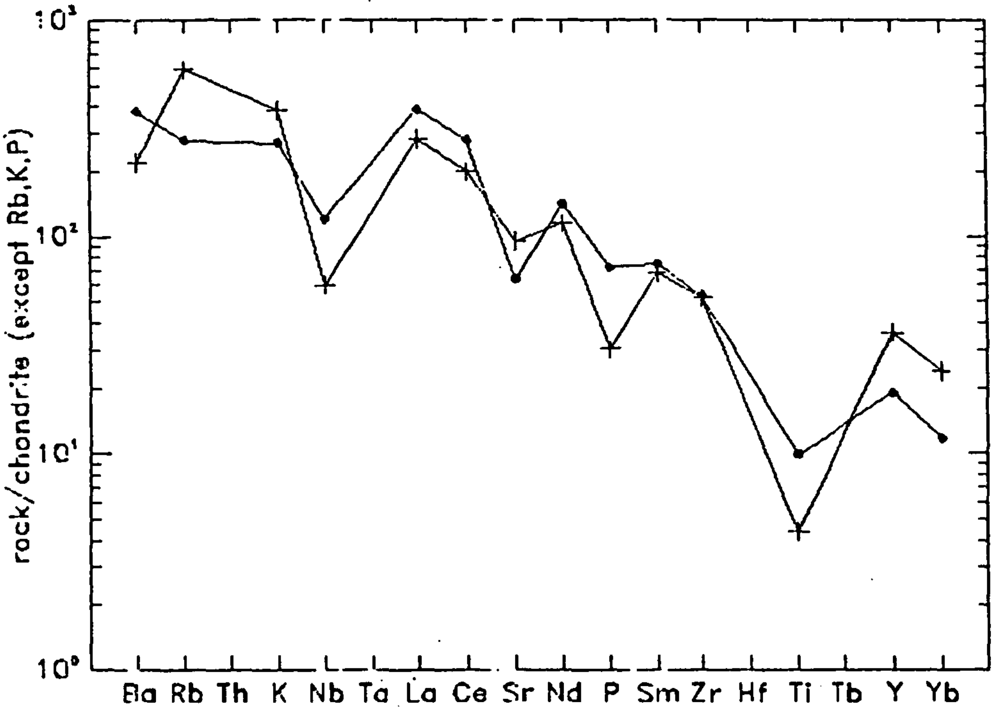

Fig. 7 a Normalized chondrite comparison diagram for trachyandesite [65973 (+)] and phonoteprite [65968 (•)] .

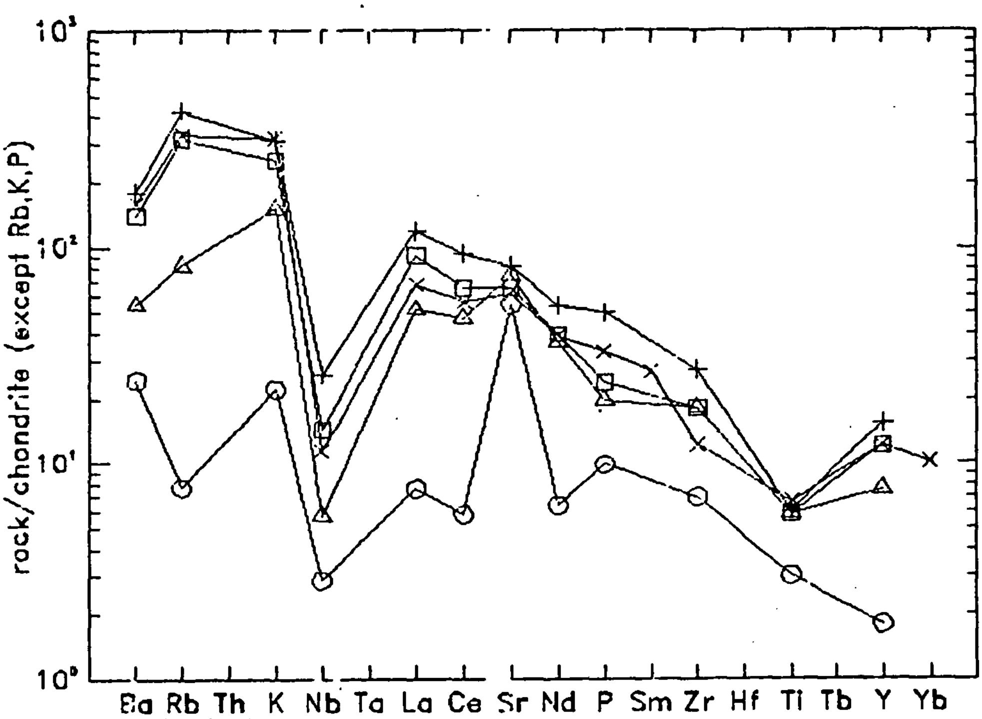

Fig. 7 b Diagram for trachy andesite [65978 (+) , 69402 (x),69400(△)] , trachy dacite [69401 (□), and dacite 65971 (O)]

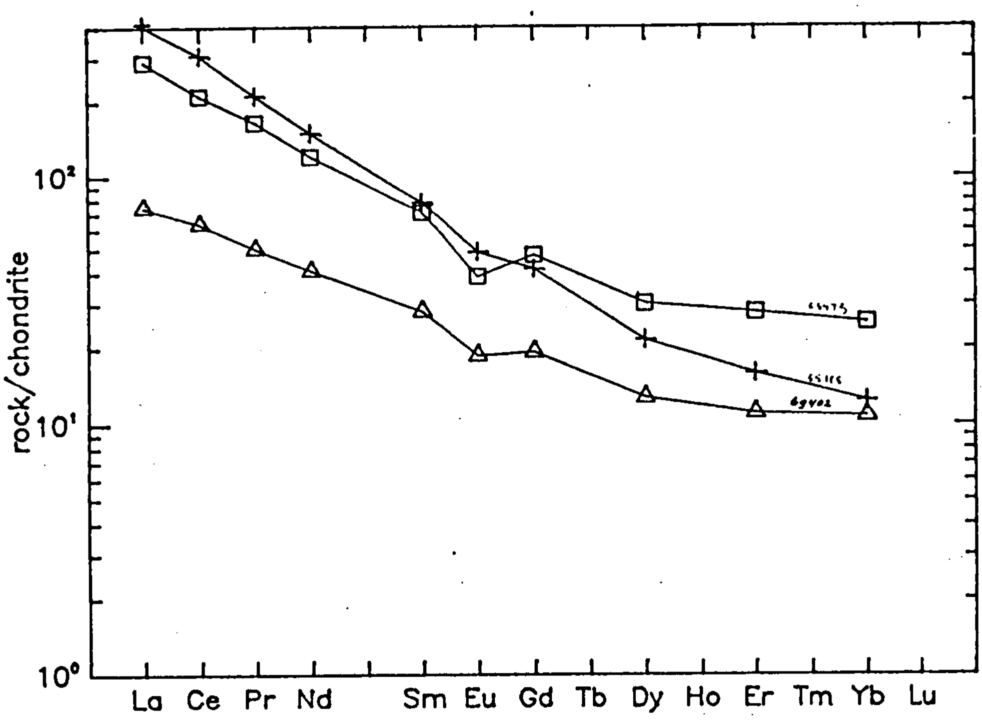

Fig. 8 Chondrite normalized REE pattern for phonoteprite [65968 (+)], trchyandesite [65973 (□) and 69402 (△)]

Conclusion

The subvolcanic rocks from WSS are composed of high-K calcalkaline and alkaline arc volcanics. They include biotite-clinopyroxene-hornblende-plagioclase phyric trachyandesite, biotite-quartz-hornblende-plagioclase phyric trachydacite, sanidine-phlogopite-hornblende-orthopyroxene lamprophyre, and quartz-plagioclase dacite.

The pyroxenes are Ca-rich and Mg-rich, ranging up to Mg values of 89. The zonation is mostly reversed. The magnesio-hastingsite has a Mg value of 70. The plagioclase phenocrysts are mostly labradorite, while the K-feldspar sanidine. Phlogopites occur with Mg values ranging up to 86.

Normatively the WSS rocks have high orthoclase contents and are richer in K, Sr, Ba, Nd, La, Ce, Rb and LREE than rocks from West Kalimantan.

The WSS rocks resemble eastern Sunda Arc volcanics (Varne & Foden, 1986). The REE abundances and distribution patterns are also comparable to the REE pattern of highly undersaturated lava from G. Sangenges and G. Soromundi (Foden & Varne, 1981a,b; Foden, 1979).

Sukamto (1975) and others have proposed that the island-arc situation in Sulawesi has been disturbed by the presence of major strike slip faults since the Mio-Pliocene. The petrological data from South Sulawesi support this model, as the Mio-Pliocene volcanics in this region are alkaline. Arc chemistry is often modified near cross-arc fractures (Gill et al., 1984) and this may prevent the recognition of arc-related magmas such as those predicted by Hamilton (1979) in this region.