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Record 1970/72

Short Papers on Quaternary Volcanic Areas in Papua - New Guinea

by

R. W. Johnson, D. E. Mackenzie and I. E. Smith

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CONTENTS

SUMMARY

The lavas of three Quaternary volcanic areas in Papua-New Guinea have a wide range of compositions. Tholeiitic basalts, "andesites" (sensu lato), dacites, and rhyolites are found in New Britain. Volcanoes in the New Guinea Highlands and eastern Papua are made up of calc-alkaline lavas and high-potash basalts (shoshonites).

The Quaternary volcanoes in New Britain define the eastern part of the Bismarck Volcanic Arc. The lavas are dominantly "andesites" (53-63 wt % SiO_2) that show moderate iron-enrichment. Tholeiitic basalts and dacites are commom, but rhyolites (more than 70 wt % SiO_2) are rare. All these lavas are hypersthene-normative. Rocks with the same silica content have variable percentages of total alkalies. The K_2O-content of lavas along the north coast of New Britain and Willaumez Peninsula increases northwards for rocks with the same silica content, and this increase can be corellated with increasing depth to the seismic, or Benioff, zone which dips northwards at about 70° beneath the volcanoes. There is no Benioff zone beneath the western part of the Bismarck Volcanic Arc; this may have given rise to differences in composition between lavas in the eastern part of the volcanic arc, and those in the western part.

The Pleistocene volcanoes of the New Guinea Highlands have produced lavas ranging from olivine-augite basalts to hornblende - and hypersthene-augite andesites. Chemically, these rocks range from high-alumina, low-silica andesites to high-potash alkaline basalts (shoshonites). The composition of the lavas may have been influenced by the presence of thick continental crust beneath the Highlands region, rather than by any planar seismic feature in the underlying mantle.

Volcanic rocks in eastern Papua can be divided into a pre-Middle Miocene tholeiitic basement series and a Pliocene to Recent superficial series of calc-alkaline and high potash alkaline rocks. The chemical variation observed between the volcanics compares with that observed in Fiji, and supports the observation of Jakeš and White (1969) and Gill (1970) that, in island arc environments, eruption of tholeiitic lavas is followed by eruption of calc-alkaline and potash-rich alkaline lavas.

INTRODUCTION

The Territory of Papua-New Guinea is a tectonically complex and active region at the margin of the Australasian continental mass. Throughout the Quaternary - and concurrently with tectonism - extensive volcanism took place in widely separated areas, producing clusters of volcanoes in regions such as the New Guinea Highlands, and narrow arc-like chains of volcanoes in zones such as the Bismarck Volcanic Arc north of New Guinea and New Britain.

A geological and petrological study of these areas of Quaternary volcanism is being made by geologists of the Bureau of Mineral Resources, and this Record presents preliminary results from three areas in the Territory: New Britain, the New Guinea Highlands, and Eastern Papua (Figure 1). The three papers presented here were read at the 1970 ANZAAS Conference in Port Moresby; they are progress reports on work which later will be synthesised into a comprehensive account of the Quaternary volcanic geology and petrology of Papua-New Guinea.

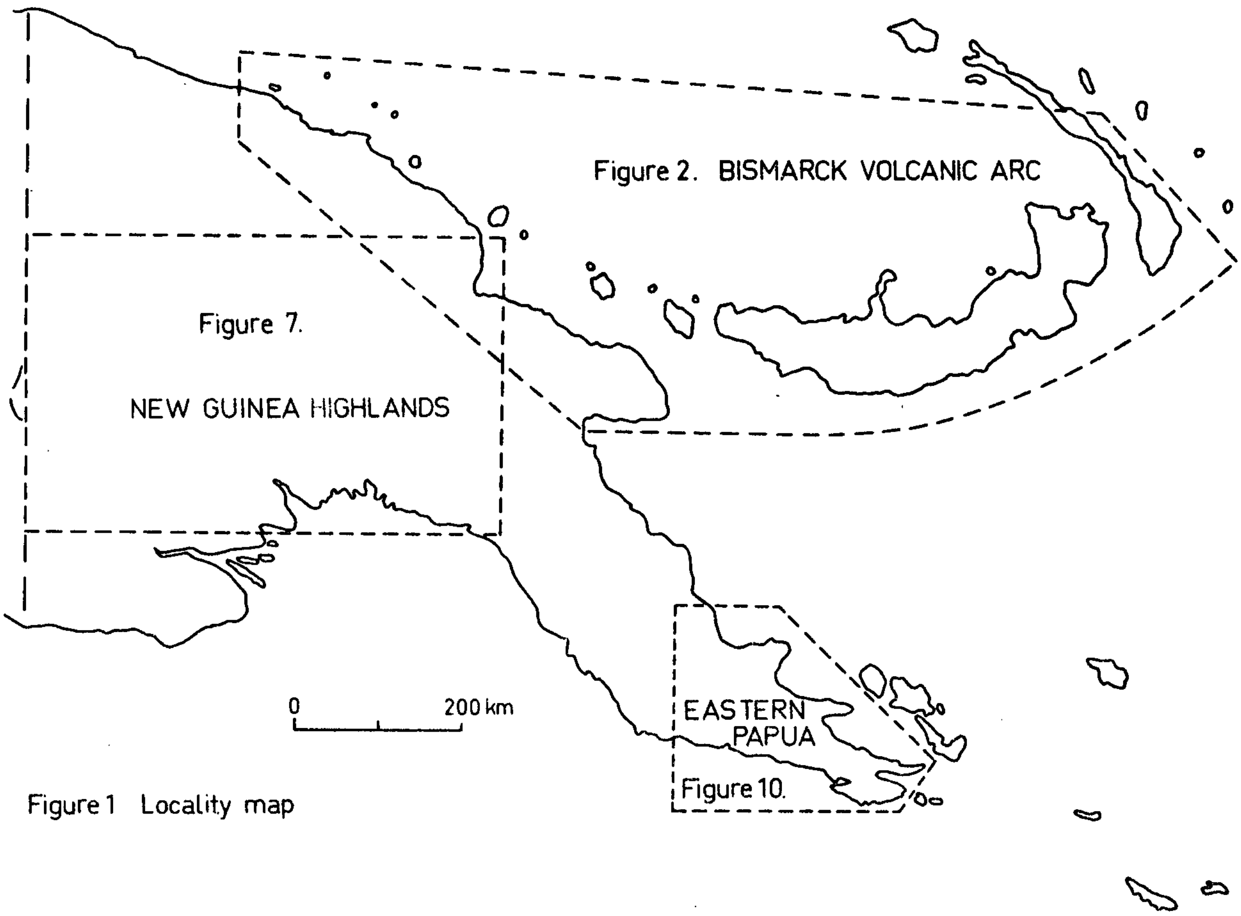

Figure 1 Locality map

To accompany Record 1970/72

P/A 318

VOLCANOES OF NEW BRITAIN: A SUMMARY OF PRELIMINARY PETROLOGICAL DATA

There are three areas of Quaternary volcanism in New Britain: (1) the Rabaul area, in the east (Heming, in preparation); (2) an area along the north coast, from Open Bay in the east up to, and including, Willaumez Peninsula in the west; (3) the Cape Gloucester area at the western end of the island. These areas form the eastern part of the Bismarck Volcanic Arc, a chain of Quaternary volcanoes over 1000 km long, that borders the southern part of the Bismarck Sea, from the Schouten Islands in the west to Rabaul in the east (Figure 2). The lavas of the New Britain volcanoes range from tholeiitic basalt to rhyolite, and the most abundant lava type appears to be of intermediate composition, with silica percentages in the range 53-63 ("andesites" sensu lato).

Active volcanoes and areas of hydrothermal activity are present in each of the three areas of Quaternary volcanism in New Britain. Tavurvur and Vulcan volcanoes in Rabaul Harbour, for example, erupted explosively in 1937, and inundated the town of Rabaul with ash, causing temporary evacuation of the population (Fisher, 1939). Along the north coast, Ulawun, Lolobau Island, and Pago have each erupted this century, the last eruption being in January, 1970, when Ulawun produced basaltic nuées ardentes and lava flows (Davies, 1970). Langila volcano, in the west of the island, has also erupted explosively several times this century; in 1960, for example, eruptions broke out from a new vent just north of the active craters described by Taylor et al. (1957).

BISMARCK VOLCANIC ARC

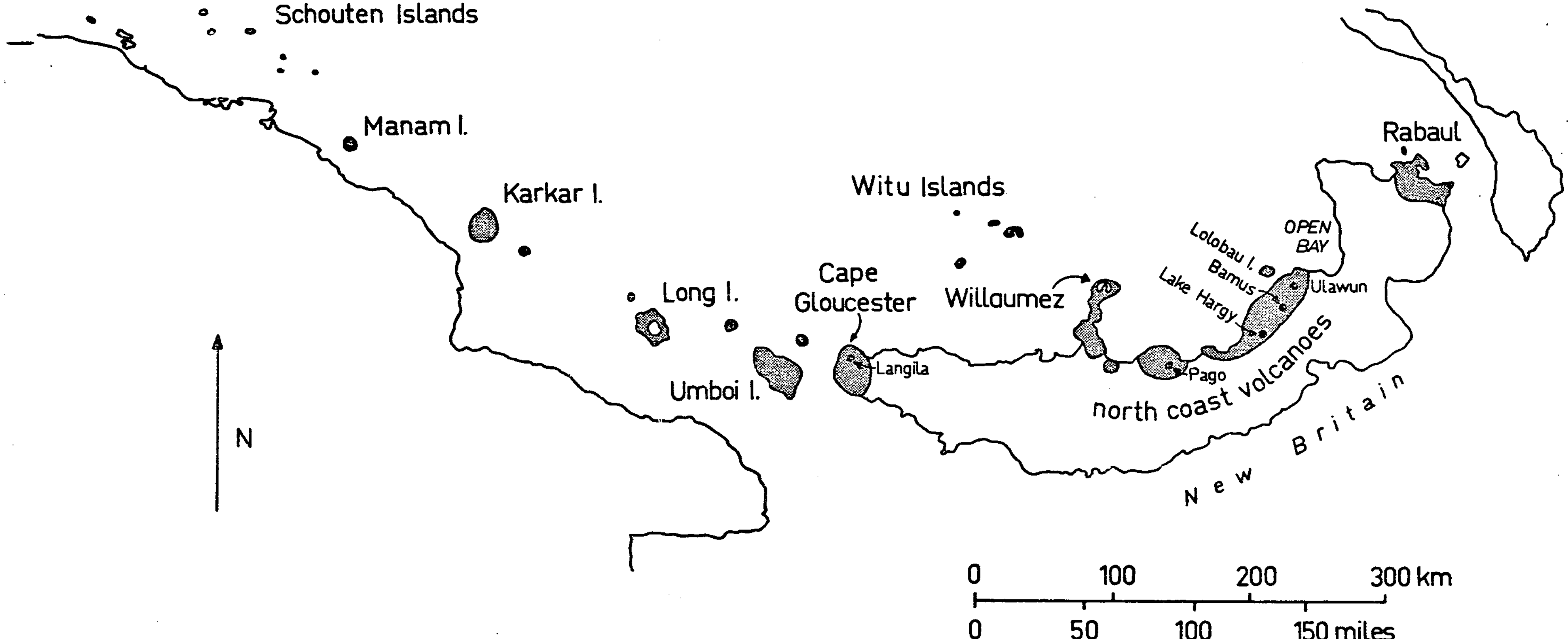

Fig. 2. Locality map
Areas of Quaternary volcanic rocks shown by shading.

To accompany Record 1970/72

P/A 319

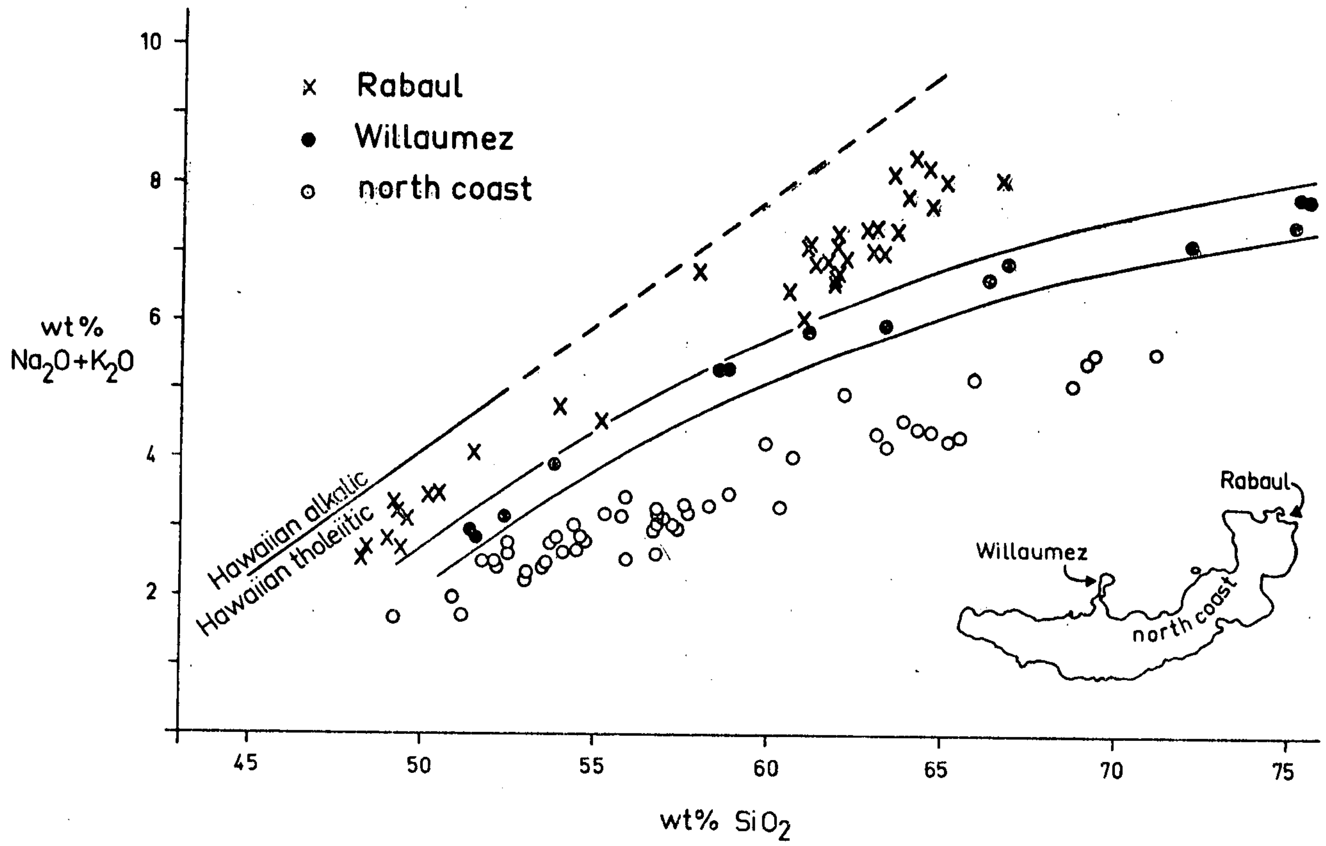

Fig. 3. Total alkalies vs. SiO_2 diagram

showing variation in alkali-content in Quaternary lavas from New Britain. Boundary between Hawaiian alkalic and tholeiitic fields taken from Macdonald and Katsura (1964).

To accompany Record 1970/72

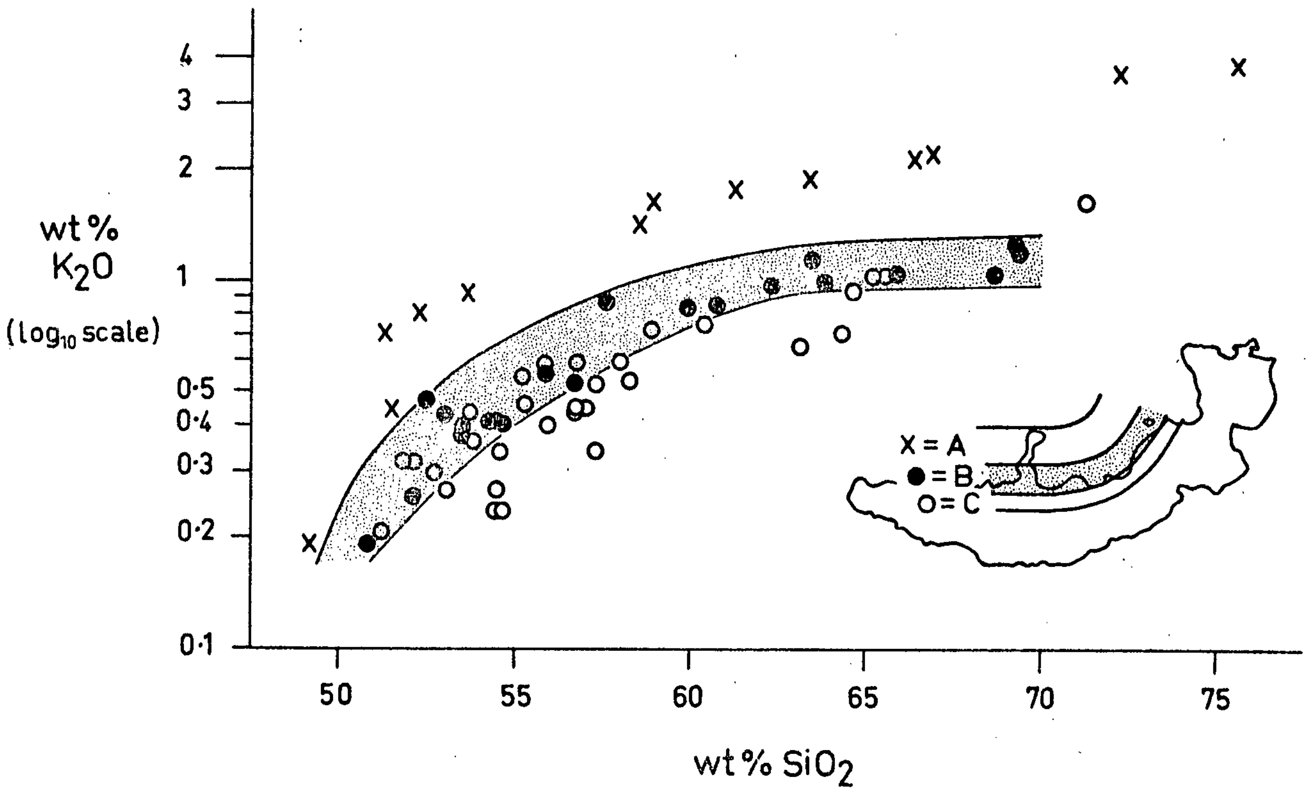

Fig. 4. K_2O vs. SiO_2 Diagram.

Illustrating the increases in K_2O-content, in lavas of equivalent silica percentages, northwards across the north coast of New Britain. Lavas of zone A have the highest, and those of zone C the lowest, K_2O-contents. Lavas of zone B (stippled area) have intermediate K_2O values.

To accompany Record 1970/72

M(P+) 75

New Britain, as well as being an area of active volcanism, is also one of intense seismic activity. In order to test the belief that the compositions of lavas in circumoceanic volcanic chains are related to the depth at which earthquakes take place beneath the volcanoes (see, for example, Kuno, 1959), the distribution of earthquakes in New Britain has been examined in detail (Johnson, 1970; this examination is an extension of the study by Denham (1969), and it incorporates new seismic data for the period 1966-1969). A map of earthquake epicentres and three seismic cross-sections for New Britain shows that a seismic, or Benioff, zone dips northwards beneath the island at about 70°, and underlies the volcanoes of the north coast, Willaumez Peninsula, and Cape Gloucester at depths between 100 and 250 km. (The submarine trench south of New Britain is underlain by earthquake foci up to about 70 km deep.) The Rabaul volcanoes, on the other hand, are not associated with a Benioff Zone; instead they appear to overlie the locus of three seismic lineaments: the New Britain belt of earthquakes; the line of shallow earthquake foci extending zcross the Bismarck Sea (Denham, 1969); and the New Ireland-Bougainville seismic belt.

The lavas from the New Britain section of the Bismarck Volcanic Arc are hypersthene-normative(no undersaturated rocks have been found). For equivalent silica values, there are different percentages of total alkalies (Na_2O + K_2O) in lavas from different parts of the volcanic chain (Figure 3). The Rabaul lavas, for example, are the most alkali-rich, and the basaltic varieties plot only just within the tholeiitic field defined by Macdonald and Katsura (1964). Lavas from the northern end of Willaumez Peninsula (analyses mainly by Lowder and Carmichael, 1970) are alkali-poor compared with the Rabaul lavas, but they are richer in total alkalies than rocks from the north coast volcanoes. Figure 3 also shows that most of the Rabaul rocks are either basaltic (about 50 wt % SiO_2) or high-silica andesites and dacites (60-65 wt % SiO_2), and that rocks between 50 and 60 wt % SiO_2 appear to be poorly developed in the Rabaul area. In contrast, most lavas from the north coast volcanoes appear to be andesitic (53-63 wt % SiO_2). Lowder and Carmichael (1969) also point out that andesite is the most abundant rock type at the northern end of Willaumez Peninsula.

On a K_2O vs. SiO_2 diagram (Figure 4), a progressive increase in K_2O-contents can be demonstrated in rocks from volcanoes along the north coast of New Britain, northwards, to those at the end of Willaumez Peninsula. This increase is consistent with the relationship demonstrated for other island arcs, that volcanoes with lavas of high K_2O- content overlie the deepest parts of the Benioff earthquake zone (see, for example, Dickinson and Hatherton, 1967). In the case of New Britain, the Benioff Zone is about 100 km below the north coast volcanoes, and about 250 km below the northern end of Willaumez Peninsula.

The rocks from volcanoes on the north coast and Willaumez Peninsula show a trend of moderate "iron-enrichment" when plotted in the variation diagram FeO + 0.9 Fe_2O_3 : MgO : Na_2O + K_2O ("F"MA diagram; Figure 5). This trend falls between the Hawaiian tholeiitic trend of Macdonald and Katsura (1964) and the "typical" calc-alkaline trend exemplified by the Cascade volcanoes of the western U.S.A., and it closely follows the trends shown by many other Quaternary volcanic series from island-arc regions in the western Pacific. The New Britain rocks therefore support the contention of Jakeš and Gill (1970) that trends of moderate iron-enrichment are characteristic of many western Pacific volcanic areas, and that these volcanoes are not "calc-alkaline" in the generally accepted sense.

On the variation diagram, iron oxide-magnesia ratio vs. SiO_2 (total iron as FeO : (total iron as FeO) + MgO vs. SiO_2; Figure 6) the rocks of the north coast and Willaumez volcanoes show a scatter of points which again illustrates iron-enrichment compared to lavas of a calc-alkaline series. The scatter of points is due to the tendency of certain volcanic centres to show different iron oxide-magnesia ratios for equivalent silica values, and this leads to the belief that petrogenesis may be influenced by processes operating at high crustal levels in separate magma chambers immediately beneath the volcanic centres (see, for example, the well-defined trend of rocks from Bamus volcano and the Lake Hargy area in Figure 6).

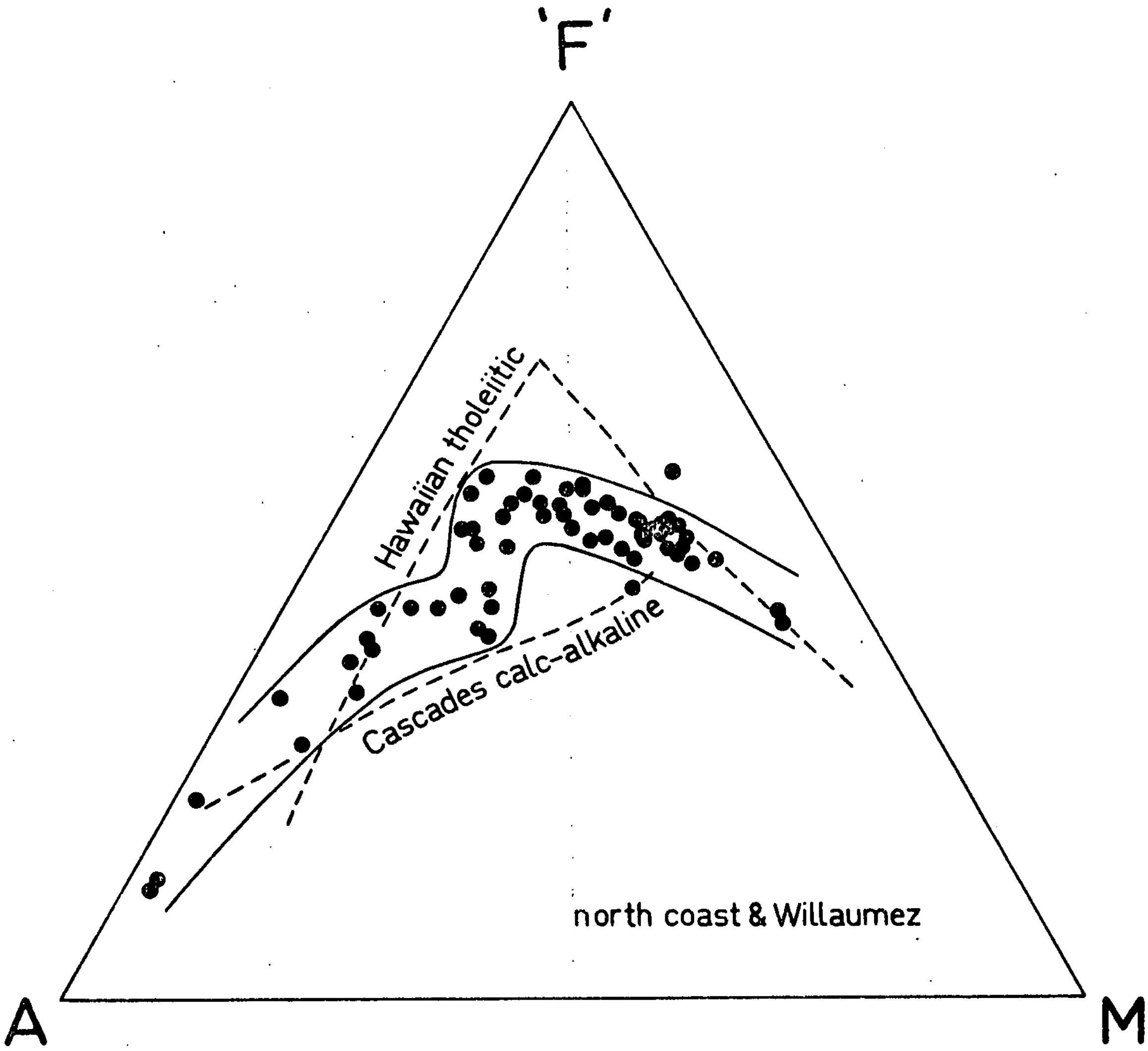

Fig. 5. 'F'MA diagram
('F' is total iron expressed as FeO)
for lavas from the north coast of New Britain and Willaumez Peninsula.
Most of the rocks plot in a sinuous belt between the Hawaiian tholeiitic trend (Macdonald and Katsura, 1964) and the Cascades calc-alkaline trend (Carmichael, 1964).

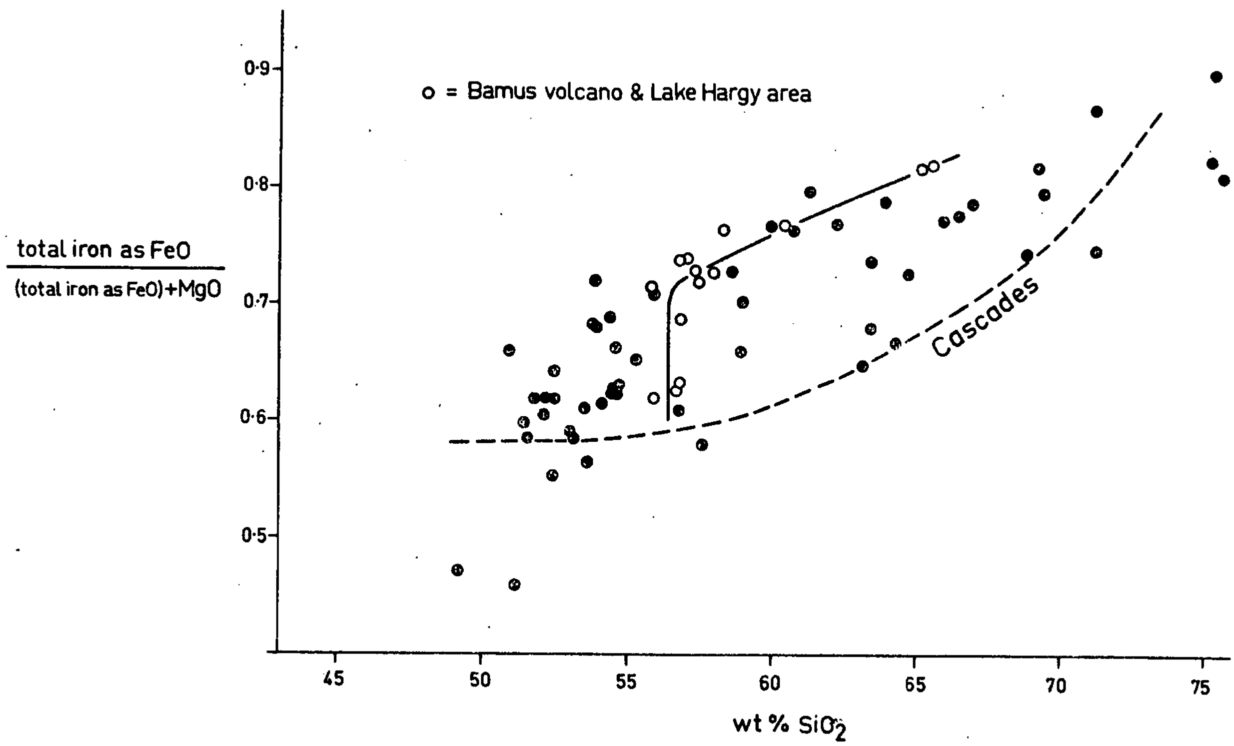

Fig.6. Total iron: magnesia ratio vs. SiO_2 diagram for lavas from the north coast of New Britain and Willaumez Peninsula. Within the scatter of points, rocks from Bamus volcano and the Lake Hargy area plot in a well-defined trend.
Cascades calc-alkaline trend taken from Carmichael (1964).

These petrological data from the New Britain volcanoes are preliminary, and must be considered with data from the rest of the Bismarck Volcanic Arc before a general petrogenetic theory can be proposed for the entire chain. Samples from the volcanic islands west of New Britain are to be collected in September and October, 1970, and it is hoped to incorporate new petrological results by the end of 1971.

The volcanic islands west of New Britain extend from Umboi Island in the east to the Schouten Islands in the west, and they include several active centres (for example, Manam and Long Islands; Figure2). This western part of the Bismarck Volcanic Arc is characterised by a seismic regime distinct from that of the eastern part (Johnson, 1970). Neither a Benioff Zone nor a submarine trench is associated with it, and most of the high-magnitude earthquakes take place to the south of the islands, on the New Guinea mainland, and have foci which are distributed at all levels down to about 120 km. Several deep-focus earthquakes, however, centre around Long Island, and define a "seismic cylinder" between about 120 and 230 km. If there is a relationship between the composition of lavas and the distribution of seismic events beneath the volcanoes, then significant differences in composition can be anticipated between the volcanic islands in the western part of the Bismarck Volcanic Arc and the volcanoes of New Britain in the eastern part.

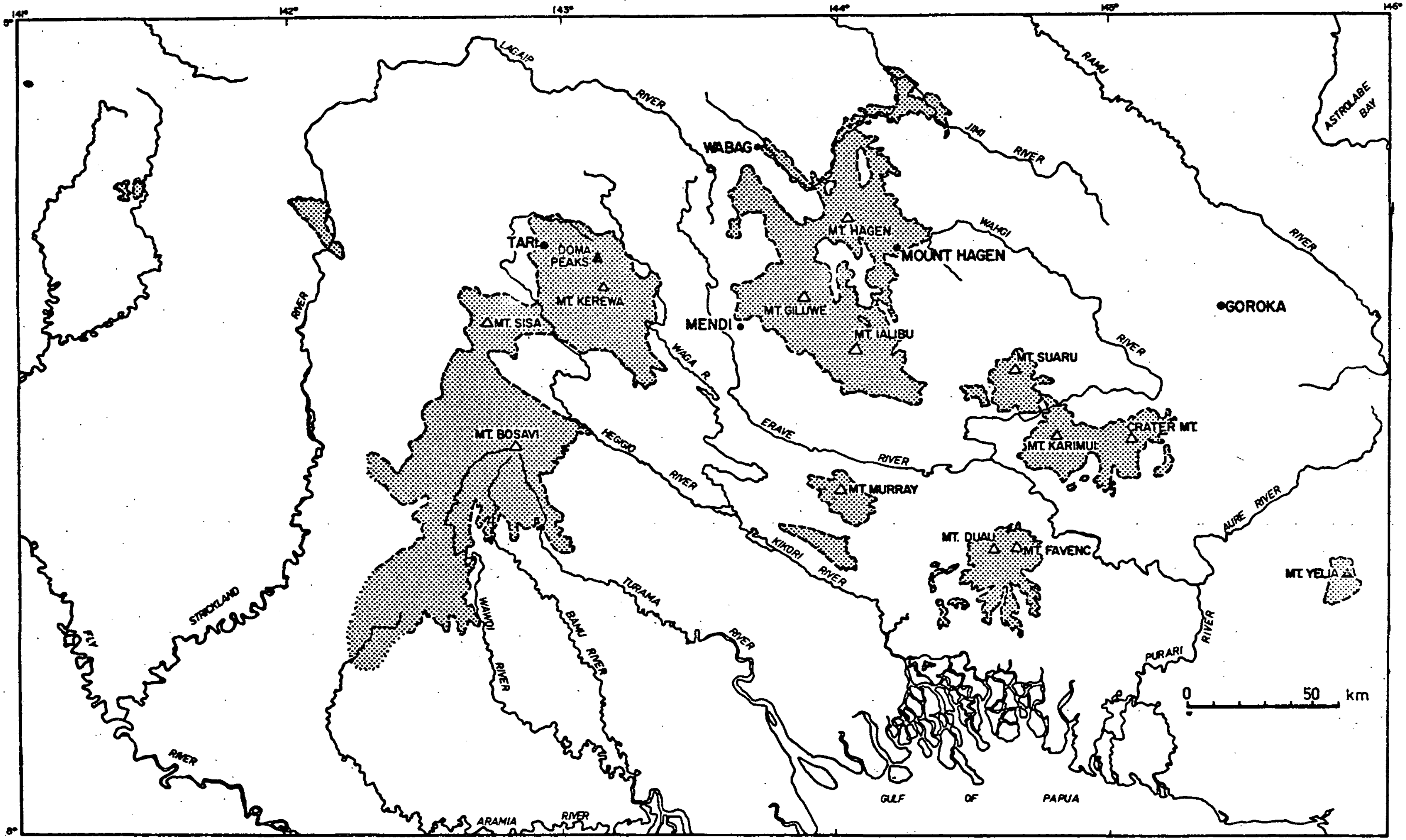

Fig. 7. Location of Quaternary volcanic centres and distribution of extrusives, New Guinea Highlands.

△ Inactive centre. ▲ Active centre. Minor centres not shown.

To accompany Record 1970/72

P/A 320

Pleistocene Volcanoes of the New Guinea Highlands

Introduction

There are fifteen major volcanic centres and at least ten small vents in the Highlands of Papua-New Guinea. They extend from near Marawaka, 160 km west-southwest of Lae, along the southern side of the central ranges to the West Irian border (Figure 7). The main centres are concentrated in an area northwest of the Gulf of Papua, bounded by 5°S and 7°S, $142^{\circ}30'$E and 145°E.

Collections of small numbers of samples from Mounts Hagen, Giluwe, Ialibu, Suaru, Karimui, and Crater Mountain were made in 1968; geological descriptions of these centres are given in B.M.R. Record 1970/79 (Bain et al.). British Petroleum geologists made available a small number of samples from Mounts Murray, Giluwe, Bosavi, Sisa, and Kerewa. Apart from Giluwe (Blake and Löffler, in press), little is known of these latter centres, except that they, like the others, are large stratovolcanoes, broadly circular in plan, and with simple conical shapes cut by deep gullies. Each is surrounded by a broad apron of gently sloping lavas, lahar deposits, volcanic breccias, and tuffs. The B.M.R. plans to map and sample all the Highlands volcanic centres in greater detail during 1971.

Solfataric activity has been recorded on Mount Yelia (Branch, 1967), and Doma Peaks is said by the local inhabitants to have erupted last century, destroying several villages (G.A.M. Taylor, pers. comm., 1970). Crater Mountain must have been active relatively recently, as there are several almost uneroded, sparsely vegetated flows on the mountain.

Mapping by the B.M.R. and several oil companies has shown that 5 to 10 km of Mesozoic and Tertiary sediments are underlain by Palaeozoic granitic and sedimentary basement. Gravity data (St. John, 1967) indicate that the crust beneath the Highlands volcanoes is 30 to 35 km thick, and is isostatically adjusted. The basement is therefore at least 20 km thick; it has behaved as a semi-rigid plate and has undergone only slight buckling prior to the initiation of Quaternary volcanism in the Highlands. Since the Pliocene there has been slight uplift and surficial tectonic activity (gravity sliding) in the area (Jenkins and Martin, 1969).

Petrography

Examination of about 60 thin sections shows that a continuous range of rock types exists, from olivine-augite basalt to hypersthene-augite and hornblende-augite andesites. Types intermediate between these end members contain phenocrysts of augite and either olivine and hornblende, or olivine and hypersthene, or hornblende and hypersthene. These various combinations of ferromagnesian phenocrysts are accompanied by large, complexly zoned plagioclase (andesine or labradorite) phenocrysts, and are set in a fine-grained groundmass of andesine laths, augite, and, in some samples, olivine. Small phenocrysts and groundmass grains of iron-titanium oxides are abundant. Low relief, potash-rich alkali feldspar occurs as narrow rims on plagioclase phenocrysts and in interstices in the groundmass of lavas rich in olivine and lacking hypersthene.

The hornblende is a yellow-brown variety (lamprobolite), and has either been completely replaced by, or has a wide rim of fine-grained titano-magnetite and augite. In some hypersthene-bearing samples, there is a narrow rim of fine-grained pyroxene surrounding the olivine phenocrysts.

A detailed discussion of the petrography of the Highlands volcanoes appears in Bain et al. (1970).

Chemistry

Thirty-six silicate analyses (by X-ray fluorescence) have been supplied by Dr B.W. Chappell of the Australian National University. A further 8 analyses of samples from Mounts Hagen, Giluwe, and Ialibu have been taken from Jakeš and White (1969). The analyses show that there is a chemical continuum from high-potash, low-silica "andesites", to high-potash basalts or shoshonites. This chemical range corresponds to the petrographic continuum from hypersthene-augite to olivine-augite bearing lavas.

Noteworthy features of the analyses are high K_2O and total alkalies, and low MgO and CaO as compared to calc-alkaline andesites (Taylor and White, 1969). Compared to alkali basalts, the Highlands lavas are high in SiO_2 and K_2O, and low in MgO and CaO. They are not as high in K_2O, or in K_2O/Na_2O ratio, as the shoshonites of Yellowstone Park, Wyoming (Nicholls and Carmichael, 1969). K_2O/Na_2O ratios of the Highlands lavas vary continuously from just over 0.4 in the "andesites", to just over 1.0 in the "shoshonites".

The high K calc-alkaline and shoshonitic lavas from Eastern Papua described by Smith (this Record) are petrographically and chemically similar to the Highlands lavas. Other eastern Papuan lavas are very high in K_2O/Na_2O, and are unlike any of the lavas of the Highlands volcanoes.

Figure 8 (total alkalies versus silica) shows an overall broad scatter of points with only a small general increase in total alkalies with increase in silica. However, when groups of points representing lavas from Mounts Suaru, Giluwe, and Hagen, and Crater Mountain are considered separately, distinct trends become apparent. The trends of Crater Mountain and Mount Hagen are parallel, and cross the dividing line M-K between the Hawaiian alkaline and tholeiitic fields (MacDonald and Katsura, 1964). They show only a slight increase in $Na_2O + K_2O$ with increasing SiO_2.

Plots of K_2O and K_2O/Na_2O versus silica show a broad scatter of points, with a general tendency towards positive correlation. There is a separation of hypersthene-bearing from non-hypersthene-bearine lavas in each graph.

In an "F"MA diagram (total iron as FeO: MgO: total alkalies), the Highlands rocks again show a wide scatter of points. Analyses of lavas from Mount Suaru, however, fall on a slightly curved trend through the centre of the field. Lavas from the southernmost centres (Murray, Bosavi, Sisa, Kerewa) plot on the iron-rich side of the field.

Trace element determinations made by direct reading optical spectrograph (at B.M.R.) brought out by only one notwworthy feature: Ni and Cu in the hypersthene-bearing rocks are lower by a factor of five to ten than in the olivine-bearing rocks.

Discussion

The olivine-bearing lavas of the Highlands volcanoes are petrographically similar to the shoshonites of Yellowstone Park, Wyoming (Nicholls and Carmichael, 1969), Fiji (Dickinson et al., 1968), and the Lesser Sunda Islands and Java (Joplin, 1968). In these areas, hypersthene-bearing lavas are either absent (Wyoming) or temporally and spatially separated from the shoshonites.

Joplin (1968), and Dickinson et al. (1968) suggested that shoshonitic lavas are characteristic of continental margins and newly stabilized or recently consolidated orogenic regions. Others (including Sugimura, 1968, and Condie and Potts, 1969) have correlated increasing crustal thickness with increase in potash in the overlying lavas. The area of the Highlands volcanoes satisfies the above criteria of Joplin and Dickinson et al., and is underlain by a thick continental crust.

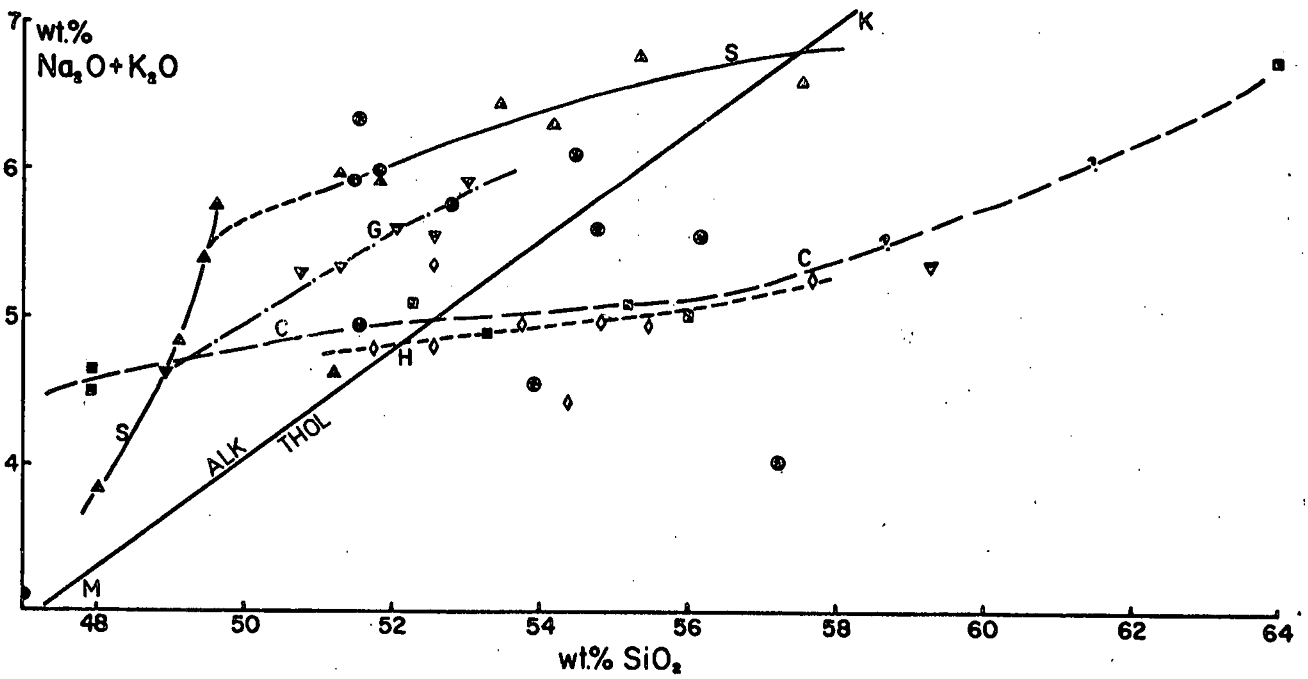

Fig. 8 Total alkalies vs. silica diagram, N.G. Highlands volcanoes

⊙ Lavas from Mts. Karimui, Murray, Bosavi, Sisa and Kerewa; △ Lavas from Mt. Suaru(S); ▽ Lavas from Mt. Giluwe (G); ⊡ Lavas from Crater Mt.(C); ◇ Lavas from Mt. Hagen(H).
Line M-K separates Hawaiian alkaline(ALK), and tholeiitic(THOL) rocks(MacDonald and Katsura,1964).

To accompany record 1970/72

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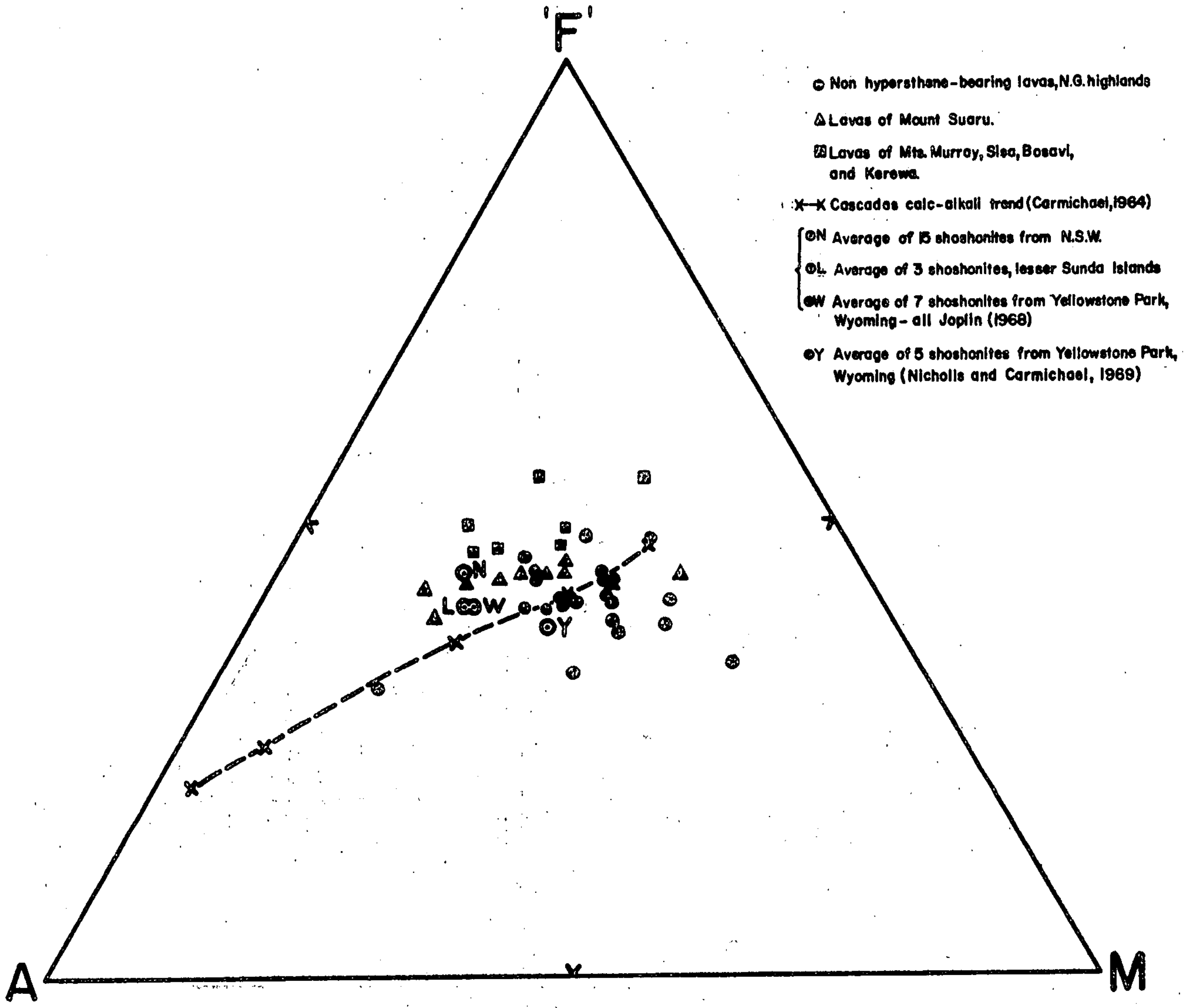

Fig.9 Total iron-magnesium-alkalies diagram, Highlands volcanoes.

To accompany Record 1970/72

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Jakeš and White (1969), applying the correlation made by Dickinson and Hatherton (1967), related the high potash of the New Guinea Highlands volcanoes to a Benioff zone 170-200 km beneath them. However, recent seismic data from northern New Guinea, plotted by Johnson (1970), and from the adjacent highlands, plotted by the writer, show that there is no planar seismic feature beneath the Highlands volcanoes. It is possible, however, that a Benioff zone existed beneath the Highlands region in the Pleistocene, and has since disappeared.

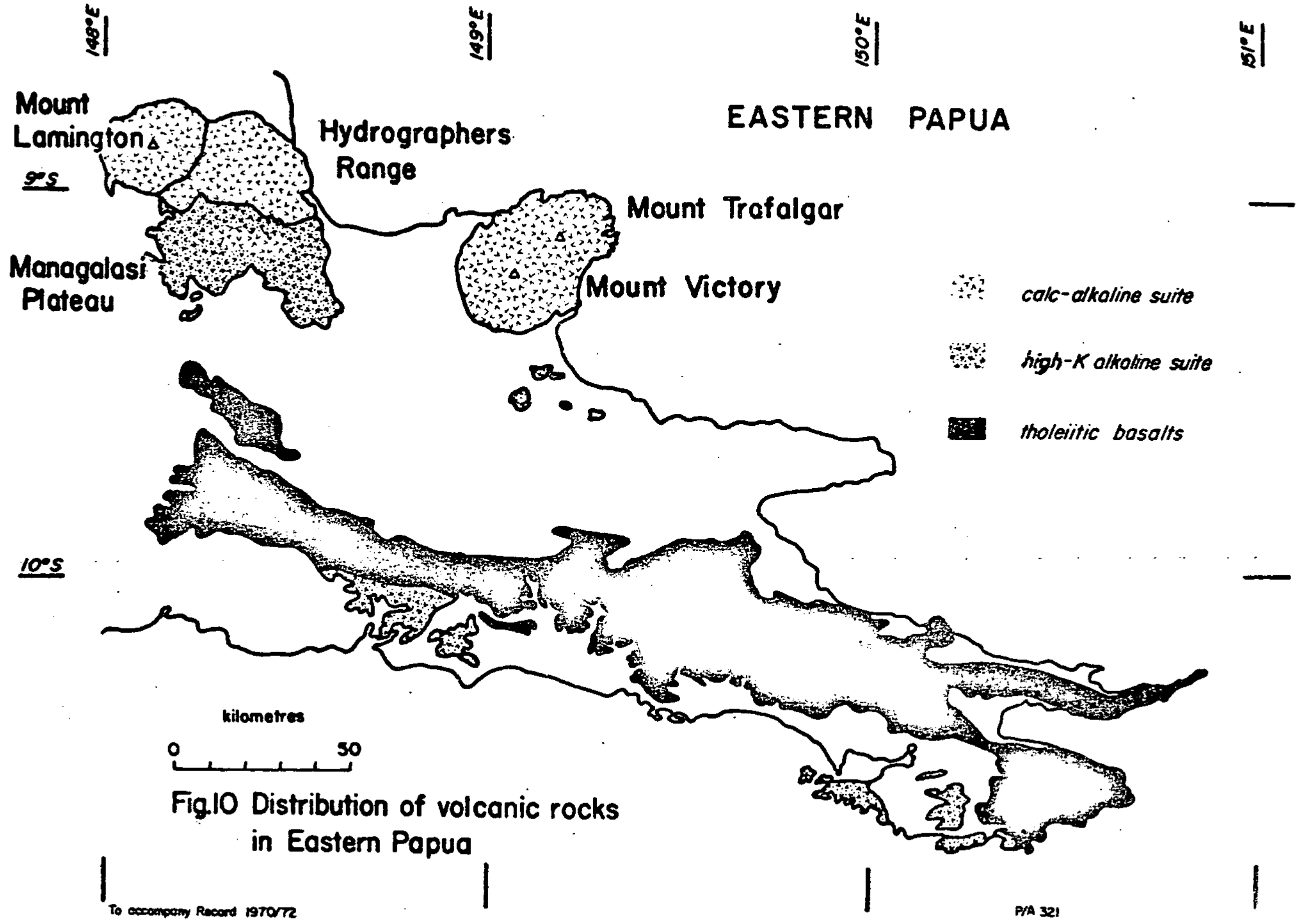

Fig.10 Distribution of volcanic rocks in Eastern Papua

LATE CAINOZOIC VOLCANISM IN EASTERN PAPUA

In this paper the late Cainozoic volcanic activity of mainland eastern Papua is discussed in the context of recent work on the evolution of volcanic arcs in the Melanesian region (Jakeš and White, 1969: Gill, 1970).

Over 40% of the land area of Papua east of 148°E (Figure 10), is composed of volcanic products, which can be divided into a basement series and a superficial series. The basement series is composed of over 3 km of tholeiitic submarine basalts ranging in age from Late Cretaceous to Middle Miocene. They represent an extended period of volcanic activity in an oceanic environment separated from any appreciable source of terrigenous sediment. These basalts were uplifted during the Late Cainozoic, and form part of the axial mountains in eastern Papua.

The superficial volcanic series ranges in age from Pliocene to Recent, and is mainly terrestrial. The recent eruptions of Mount Victory (1890's), Waiowa Volcano (1943-44), and Mount Lamington (1951) show that the area is still volcanically active. These Late Cainozoic volcanics comprise two chemically and petrographically distinct suites.

Along the north coast, calc-alkaline rocks form the large strato-volcanoes Mount Lamington, Hydrographers Range, Mount Victory, and Mount Trafalgar; calc-alkaline rocks also occur immediately south of Hydrographers Range on the Managalasi Plateau. The suite is composed of andesites and subordinate basalt, dacite, and rhyodacite, and is comparable to the high-K calc-alkaline rocks of Taylor (1969).

To the south of the calc-alkaline suite, the Pliocene to Recent volcanics are high-K alkaline rocks. (In this paper high-K alkaline suite is synonomous with shoshonite association as used by Jakeš and White (1969) and Jakeš and Smith (1970)). In the north the high-K alkaline suite is Quaternary, and along the south coast it is Pliocene to Pleistocene; it overlaps with the calc-alkaline suite on the Mangalasi Plateau. Rock types include basalts, trachyandesites, and the less well known basaltic types, absarokite, shoshonite, and banakite (cf. Joplin, 1968; Nicholls and Carmichael, 1969). The potash-rich character of the high-K alkaline suite is indicated by the presence of biotite as phenocrysts and of biotite and sanidine in the groundmass of basic members of the suite.

The high-K calc-alkaline and high-K alkaline suites in eastern Papua have many petrochemical similarities, although generally chemical trends are emphasised in the high-K alkaline suite. A total of 74 major element analyses from published (Taylor, 1958; Ruxton, 1966; Jakeš and Smith, 1970) and unpublished (Smith and Davies, in prep.) sources have been used in the comparative account which follows.

Features which are common to both suites are relatively high K_2O contents, variable Al_2O_3, and lack of any trend towards iron enrichment. For available analyses, SiO_2 contents are lower in the high-K alkaline suite (44-56 wt %) than in the calc-alkaline suite (50-69%); this is reflected on an "F"MA diagram (Figure 11) where the high-K alkaline rocks plot around the basic end of the calc-alkaline trend. At present it is not known whether this observation is a function of sampling or whether it reflects a fundamental difference between the suites.

Significant differences between the two suites are mainly in alkali contents and alkali ratios. The high-K alkaline suite is appreciably higher in total alkalies than the calc-alkaline suite, and comparison of total alkali/SiO_2 and K_2O/SiO_2 plots (Figure 12) shows that this difference lies in K_2O content. K_2O/Na_2O values (Fig. 12) for equivalent SiO_2 contents are higher in the high-K alkaline suite, and show a wide spread of values which is possibly due to accumulation, during fractionation, of a potash-rich phase.

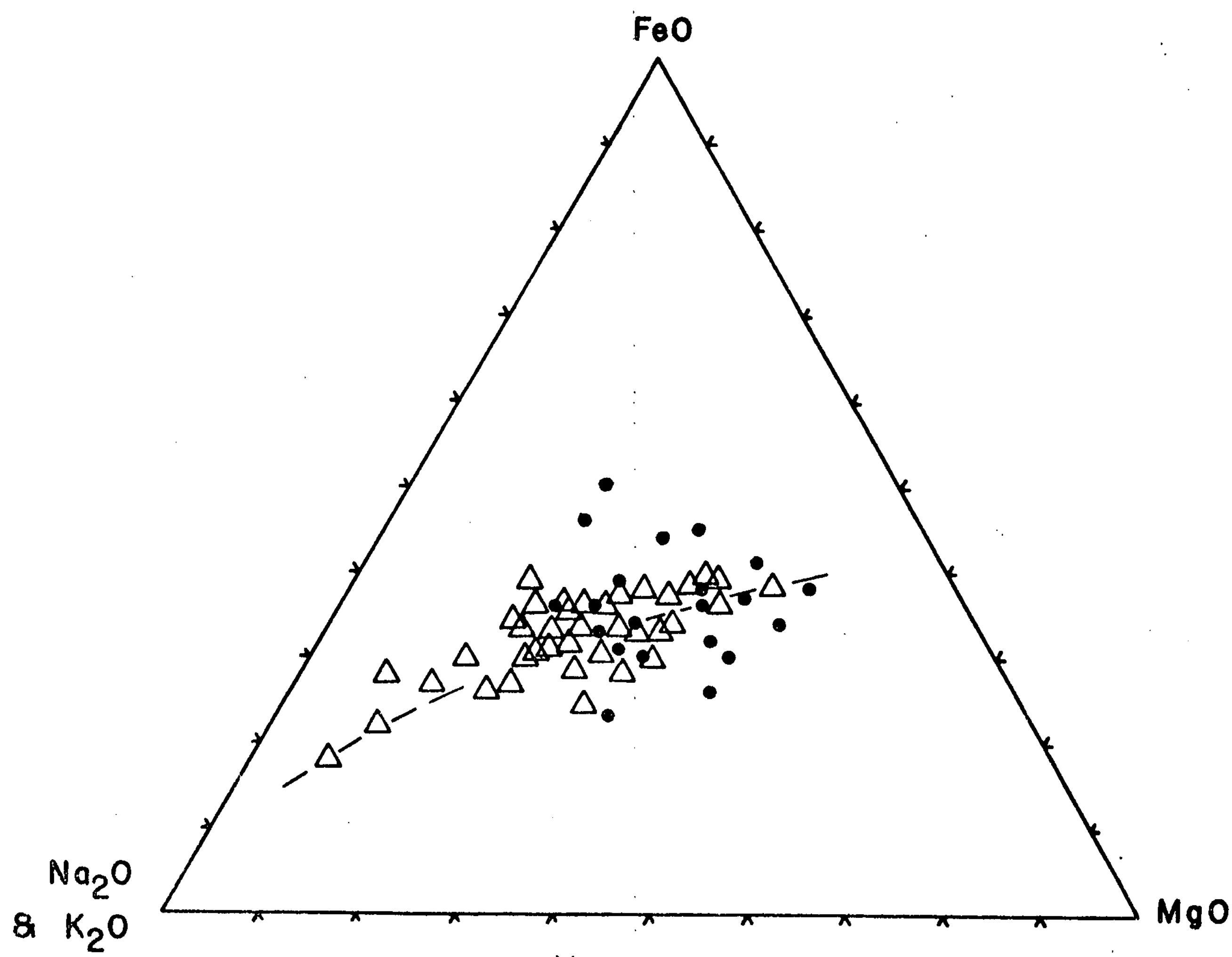

Fig. 11. 'F'MA diagram of calc-alkaline and high-K alkaline volcanic rocks from eastern Papua.
(analyses recalculated H_2O-free).

Δ Calc-alkaline
● High-K alkaline

To accompany record 1970/72

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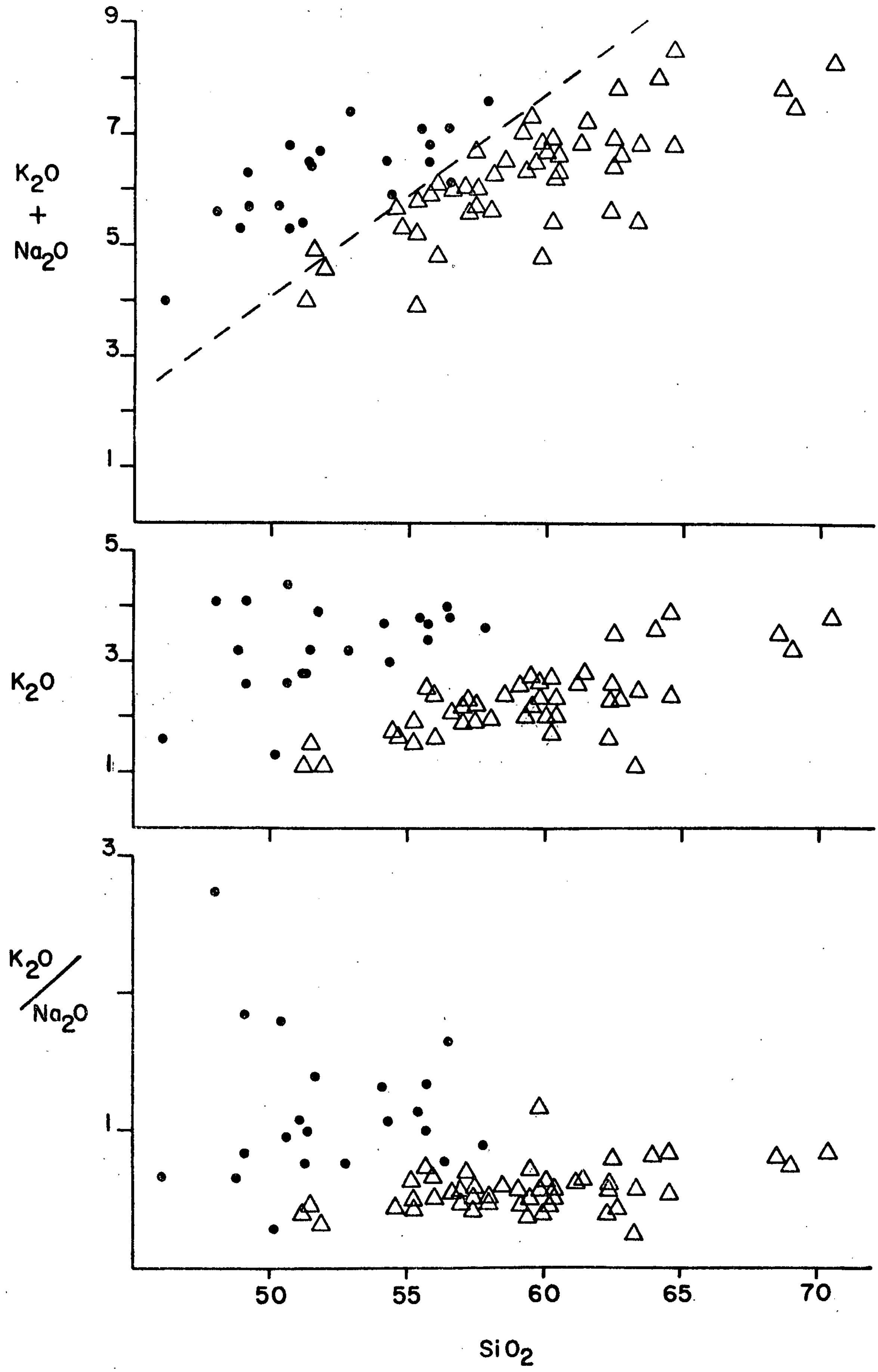

Fig.12. Total alkali/SiO_2, K_2O/SiO_2, and K_2O/Na_2O vs. SiO_2 plots for calc-alkaline and high-K alkaline volcanic rocks from eastern Papua.
(analyses recalculated H_2O-fr)

Δ Calc-alkaline

• High-K alkaline

Recent work by Dickinson (1968) has emphasised the role of alkalies, particularly potassium, in determining a model for the genesis of magmas in volcanic arcs. It has been demonstrated that, for a given value of SiO_2 the K_2O content of volcanic rocks increases towards the continental side of an arc. This variation is characterised by a progression from tholeiitic rocks on the oceanic side, through calc-alkaline rocks to alkaline rocks on the continental side of an arc. It has been widely suggested that the variation in K_2O content can be correlated with depth to the Benioff zone, and that the origin of the different suites can be explained by differing degrees of partial melting of the parental material under different pressure-temperature conditions at various depths within the Benioff zone.

Jakeš and White (1969) suggested that a variation in K_2O also takes place with time during the development of a volcanic arc. In their model a volcanic arc consists of a tholeiitic basement followed by calcalkaline and later by alkaline rocks. Support for this model comes from the Fiji Islands where a tholeiitic basement is overlain by calc-alkaline volcanics which are in turn overlain by high-K alkaline (shoshonitic) volcanics (Gill, 1970).

In eastern Papua eruption of tholeiitic submarine basalts was followed by eruption of calc-alkaline volcanics along the north coast, and of alkaline volcanics to the south. There is thus an increase in the K_2O contents of erupted lavas with time and with distance across the eastern Papuan peninsula which is similar to the volcanic arc model of Jakeš and White (1969), but differs in two important aspects. In their model Jakeš and White suggest that the high-K alkaline (shoshonitic) rocks follow in time the calc-alkaline rocks the implication being that as the arc evolves, partial melting takes place at greater depths and produces more highly potassic magmas. In eastern Papua, the high-K alkaline and calc-alkaline suites are essentially contemporary, and lavas of both suites have been erupted within the last 30 years (Waiowa Volcano, 1943-44; Mount Lamington, 1951). A further problem is that although K_2O variations can be compared with those of volcanic arcs with an underlying Benioff zone there is no Benioff zone underlying eastern Papua at the present time (Denham, 1969). This could be explained if present volcanic activity is at a dying stage, and that conditions under which the present magmas were generated are no longer operative. The alternative, that seismic zones are not essential to the generation of magmas in volcanic arcs, should also be considered.

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