PETROLOGY AND GEOCHEMISTRY
OF SOME ROCK SAMPLES
FROM THE NORTHERN FIJI PLATEAU

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By

Patricia Fryer

Thesis Committee:

Gordon A. Macdonald, Chairman
Patrick J. Coleman
Kost A. Pankiwskyj

We certify that we have read this thesis and that in our opinion it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Geology and Geophysics.

THESIS COMMITTEE

Gordon A. Macdonald
Chairman

[illegible] J. Coleman

Kost A. Pankiwskyj

ABSTRACT

Samples were collected from Anuda and Tikopea, two islands on the northern part of the Fiji Plateau, not previously investigated by geologists; samples were also dredged from the southwest wall of the Vitiaz Trench. Although the mineralogy and petrology of the samples from Tikopea, the closest of the two islands to the New Hebrides, is similar to andesites from that island chain, the Tikopea samples are enriched in silica and alkalis as compared with the New Hebrides andesites. The formation of Tikopea Island might be related to crustal fracturing on the Fiji Plateau. The rock samples from Anuda and the Vitiaz Trench are tholeiitic. It is possible that the formation of Anuda was tectonically related to the Vitiaz Trench. Investigation of the northern Fiji Plateau by geophysical means is necessary to verify the speculations offered in this paper. Conclusions about the petrologic relationships of the islands and the Vitiaz Trench must remain limited until more samples are procured.

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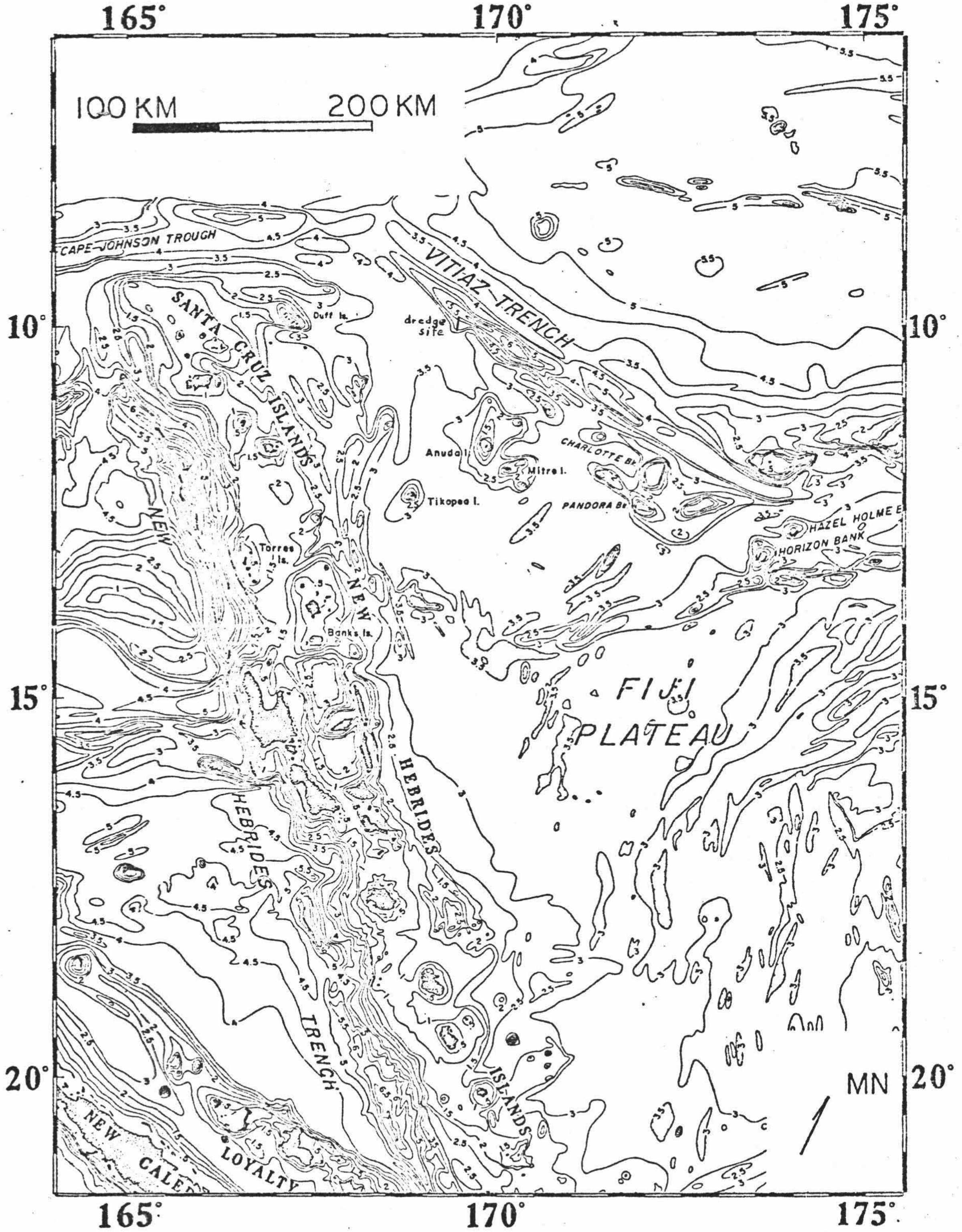
INTRODUCTION

The northern part of the Fiji Plateau is a triangular area bounded on the south by the Hazel Holme Fracture Zone, on the west by the Santa Cruz and northern New Hebrides island groups and on the northeast by the Vitiaz Trench (Fig. 1). Water depth over the Plateau is relatively shallow, averaging 3 km as compared to normal ocean basins which are 4.5 to 5 km deep. It has very complex topography with little sediment cover except in isolated lows. On the southern side of the Vitiaz Trench is a roughly linear chain of guyots, seamounts and volcanic islands that trend northwest-southeast parallel to the trench, of these Anuda Island and Fatutaka Island (Mitre) are the northern most. Pandora Island, southeast of Fatutaka, is a small coral and sand island that appears and disappears in response to storms and seasonal changes in weather. The only other island on the northern part of the Fiji Plateau is Tikopea, an isolated volcano about half way between Anuda and the northern Banks Islands. The floor of the Plateau near Anuda is relatively flat and bathymetric profiles show sediments approximately 80 to 150 m thick. However, the vicinity of Tikopea has little sediment cover and profiles taken there show a high relief, complex topography.

Prior to October of 1971, the geology of these islands had not been described. During leg 5 of the 1971 cruise of R/V Kana Keoki short stops were made on Anuda and Tikopea in order to collect rock samples and make notes on the geology of the islands. A landing on Fatutaka was not possible, but from its appearance it, like Anuda and Tikopea, is volcanic. The samples obtained are as representative of the rock types on the islands as possible. Outcroppings of fresh lava

Figure 1. The northern Fiji Plateau and surrounding area. Contour interval 0.5 km (after Chase, 1971).


165°
170°
175°
100 KM
200 KM
CAPE JOHNSON TROUGH
VITIAZ TRENCH
SANTA CRUZ ISLANDS
Duff Is.
dredge site
10°
Anuda I.
Mitre I.
CHARLOTTE Bk
PANDORA Bk
Tikopea I.
HAZEL HOLME B
HORIZON BANK
Torres Is.
NEW
NEW
Banks Is.
15°
FIJI PLATEAU
HEBRIDES
HEBRIDES
TRENCH
ISLANDS
20°
MN
NEW CALED
LOYALTY
165°
170°
175°

are limited on Anuda and the time available for sampling on Tikopea was insufficient for the collecting of rocks on the eastern side of the island. Of over a dozen rocks collected on Anuda, four were fresh enough to warrant examining in thin section. Of the twenty-four samples taken on Tikopea, nine were sectioned and studied. In addition to the collecting of island samples, a rock-dredging operation was conducted over the south wall of the Vitiaz Trench and a large haul was retrieved. Nine of the igneous rocks from the trench were studied in thin section. The twenty-two rock samples on which this study is based are altered to some degree, but eight of them are relatively fresh and were analyzed for major elements at the Japan Analytical Chemistry Institute by Tadashi Asari. Modal analyses of all twenty-two rock samples were carried out by the author and x-ray diffraction patterns obtained for most of the rocks supplemented microscopic determination of the minerals in the samples. The refractive indices of the major phases present were determined, when possible. Two of the samples, All and Tl, were subjected to microprobe analysis at California Institute of Technology, Division of Geological and Planetary Sciences, by Charles Fein, the results of which are compared to and in most cases substantiate the petrographic determinations of certain minerals.

The immediate purpose of this report is to present petrographic descriptions and chemical analyses of rock samples from localities not previously studied. It is hoped that the results of this investigation will benefit further study of the geologic history of the northern Fiji Plateau.

GEOLOGY OF THE ISLANDS

Anuda Island

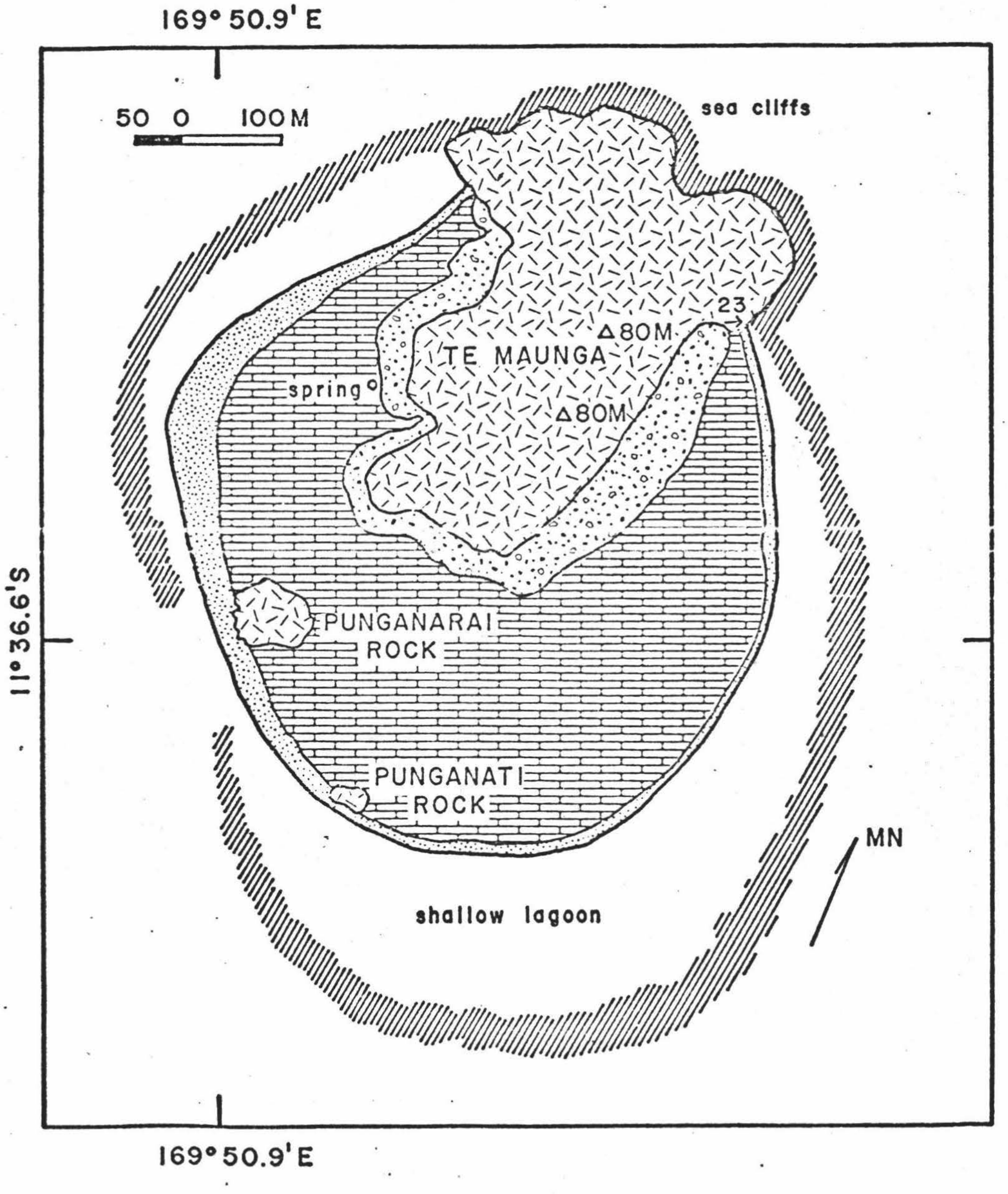
Anuda is a small, roughly circular island located at latitude 11°36.6'S and longitude 169°50.9'E (Fig. 2). It has an area of approximately 1.89 km^2. The northern portion of the island is comprised of two coalesced hills, Te Maunga, with a small swale in between. The hills are rounded and each reaches an elevation of about 80 m above sea level. A crescent-shaped platform of calcareous sand and weathered rock material girds the southern portion of the hills. The northern most of the two hills meets the sea in cliffs from 7 to 15 m high and there are highly weathered, buff colored lavas exposed in these cliffs. Vestigial phenocrysts of plagioclase are evident in some hand specimens of the lavas, but the groundmass is altered and chalky, so the minerals of which it is composed are not identifiable. Fresher porphyries outcrop in the sea cliffs on the eastern side of Anuda. There the flows, from 0.2 to 0.5 m thick, dip 23° to the northeast; they have a dark gray groundmass and contain lath-shaped plagioclase phenocrysts up to 15 mm in length. In some of the flows the phenocrysts show parallel alignment and the lavas are slightly to moderately vesicular. Fresh rocks are also exposed on the top of Te Maunga; they are highly porphyritic and have a dark gray groundmass. The phenocrysts of these rocks are plagioclase crystals up to 11 mm in length which are so strongly zoned that in some specimens the zoning can be seen without the aid of a microscope. The plagioclase crystals in these rocks are generally tabular rather than elongate and show very little preferred orientation; the rocks are only

Figure 2. Anuda Island

Legend

░	. . . . calcareous beach sand
▤	. . . . unlithified calcareous sand and rock debris
▒	. . . . talus
▨	. . . . porphyritic lavas
⫽	. . . . approximate position of reef
→23	. . . . attitude of flows

(base map courtesy of D.E. Yen,
Anthropology Department, Bishop
Museum)


169° 50.9' E
50 0 100 M
sea cliffs
23
Δ80M
TE MAUNGA
spring
Δ80M
11° 36.6'S
11° 36.6'S
PUNGANARAI ROCK
PUNGANATI ROCK
MN
shallow lagoon
169° 50.9' E

slightly vesicular. All, a sample of the fresher Anuda lava, was submitted for K-Ar age determination, but the sample was contaminated with chloride and an age determination was impossible.

The southern part of Anuda is a sedimentary shelf of low relief, composed largely of unlithified calcareous sand; weathered rock material is intermingled with the sand, especially near the base of the hills, and is probably derived from the scree mantle. Volcanic rock outcrops in two erosional remnants on the south shore of Anuda. The larger is Punganarai Rock, about 15 m high and composed of weathered lava similar to that exposed in the northern sea cliffs; the other is Punganati Rock, 3 to 5 m high, composed of slightly weathered which is dark gray in color, has a few plagioclase phenocrysts and is moderately vesicular.

The degree of weathering of the lavas on Anuda suggests that there were at least two periods of activity on the island. The earlier is represented by the highly altered rocks exposed in the northern sea cliffs and in Punganarai Rock. There followed a period of erosion during which the sea cliffs on the northern side were partly cut back and Punganarai Rock was partly eroded. The later period of activity is represented by the fresher lavas exposed on the top of the hills, in Punganati Rock and in the sea cliffs on the eastern side of the island. Following the eruption of these lavas relative sea level changed to about 2 or 3 m above its present level and the sedimentary shelf was formed. It was probably during this stand of the sea that Punganarai Rock was undercut since the floor of the undercut is about 2 m above sea level.

A fringing reef nearly encloses the island, but there are passages in the reef on the western side. There are no permanent streams on Anuda, but a fresh water spring approximately 5 m above sea level delivers an adequate supply of water for the 180 inhabitants.

Tikopea Island

Tikopea is an isolated volcano (latitude 12°17.5'S and longitude 168°48.6'E) the essential geology of which has been described by Hughes (1972). The island (Fig. 3) covers about 2.25 km^2 and is comprised of a single cone which reaches a maximum elevation of 379 m on its northern rim. Confined within the large central vent of the volcano is a fresh water lake which is surrounded on all but the southeastern side by steep cliffs mantled with talus. Along the southeastern shore the lake is separated from the sea by a relatively narrow barrier of sand and rock debris. There is a low relief shelf of similar material forming the western end of the island. The strip of land along the southeast shore of the lake is at most 3 m above sea level, but projecting well above it are two erosional remnants of the lava which makes up the major portion of the cone. On the western side of the island there is an uplifted block of consolidated coralline limestone, the only such outcrop on the island.

Three volcanic sequences are exposed on Tikopea (informally named by Hughes, 1972). The oldest of these is the Nuku Orthobreccia, a brown lithic tuff which contains abundant rounded to angular fragments of andesitic basalt in a matrix of ash, glass fragments and small plagioclase laths. It is distinctly bedded although individual layers show poor sorting and was probably deposited by subaerial eruptions,

Figure 3. Tikopea Island

Legend

▦ .... calcareous sand

⁘ .... talus

□ .... uplifted and recrystallized coralline limestone

▨ .... Korofao Volcanic Parabreccias

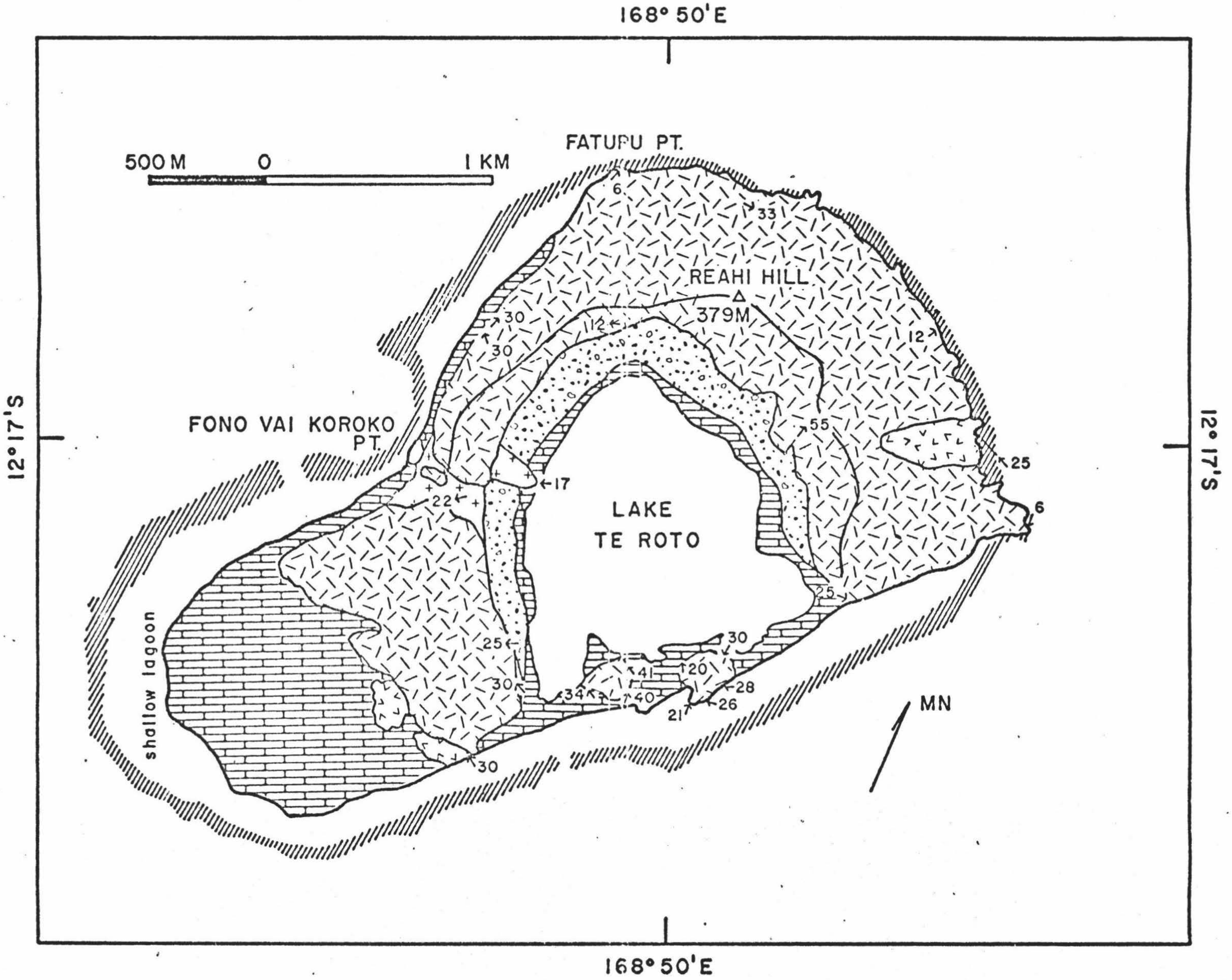
▧ .... Reani Lavas

⊞ .... Nuku Volcanic Orthobreccias

//// .... position of reef

→21 .... attitude of beds

(after Hughes, 1972)


168° 50'E
168° 50'E
12° 17'S
12° 17'S
500 M
0
1 KM
FATUPU PT.
REAHI HILL
379M
FONO VAI KOROKO PT.
LAKE TE ROTO
shallow lagoon
MN
6
33
30
30
12
12
55
25
6
17
22
25
25
30
30
34
41
40
20
30
21
28
26
30

of a type similar to that which produced the tuff cones of the Honolulu Series volcanics on Oahu (Stearns and Vaksvik, 1935). The Nuku Orthobreccia is conformably overlain by the Reani Lavas, which are porphyritic flows from thin laminae to a meter thick; the estimated maximum thickness of this unit is 304 m. There seems to be a gradation towards larger phenocrysts from the southwest to the northeast. The Reani Lavas are the most extensively exposed rock on Tikopea and were produced during a phase of effusive vulcanism. One sample of Reani Lavas, T4 collected from the lower slopes of the cone on the western shore, was submitted for K-Ar age determination. Although possibly contaminated, it gave an age of probably less than 80,000 years B.P. While older than expected, this age is not inconsistent with the stratigraphic position of the sample. The Reani Lavas dip outward from the vent everywhere except in the two hills along the southeastern shore of the lake; there they are very thin bedded and dip toward the vent. The youngest volcanics, the Korofao Volcanic Parabreccias, conformably overlie the Reani Lavas and outcrop in three places on the eastern side of the island. They are porphyritic lavas, containing abundant accidental inclusions of fragmented Reani Lavas, and were extruded in nonexplosive eruptions following those of the Reani Lavas.

PETROLOGY

Anuda

The rocks collected on Anuda were taken from the sea cliffs on the northeastern side of the island, from the top of the hills and from the two erosional remnants on the southern shore. Only those samples which were relatively fresh were studied in thin section. The dominant mineral present is labradorite with an average composition of An_{62} (see Table 1); it makes up between 53 and 67 percent of the rocks and occurs both as phenocrysts and as laths in the groundmass (see Table 2). Monoclinic pyroxene, second in abundance, occurs in groundmass. Small grains of black opaque minerals, probably magnetite, are disseminated throughout the rocks or occur as inclusions in the phenocrysts. Green to red-brown glass occurs in the interstices between the labradorite and monoclinic pyroxene and is included in some of the phenocrysts. The glass is green when fresh, however most of it is devitrified and ranges from pale brown to red-brown. The altered glass contains abundant microlites and/or spherulites. One of the samples, A12, has a few large phenocrysts of olivine, completely or largely altered to iddingsite, as well as plagioclase.

All of the rocks studied are porphyritic. They contain lath-shaped or tabular plagioclase phenocrysts from 0.1 to 15 mm in length and are most commonly subhedral to euhedral, although some of the crystals are rounded or show corrosion effects. Nearly all of the phenocrysts have at least marginal zoning; oscillatory zoning is also present. The cores of some of the crystals are large and have mottled extinction, possibly indicating slight variations in composition. The

Table 1. Explanation: Plagioclase composition of Island samples was determined by Michel-Levy Statistical method. Composition of Vitiaz Trench plagioclase was determined by refractive indices. Determination of all three refractive indices of all mineral phases in the rocks was not possible because of characteristic cleavages of the minerals, small grain size or alteration.

Table 1

Mineralogy of Some Rock Samples from the Northern Fiji Plateau

Sample	Plagioclase (in % An)		Clinopyroxene					Olivine					Amphibole				
	P	GM	$^{o}2V_{z}$*	α**	β	γ	$\gamma\wedge c$	$^{o}2V_{x}$	α	β	γ	% Fa	$^{o}2V_{x}$	α	β	γ	$\gamma\wedge c$
A3	69	62															
A10	69	61															
A11	62	57															
A12	63	55						nd***									
T1	51	40	40	1.701		1.724	46^{o}	86	1.675			21					
T2	53	45	45	nd				85	1.680		1.714	23					
T3	57	41	43		1.704		41^{o}	82		1.713		28					
T4	49	45	41	1.698	1.703	1.725		85	1.680		1.720	23					
T8	56	39	42	1.699	1.705	1.725	42^{o}	83	1.690		1.780	27					
T14	50	41	44			1.726		83	1.685	1.713		27					
T21	52		nd					85		1.702	1.716	23					
T23	59	42	nd					86		1.696	1.713	21					
T24	59	43	43	1.698	1.704	1.724	41^{o}	nd									
V1		48	57										70-75				
V2	49	46	nd										78	1.662		1.681	
V4		47	55										78-81	1.659	1.672		
V5		54	56					84	1.682	1.703		25	75-80	1.654	1.670		14^{o}
V6		52	58										nd				
V7		42	54	1.697									77	1.658		1.674	16^{o}
V8		60	44										74				
V9		56	58	1.699									73-75		1.667		
V11													70-75		1.668		

* error in $^{o}2V = \pm 2^{o}$

** error in refractive indices = ± .003

*** nd = not determined

Table 2

Modal Analyses of Some Rock Samples from the Northern Fiji Plateau

Sample	Plag		Cpx		Ol	Am	BO	Ap	Zeo	Ep	Calc	Qtz	Sph	Zir	Leu	Idd	Fib and Bio	Glass	Other
	P	GM	P	GM															
A3	36.0	22.5	28.5				7.0											3.6	2.4
A10	40.3	26.2	21.7				6.7											4.3	.9
A11	38.9	17.3	30.6				10.5											2.3	.4
A12	33.8	18.7	26.6		.1		14.6									.4	tr	6.1	.5
T1	18.9	38.6	1.6	28.5	1.0		7.2	.6								1.1		.6	2.0
T2	21.6	38.5	.4	18.4	1.5		14.4	.4								2.0		.1	2.8
T3	21.5	46.2	1.4	23.0	2.4		4.4	.6								.1		.1	.1
T4	17.0	48.6	.4	23.4	2.3		7.6	.4								.2			
T8	21.6	36.5	.8	23.4	.9		9.4	.4								1.1			6.0
T14	18.0	42.8	1.0	19.3	1.6		11.9	.5								1.1			3.8
T21	15.6	42.0		5.4	1.7		26.9	.4								1.6			3.4
T23	17.4	46.1	.1	13.3	3.9		13.2	.2								2.7			3.0
T24	7.4	53 9	1.5	20.4	.4		10.7	.4								3.5			5.0
V1		15.9		5.5		60.1	2.4	tr	8.7	tr	1.1	.2					1.0		5.0
V2	3.4	10.9		3.2		73.6	2.7		.1	.5	.6	1.9							2.3
V4		20.2		15.9		41.3	2.9	tr	1.5	.3			t		tr		2.8		15.1
V5		29.0		15.5	5.3	30.4	5.5	.2	.1	tr				tr		5.0	1.8		7.4
V6		16.4		12.9		51.8	5.4		.7	tr	.1	.1					4.1		8.5
V7		24.0		9.9		58.1	4.0	tr	1.1	tr			t		tr		.2	2.8	
V8		29.0		13.1		34.1	3.4	.1			tr	tr	t		tr		14.8		5.6
V9		24.5		82		38.1	5.3	tr	3.3	.6			t		tr		12.0		8.1
V11						57.9	9.4	1.1		3.3	4.4	7.1	1		3.6		11.8		

areal proportion of the core to margin differs greatly, for instance, the ratio of core to margin area in the thin section of specimen A10 is as much as 6 to 1 or as little as 2 to 3. The margins show either oscillatory or normal zoning, but the former is commoner. The difference in average core to margin composition, based on variation in extinction angles of albite twins, is less than 10 percent. In some instances, the anorthite content of plagioclase in the phenocrysts grades to that of the groundmass. Commonly, however the range in composition of the plagioclase is hiatal. Nearly all the crystals are twinned on either the Carlsbad or the albite law and commonly both, but pericline twinning is very rare. The phenocrysts occur as separate crystals in the groundmass and show slightly parallel alignment. They may also occur as glomerocrysts of a few crystals. In this habit there are some interpenetration twins with a characteristic cross or X-shaped outline. The plagioclase phenocrysts contain inclusions of glass, black opaque minerals, clinopyroxene and groundmass. Inclusions are concentrated in the cores of some phenocrysts and they may be randomly distributed or arranged in patterns paralleling one or both cleavage directions. They concentrate along the boundaries of twin lamellae or occur in the zoned margins of some phenocrysts.

A few altered phenocrysts of olivine, 0.6 to 2.5 mm in length were noted in sample A12. They are subhedral to rounded, dark red-brown in color and show minor embayment. Most of them have a thin border of granular magnetite. The precise original composition of the mineral is impossible to determine, but it is probably olivine altered to iddingsite.

The groundmass plagioclase of the Anuda rocks is labradorite and has an average composition of An_{59}. Although the plagioclase shows normal zoning, the variation in extinction angle of albite twins between core and margin of the crystals is small and the range in composition of the crystals is less than 5 or 6 percent. The plagioclase crystals are lath-shaped average about .05 mm. They are disposed roughly parallel to one another and impart a trachytic texture to the groundmass. They contain tiny inclusions of black opaque minerals, glass or clinopyroxene, and although they are twinned on the Carlsbad or albite law, or on a combination of these, and are zoned, the inclusions are not arranged in any obvious pattern.

There are small, .01 mm, anhedral grains of monoclinic pyroxene in the groundmass. They are too small to yield good interference figures, however the optic sign is positive and the 2V appears small. Microprobe analysis of the pyroxene shows a composition equivalent to subcalcic augite (see Appendix, p. 44).

Small equidimensional grains of black opaque minerals, predominantly magnetite, and possibly ilmenite, are evenly dispersed through the groundmass. Most of the grains are rectangular in outline and are usually from .01 to .06 mm in length, although a few skeletal crystals up to .7 mm long were noted. Some of the black opaque minerals have a thin margin of red-brown translucent material, probably resulting from oxidation of the grain.

Glass occurs chiefly in the groundmass. It is green to red-brown depending on degree of devitrification. When fresh, the glass is green and shows complete extinction under crossed nicols. The altered glass has a mottled extinction resulting in part from numerous small grains of nearly crystallized minerals. Some of these minerals are arranged in fibrous, radial patterns and are possibly chlorite formed as a result of hydration of the glass.

Tikopea

Three samples of Reani Lavas and one of the Nuku Orthobreccia were collected from the upper slopes of the vent on the western side of the lake. Samples 4 through 24 were collected at various points along the western shore of the island. The time available for exploration of the island was insufficient for sampling of the eastern side, therefore no samples of the Korofao Parabreccia were obtained. The Reani Lavas are andesitic porphyries. Lath-shaped plagioclase makes up the greatest proportion of the rocks and the crystals commonly show moderate to strong alignment. Olivine and monoclinic pyroxene also occur in the rocks. Grains of black opaque minerals, both magnetite and ilmenite are dispersed throughout the rocks. There is much accessory apatite in the groundmass and included in the phenocrysts. Three of the rocks have some devitrified glass in the groundmass.

Plagioclase is the dominant phenocryst in the Reani Lavas, it ranges from An_{49} to An_{59}. The crystals are euhedral to subhedral laths or tabular grains, 0.1 to 7 mm in length and generally show parallel alignment. Nearly all of the phenocrysts have marginal, oscillatory or normal zoning (the latter is most common), and the difference in composition between the cores and margins of the crystals, based on variation in albite extinction angles, is from 2 to about 15 percent. Some of the cores have a patchy extinction which might represent slight compositional variations. The composition of the phenocrysts is generally from 4 to 7 percent more calcic than that of the groundmass plagioclase, based on differences in albite twin extinction angles. However, some of the zoned crystals grade in composition to that of the groundmass. Most of the phenocrysts show Carlsbad, albite, pericline or combined twins (pericline twinning is very rare); interpenetration twins occur in some plagioclase phenocrysts, particularly those which form glomerocrysts with olivine and monoclinic pyroxene. The phenocrysts contain inclusions of olivine, clinopyroxene, apatite, opaque minerals, glass and groundmass. In some crystals the inclusions are surrounded by halos of plagioclase with a slightly larger extinction angle than that of the encompassing phenocryst. The inclusions in most zoned phenocrysts concentrate in the core, less commonly they occur in the marginal zone, and in some crystals they concentrate along cleavages or twin lamellae. There is a red-brown isotropic material within the plagioclase of the more weathered rocks; it occurs in the cracks and cleavages of the crystals or forms a grid covering a large portion of the grain. Microprobe analysis of the material indicates that it is an iron oxide (see Appendix, p. 44).

Olivine makes up from 0.4 to 0.9 percent of the samples of Reani Lavas. Phenocrysts of the mineral range in size from 0.1 to 0.6 mm, most are rounded and some are embayed. Nearly all the olivine shows alteration to iddingsite around the edges and along cracks within the crystals. The average composition of the olivine ranges from Fa_{23} with a $2V_x$ of 86° to Fa_{30} with a $2V_x$ of 82°. In sample T1 the olivine has an average $2V_x$ of 86°. The phenocrysts are not zoned and the indices measured are γ 1.718 and β 1.700 (Table 1). Thus the composition of the olivine, based on its optical properties, is Fa_{24}. Microprobe analysis of one olivine crystal from the same sample indicates a composition of Fa_{57} (see Appendix, p. 44). The olivine, which commonly shows alteration to iddingsite, contains inclusions of opaque minerals, apatite and plagioclase. The high iron content of the olivine shown in the microprobe analysis might reflect preferential leaching of magnesium concomitant with alteration to iddingsite. It is also possible that the area probed included small grains of iron ore. Some of the olivine phenocrysts are rimmed by small grains of monoclinic pyroxene; there are also mantled pyroxene phenocrysts in these rocks. The small grains that surround the phenocrysts apparently have the same composition as the groundmass pyroxene so it is probable that the olivine and pyroxene phenocrysts have not chemically reacted with the groundmass, but rather provided loci of crystallization for the groundmass pyroxene.

Subhedral to anhedral monoclinic pyroxene, ranging from 0.1 to 5 mm in length, occurs as phenocrysts in the rocks. Some of the crystals are rounded or embayed. The pyroxene has the optical properties of augite, $2V_z$ ranges from 40° to 44° and $\gamma \wedge c$ from 41 to 46 (Table 1), and the microprobe analysis of the pyroxene in sample T1 shows a composition equivalent to that of augite (see Appendix, p. 45, col. 5). There is little or no zoning of the augite phenocrysts, however many of them show simple or multiple twinning developed on the (100) plane. Augite phenocrysts occur as isolated crystals, but they also occur in glomerocrysts along with plagioclase, olivine, opaque minerals and apatite. The augite has minor iron staining, but shows no other signs of alteration.

The groundmass of the Reani Lavas is made up of small plagioclase laths averaging .01 mm in length, small interstitial grains of clinopyroxene averaging .005 mm in diameter, elongate brown apatite crystals from .05 to 4 mm long and black opaque minerals from .003 to .02 mm in diameter. The plagioclase laths are aligned roughly parallel and give the groundmass a pilotaxitic texture. In thin section the groundmass of the fresher samples is colorless or slightly gray, but upon weathering it becomes brownish as a result of oxidation of the iron ore.

Andesine (from An_{39} to An_{45}) is the most abundant mineral in the groundmass; it is often zoned and has a slightly more sodic rim. The variation in composition of the plagioclase, based on albite twin extinction angles, is less than a few percent. Carlsbad twinning is more common in the groundmass plagioclase, although albite twinning was noted. There are opaque minerals, tiny blebs and rods of pyroxene and tiny apatite crystals included in the andesine laths.

It is impossible to obtain good interference figures for the groundmass pyroxene because of the small size of the grains (.001 to .008 mm), however the pyroxene appears to have a small $2V_z$, $\gamma \wedge c$ is slightly less than 40°, so the pyroxene is probably subcalcic augite or possibly pigeonite.

There are small amounts of fine grained olivine in the groundmass. Some grains are completely or largely altered to iddingsite. Because of their small size they do not yield identifiable interference figures and it is impossible to determine whether they are of the same composition as the olivine of the phenocrysts.

The accessory minerals in the groundmass are apatite and opaque minerals. Brown apatite forms elongate crystals as much as 4 mm in length. Tiny cubic and irregular grains of black opaque minerals, .003 to .02 mm in diameter, are evenly dispersed throughout the groundmass. The margins of some grains are translucent and deep red in color, other grains are completely altered to this material which probably represents oxidation of the iron ore. There is a small amount of devitrified glass in the rocks collected from the rim of the vent.

Vitiaz Trench

Rocks were dredged from a depth of slightly more than 5,300 m on the south wall of the Vitiaz Trench at approximately 169°42.23'E longitude and 10°4.13'S latitude. About 600 kg of material was recovered; more than 400 kg is manganese nodules, but an assortment of igneous rocks was also brought up in the dredge. Of the igneous rocks a few are lithic tuffs, two are light gray pumice and the rest of the samples are fine to medium grained igneous rocks, dark gray to grey-green, which often contain white veins of secondary minerals. There were nine of these igneous rocks recovered and all of them were studied.

Most of the rocks had a mantle of manganese and none of them showed fresh surfaces when they were recovered; they were probably not broken from outcrop by the dredge, but were scooped up from the surface of the trench wall. A few of the rocks show slickensides on fracture surfaces when they are broken open; many of them are fractured and break along possible joint patterns. Secondary minerals such as zeolites, calcite and various clays are concentrated in the fractures and occur on surfaces along which movement has produced slickensides.

The nine rocks studied fall into three general categories. They all show evidence of low grade metamorphism. Most of them contain plagioclase that is albitized or saussuritized, uralitized pyroxene, olivine altered to iddingsite, chloritized amphibole, iron ores and various amounts of accessory apatite, sphene, zircon, epidote, calcite, quartz and zeolite. The latter four minerals fill veins and vugs in the rocks, but also occur in the groundmass. The texture of most of the rocks is ophitic, one is porphyritic and one has a texture reminiscent of the lamprophyres. The rocks are fine to medium grained, but lack vesicles, chill margins or other evidence of their manner of emplacement.

Seven of the samples have similar texture and mineral assemblage. They are ophitic and contain elongate, anhedral crystals of plagioclase (An_{42} to An_{60}) which average 0.8 mm in the medium grained rocks and 0.3 mm in the finer samples. The plagioclase shows Carlsbad twinning, also albite or combined twinning; interpenetration twins are fairly common, but pericline twins are rare. Most of the crystals are zoned and range in composition from a calcic core to a sodic margin. Although it is difficult to determine the composition of the more altered grains, the difference in composition between cores and margins (based on albite twin extinction angles) is less than 10 percent. All of the rocks show albitization and/or saussuritization of the plagioclase, but the amount of alteration differs considerably among the samples and in at least one sample the amount of alteration differs within the rock. Alteration concentrates in the core of the crystals it affects and makes the center of the grains appear turbid. This effect is attributed to numerous inclusions of fine grained minerals such as chlorite, calcite, epidote, quartz and micaceous minerals which are products of the alteration.

Monoclinic pyroxene is present in all of the seven samples, but most of it is affected by uralitization. The pyroxene has a $2V_z$ of 44° to 58° (Table 1). It is probably augite, but the composition of the pyroxene cannot be substantiated by determination of its refractive indices because the grains are too altered. Nearly every grain contains fine grained inclusions of exsolved magnetite, in some these grains are arranged in a meshwork that follows the cleavage of the mineral. The angles at which the patterned inclusions intersect differs with the degree of alteration of the pyroxene. Reticulate patterns predominate in the less altered pyroxene and diagonal patterns are associated with grains almost completely altered to amphibole.

The amphibole that occurs principally in the margins of the pyroxene grains has a $2V_x$ of from 70° to 80°. The refractive indices of the grains range from α 1.654 to 1.659 and β 1.667 to 1.672 (Table 1). The amphibole is green hornblende with pleochroism of: α light green, β olive green or bluish green and γ dark green. Most of the hornblende is zoned with $2V_x$ decreasing outward. A low birefringent amphibole, pleochroic with α yellow-green and γ blue-green or violet, occurs as fringes on some of the hornblende grains. These borders are strongly zoned and probably reflect increasing sodium content of the amphibole. The hornblende often shows incipient alteration to brown chlorite or biotite. The alteration which has produced the green hornblende in the rocks is very similar to uralitization. The margins of the pyroxene grains are completely altered and the remnant pyroxene occurs in patches clustering near the center of the grains. Uralitization is a common alteration of pyroxenes in basalts exhibiting low grade metamorphism, however the pyroxene in other rocks of this type is generally altered to actinolite. The presence of excess sodium is probably responsible for the formation of hornblende rather than actinolite in the rocks from the Vitiaz Trench.

Olivine occurs in only one sample, V5. The crystals are anhedral and generally about 0.15 mm in diameter. They have a $2V_x$ of 84° and the indices are α 1.682 and β 1.703; the composition is Fa_{25} (Table 1). The edges of the grains show iddingsite alteration. This sample has considerably more blue-green amphibole than the others and has the greatest amount of apatite of any similar rock, it is also the only one in which zircon was identified (Table 2).

Dispersed throughout the rocks are grains of iron oxide, predominantly magnetite. Some of the magnetite grains have a border of translucent, red material similar to that noted in the island samples and probably has the same origin. There is ilmenite present in the rocks and it commonly shows alteration to leucoxene, which appears gray-white in reflected light. Minor amounts of apatite, epidote, calcite, zeolites, zircon, biotite and sphene occur scattered throughout the rocks. Zeolites, calcite and epidote occur primarily in veins and cavities in the rocks, although they are also found in the groundmass. X-ray diffraction patterns of minerals scraped from the surfaces of slickensides show that zeolites and clays, particularly montmorillonite and illite, concentrate on these surfaces.

Sample V2 is a porphyry. The phenocrysts are crystals of plagioclase, 1 to 3 mm in length, with an average composition of An_{49}. Most of them are twinned on the Carlsbad and albite laws. The phenocrysts show normal zoning and range in composition from calcic andesine to sodic andesine, however the phenocrysts are highly altered and determination of the composition is difficult. Threr are numerous inclusions of amphibole, pyroxene, chlorite, calcite and quartz along with small amounts of fine grained opaque minerals in the phenocrysts. The inclusions make the phenocrysts appear turbid. The plagioclase crystals generally have patchy extinction, possibly a result of the alteration.

The groundmass of the rock is largely composed of fine grained, anhedral green amphibole, from 0.05 to 0.3 mm in length, with lesser amounts of pyroxene and black opaque minerals. The green amphibole is pleochroic with: α yellow-green, β blue-green and γ olive green, but there are patches of amphibole with lower birefringence and different pleochroism (α light yellow-green and γ green-blue) within the green amphibole and as fringes around it. The green amphibole has a $2V_x$ of 78° and indices α 1.662 and γ 1.681 (Table 1); it is probably hornblende. It shows little, if any, zoning. Small grains of andesine occur in the groundmass in the interstices between the hornblende. Most of the groundmass plagioclase is twinned on the Carlsbad law and some on the albite law. It shows normal zoning and the range in composition of the crystals is small; the difference in extinction angles of albite twins corresponds to a difference of about 3 to 5 percent between the cores and margins of the plagioclase. The groundmass plagioclase is altered and contains inclusions of hornblende and small pyroxene grains, as well as opaque minerals and apatite. There are very small patches of clinopyroxene in the groundmass, generally mantled by amphibole and in some cases containing clouds of minute opaque inclusions, probably magnetite. The grains are too small to yield good interference figures, but the $2V_z$ appears large and the mineral is probably augite. It is impossible to obtain accurate determinations of the refractive indices of the pyroxene because the grains are extensively altered. Apatite, epidote and opaque minerals occur in the groundmass. Vugs and tiny veins in the rock contain zeolites and calcite.

Sample V11 has an unusual mineral assemblage and texture. In comparison with the other samples it constitutes only a minute portion of the dredge haul; the specimen is about 9 cm long and 5 cm wide. The texture of the rock in thin section is similar to that of the lamprophyres. It contains phenocrysts of amphibole in a matrix of apatite, chlorite and quartz. There are two amphiboles in the rock. The more abundant is hornblende, pleochroic with α straw yellow, β sepia brown and γ brown. Most of the grains are subhedral, from 0.09 to 1.3 mm in length and have a $2V_x$ of 75° to 70° decreasing toward the margin of the grains. The β index of the hornblende is 1.668. The other is a low-birefringent amphibole with pleochroism of: α pale gray and β blue or violet-blue, which occurs both as fringes on the brown hornblende and as small anhedral grains. The blue-violet amphibole is strongly zoned, but is too small to yield good interference figures. It is probably a sodic amphibole, possibly riebeckitic hornblende. The hornblende is essentially unaltered. It contains inclusions of apatite and opaque minerals.

Small interlocking grains of quartz occur in the groundmass; they invariably show undulatory extinction and have a positive sign and some exhibit a small 2V. The groundmass also contains pale green chlorite and numerous elongate apatite crystals. There is much sphene scattered throughout the rock, but most of the grains are altered to leucoxene. Angular black opaque minerals, probably magnetite and some ilmenite, are disseminated evenly throughout the sample. Epidote and small grains of calcite occur in the groundmass and in veins along with quartz and zeolites. These minerals and radiating masses of fibrous chlorite fill former cavities in the rock. The epidote has marked pleochroism with: α pale yellow and γ bright yellow-green.

Sample V11 is the most mafic of all the samples collected from the Vitiaz Trench. The mineralogy of the sample indicates a high volatile content in the original magma and the presence of hornblende suggests formation under considerable temperature and pressure. The color index based on a modal analysis of the rock is 68.4 (see

Table 2). It is similar in texture to the lamprophyres and possibly has the same origin; V11 is probably a dike rock.

CHEMICAL COMPOSITION AND PETROGENESIS

Four samples from the Vitiaz Trench and two from each island are fresh enough to warrant chemical analysis. The results of the analyses are listed in Table 3 along with the normative calculations and modal analyses of the samples. There is relatively little variation in chemical composition among samples from the same locality, but the Anuda rocks contain slightly more SiO_2, Na_2O, P_2O_5 and less FeO, CaO and MgO than those from the Vitiaz Trench. The Tikopea samples have considerably more SiO_2, Na_2O and P_2O_5 than those from Anuda and they contain much less FeO, CaO and MgO than the Anuda or the trench rocks. Based on silica content the rocks from Anuda Island and the Vitiaz Trench are mafic and those from Tikopea Island are intermediate.

The Anuda rocks are high-alumina basalts. The most striking features of the rocks are the essential lack of mafic phenocrysts and the complexity and amount of zoning in the plagioclase phenocrysts. The presence of olivine phenocrysts in A12 indicates that the parent magma of that sample was ~~was~~ devoid of mafic crystals; although specimens A3, A10 and A11 lack mafic phenocrysts they are similar in every other respect to A12. Mafic minerals probably crystallized from the parent magmas of all Anuda lavas and the fact that they are absent from most of the rocks studied suggests that the parent magmas had undergone fractional crystallization. The oscillatory zoning of the plagioclase phenocrysts indicates variability in the conditions of equilibrium between crystals and melt. The variability was likely the result of small changes in diffusion rate of Ca ions, temperature, lithostatic or vapor pressure or other chemical conditions of the

Table 3. Explanation: Description of Samples

1. A10: feldsparphyric basalt porphyry, top of Te Maunga, Anuda Island.
2. A11: feldsparphyric basalt porphyry, top of Te Maunga, Anuda Island.
3. T1: olivine bearing andesite porphyry, southwest wall of vent, Tikopea Island.
4. T4: olivine bearing andesite porphyry, west wall of vent, Tikopea Island.
5. V2: altered hornblende basalt porphyry, south wall of Vitiaz Trench.
6. V4: altered basalt, south wall of Vitiaz Trench.
7. V5: altered olivine basalt, south wall of Vitiaz Trench.
8. V7: altered basalt, south wall of Vitiaz Trench.

Table 3

Results of Chemical Analyses, Normative Calculations and Modal Analyses

		1	2	3	4	5	6	7	8
SiO_2		50.78	50.48	60.93	61.68	48.70	46.70	47.08	46.93
TiO_2		1.77	1.70	.78	.72	1.40	1.21	1.54	1.20
Al_2O_3		20.30	20.45	16.87	16.18	15.00	14.51	14.04	14.29
Fe_2O_3		4.51	4.08	3.08	2.71	2.44	3.25	4.43	2.55
FeO		4.89	5.19	3.78	4.15	9.30	7.93	8.17	8.68
CaO		9.59	9.74	4.12	3.33	11.77	11.66	11.29	12.41
MgO		2.64	2.74	1.31	1.15	6.68	7.87	7.04	8.27
MnO		.12	.11	.16	.17	.15	.16	.16	.14
Na_2O		3.48	3.47	5.84	6.16	3.06	2.78	2.85	2.57
K_2O		.31	.26	1.72	2.03	.12	.40	.37	.24
H_2O^+		1.35	.96	.18	.49	1.45	2.39	1.50	1.75
H_2O^-		.78	.80	.39	.56	.30	.74	.82	.39
P_2O_5		.21	.18	.34	.26	.13	.10	.13	.11
Total		100.73	100.16	99.50	99.59	99.81	99.70	99.42	99.53

Norms (CIPW)

		1	2	3	4	5	6	7	8
Q		5.88	5.52	9.30	9.24				
or		1.67	1.67	10.56	11.68	.56	2.22	2.22	1.67
ab		29.34	29.34	49.78	51.87	25.68	23.58	24.10	20.44
an		38.92	39.20	14.78	10.84	26.97	25.85	24.46	26.69
di	wo	3.25	3.49	1.63	1.51	12.76	12.99	12.88	14.27
	en	2.20	2.20	.80	.60	8.00	8.10	8.00	8.50
	fs	.79	1.06	.79	.92	3.96	4.09	4.09	5.02
hy	en	4.40	4.60	3.00	2.30	1.10			
	fs	1.85	2.24	2.51	3.56	.79			
ol	fo					5.32	7.70	6.77	8.54
	fa					6.32	3.69	7.96	3.64
mt		6.50	6.03	4.41	3.94	3.48	4.64	6.50	3.17
il		3.34	3.19	1.52	1.37	2.74	2.28	2.89	2.28
ap		.34	.34	.67	.67	.34	.34	.34	.34
ne									.57
Total		98.48	99.87	99.70	98.50	98.03	96.48	100.16	95.13

Modes

		1	2	3	4	5	6	7	8
Pla	P	40.3	38.9	18.9	17.0	.7			
	GM	26.2	17.3	38.6	48.6	13.8	20.2	29.0	24.0
Cpx	P			1.6	.4				
	GM	21.7	30.6	28.5	23.4	3.2	15.9	15.5	9.9
Ol				1.0	2.3			5.3	
Am						73.6	41.3	30.4	58.1
BO		6.7	10.5	7.2	7.6	2.7	2.9	5.5	4.0
Ap				.6	.4		tr	.2	tr
Zeo						.1	1.5	tr	1.1
Ep						.5	.3	tr	tr
Calc						.6			
Qtz						1.9			
Idd				1.1	.2			5.0	
Fib and Bio							2.8	1.8	.2
Glass		4.3	2.3						
Other		.9	.4	2.0		2.3	15.1	7.4	2.8

magma; such phenomenon are commonly associated with melts undergoing fractionation or changes in partial pressure of volatiles with periodic eruptions. Without more analyses it is difficult to draw conclusions about the original magma from which these rocks crystallized and impossible to determine if there exists a relationship between them and the samples from Tikopea or the Vitiaz Trench.

The Tikopea rocks are andesitic porphyries containing phenocrysts of both plagioclase and mafic minerals. A comparison of the chemical analyses of these rocks with those of andesitic samples from the New Hebrides (Table 5) shows that the two samples are consistently higher in silica and alkalis and lower in alumina, total iron, magnesia and lime than the New Hebrides andesites.

When plotted on a silica/alkali diagram (Fig. 4) all but two of the samples fall within the tholeiitic field of Macdonald (1964). The samples cluster in distinct groups with gaps in silica content between them. There is no genetic relationship evident between the rocks as they appear in this diagram. Similarly there is no obvious trend among the samples when they are plotted on an AFM diagram (Fig. 5). The Vitiaz Trench samples fall near the magnesian end of the tholeiitic trend of Hawaiian lavas. The Tikopea rocks fall near the alkali end of the alkalic trend and the Anuda rocks fall near the center of the alkalic trend, but they are richer in iron than rocks of the Hawaiian alkalic trend. The proximity of the samples to one or the other of the two trends in Figure 5 is insufficient to classify the rocks as tholeiitic or alkalic. It is particularly difficult to place the

Table 4

Average Chemical Compositions of Vitiaz Trench Samples, Tholeiitic and Alkalic Basalts

	1	2	3	4	5
SiO_2	47.05	49.3	51.5	46.9	47.1
TiO_2	1.34	2.4	1.2	3.0	2.2
Al_2O_3	14.46	14.6	16.3	15.5	15.7
Fe_2O_3	3.17	3.2	2.8	3.1	3.4
FeO	8.52	8.5	7.9	8.6	7.8
MnO	.15	.17	.17	.16	.16
MgO	7.46	7.4	5.9	6.9	7.1
CaO	11.78	10.6	9.8	10.4	10.1
Na_2O	2.18	2.2	2.5	3.0	3.3
K_2O	.28	.53	.86	1.3	1.5
P_2O_5	.12	.26	.21	.39	.47
H_2O	1.77	.79	.81	.80	1.1
no. of samples	4	282	946	178	567

1. Average of Vitiaz Trench samples
2. Average oceanic tholeiite (Manson, 1967)
3. Average continental tholeiite (Manson, 1967)
4. Average oceanic alkalic basalt (Manson, 1967)
5. Average continental alkalic basalt (Manson, 1967)

Figure 4. A silica/alkali plot of the analyzed samples showing the boundary (solid line) between the Tholeiitic and Alkalic fields based on Hawaiian lavas. Open circles--Vitiaz Trench samples; crosses--Anuda samples; triangles--Tikopea samples.

Figure 5. AFM plot of analyzed samples showing the tholeiitic (dashed and dotted line) trend of Hawaiian lavas, the alkalic trend (dashed line) of Hawaiian lavas and the trend (solid line) of Erromangan lavas (Robertson's Thumb Group). $A = Na_2O + K_2O$, F = total iron and M = MgO. Open circles--Vitiaz Trench samples; crosses--Anuda samples; triangles--Tikopea samples.

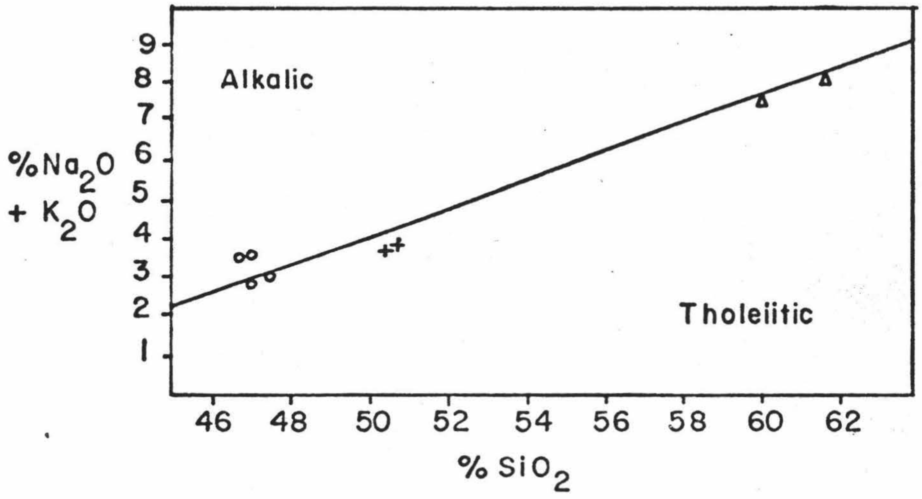


Figure 4

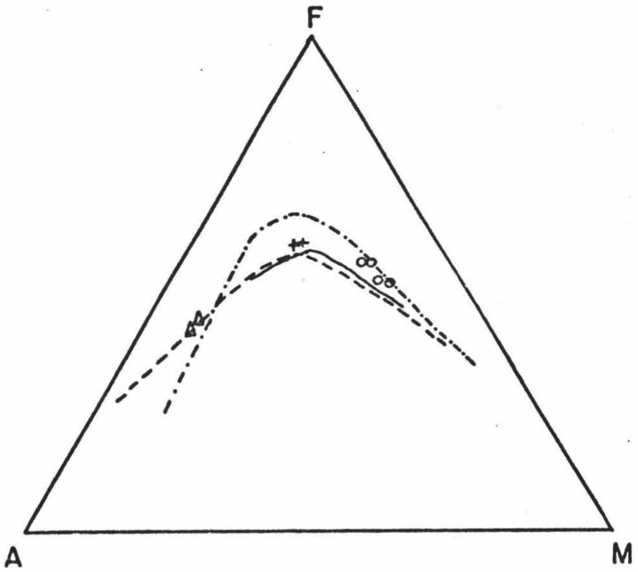


Figure 5

Table 5

Amount by which the Chemical Composition of Tikopea Samples Varies from that of New Hebrides Andesites

	1	2	3	4	5	6	7	8	9	10
SiO_2	+ 0-10	+ 5-8	+ 7	+ 7	+ 5-6	+ 5	+ 1-2	+ 10-12	+ 4	+ 6
TiO_2	- .3	- .1	+ .2	+ .1	+ .5	+ .2	+ .4	- .3-6	- .7	- .4
Al_2O_3	± 2	- 0-1.5	- 1-2	- 1	- 2-3	+ 2	- 1	- 2-3.5	=	- 3
Fe_2O_3	- 1.5-3	- .5-2.5	- .5	- 1.5	- .6	- 2	± 1	- 2	+ 3	- .5
FeO	± .7	± 1	- 1.5	- .5-1				- 1	- 4	
MnO	=	± .3	+ .01-.02		+ .03	+ .01	- .05	- .2	=	- .05
MgO	- 2-7	- 1-2	- 3	- 2	- 2	- 5	- 2	- 3-5	- 2	- 2
CaO	- 2-6	- 3-5	- 5-6	- 4-5	- 3	- 5	- 1	- 5-6	- 3-4	- 2
Na_2O	+ 2-4	+ 2-3	+ 3	+ 3	+ 1	+ 1-2	+ 1	+ 3-4	+ 1	+ 1
K_2O	+ .5-2	- 1-1.5	+ 1	+ .6	+ .6	+ .7	- .2	+ .8-1.7	+ .5	- .4
P_2O_5	+ .1-.2	+ .1	+ .1-2		+ .04-.1	+ .2	+ .05-.1	+ .3	- .01	- .1
H_2O^+	- .5-1	- .5-1	=		=		=	- 0-2	=	=
H_2O^-	- 0-3.5	- 0-.7	+ .1-.3							

1. 2 andesite intrusions, South Malekula, L.Mio. (Mitchel, 1966)
2. 3 basaltic andesites, Erromango, Robertson's Thumb Group, U.Plio.-L.Pleist. (Colley and Ash, 1971)
3. 1 clinopyroxene basalt andesite, Erromango. Mt. Rantop Fm., Recent (Colley and Ash, 1971)
4. Average of Erromango andesites (Colley and Ash, 1971)
5. 1 basaltic andesite, Karua (submarine crater), Recent (Williams and Warden, 1964)
6. 1 olivine augite basaltic andesite porphyry, Lopevi, 1963 (Warden, 1967)
7. 1 andesite, Lopevi, Recent (Warden, 1967)
8. 2 andesites, Malekula, L.Mio. (Williams and Warden, 1964)
9. 1 andesite, Santo, M.Mio. (Williams and Warden, 1964)
10. 1 basaltic andesite porphyry, Tanna, Recent (Williams and Warden, 1964)

Tikopea rocks in either of these categories because they fall so close to the intersection of the two trends.

Although the Vitiaz Trench samples straddle the line separating the alkalic from the tholeiitic field (Fig. 4), they compare very closely with average oceanic tholeiite (Table 4) and fall near the tholeiitic differentiation trend in Figure 5. They are therefore classified as tholeiitic basalts.

CONCLUSIONS AND SPECULATIONS

The rock samples from the Vitiaz Trench compare most closely in chemical composition with oceanic tholeiites. The texture of the rocks indicates that they are extrusives or shallow intrusives. All of them are altered, the primary effects of which are to increase Na_2O, CaO, water and decrease the K_2O content of the samples. Low grade metamorphism of oceanic basalt to spilitic basalt is characterized by the loss of CaO and K_2O and the addition of Na_2O and water (Engel and Engel, 1970). Sample V11 is probably a dike rock. There has been faulting on the south wall of the Vitiaz Trench evidenced by slickensides present in some of the rocks.

The Anuda samples are high-alumina, basalt porphyries containing labradorite phenocrysts and are probably the products of fractional crystallization. With the present data little can be determined about the nature of the magma from which the lava was generated. The rocks from Tikopea are also likely the products of fractionation. The mafic minerals and plagioclase of the phenocrysts are different in composition from the corresponding minerals in the groundmass. McCall (1962) suggests that olivine-labradorite basalt and hawaiite from Tikopea are differentiates of oceanic olivine-basalt parent magma.

Lateral variation in the chemical composition of volcanics in some island arcs shows an increase in alkalinity away from the trench (Kuno, 1959). However, the recent volcanics of the New Hebrides show a trend opposite to that expected; they decrease in alkalinity eastward away from the New Hebrides Trench, a phenomenon particularly noticeable in the Banks Islands (Mallick, 1973, in press). Tikopea is situated approximately 245 km northeast of Gaua (Fig. 1), but the alkali content of the Tikopea rocks is higher than that of any New Hebrides rock of similar petrology. Mallick (in press) also states that there is a general decrease in alkalinity of the lavas as they decrease in age. Tikopea is about 80,000 years old. If it is part of the New Hebrides island arc, Tikopea demonstrates the trend toward increasing alkalinity typical of some other Pacific island arcs. As admitted by Mallick, a control over lateral variation of lava types is difficult to obtain in so narrow an island chain as the New Hebrides.

Approximately 300 km southeast of and trending roughly parallel to the Vitiaz Trench is a zone of deep focus earthquakes, greater than 600 km deep. There is some debate whether this seismicity is related to the New Hebrides or to the Vitiaz Trench system (Chase, 1971). Barazangi _et al_. (1973) suggest on the basis of S wave attenuation studies that the seismicity is related to a detached lithospheric plate. Tikopea is situated above the northern end of this zone of deep focus earthquakes. The samples taken there are more alkalic than those collected on Anuda. It is possible that Anuda and the island chain trending parallel to the Vitiaz Trench are tectonically related to the Vitiaz Trench (Chase, 1971). If Tikopea were formed in response to subduction beneath the Vitiaz Trench the chemical variation between rocks collected there and on Anuda might reflect increasing alkalinity away from the locus of subduction. However, the Tikopea samples fall within the tholeiitic field of Macdonald (1964) and the depth of formation of tholeiitic magma is less than 60 km (Eaton and Murata, 1960). It is unlikely that there is a relationship between magma generated at depths of less than 60 km and seismicity that occurs 600 km deep.

Results of gravity and magnetic studies indicate that a set of fractures trend roughly perpendicular to the New Hebrides ridge (Malahoff, 1970). They find particular expression between 14° and 17° south latitude, but less obvious trends extend both north and south of these latitudes (Mallick, in press). Magnetic data suggest that these fractures have been intruded (Malahoff, 1970). The expression, if any, of these crustal rifts on the northern Fiji Plateau has not been investigated. It is possible that Tikopea (situated in an area of complex topography) is the product of vulcanism associated with intrusion along one of these rifts, if so there is little difficulty explaining the generation of Tikopea lava at shallow depths.

The rocks from Anuda are high in alumina, but only slightly enriched in silica. They fall within the tholeiitic field on a silica/alkali diagram (Fig. 4). According to Green et al. (1967) they are in the category of magma generated at depths of 15 to 35 km. Lack of seismicity related to the Vitiaz Trench makes any attempt to delineate the attitude of a proposed benioff plane impossible to verify. However a simple graphic model would place the formerly subducted plate at a depth of approximately 275 km below Anuda. Chase (1971) has suggested that the formerly subducted lithosphere might have rebounded to some extent and that the islands paralleling the Vitiaz Trench could be related to the peculiar tectonics of the area.

The speculations proposed as a result of this study warrant further testing. The origin of the northern part of the Fiji Plateau is not known. More analyses of less altered rocks are needed as are accurate dates of the rocks from the islands on the plateau and from the Vitiaz Trench. The results of refraction and reflection profiling as well as magnetic and gravity data are an indispensable supplement to petrologic work in this area.

APPENDIX

The molecular proportions of the major oxides in the olivine phenocryst microprobed (see Table 6) are: SiO_2 = .98; FeO = 1.12; MgO = .85; MnO = .04. Neglecting the minor amount of MnO in the analysis, the olivine has the formula $(Mg_{.43}\ Fe_{.57})_2\ SiO_2$, thus its composition is Fa_{57}. For the composition of the pyroxenes analyzed see Figure 6.

Table 6.

Results of Microprobe Analyses

	Sample A11					Sample T1			
	1	2	3	4	5	6	7	8	9
SiO_2	51.00	53.61	52.51	49.04	51.23	34.03	57.90	56.12	75.99
TiO_2	.75	.06	.07	.03	.42	.01	.04	.04	.26
Al_2O_3	.99	29.29	29.56	8.40	1.11	.00	26.91	28.70	15.11
FeO*	21.49	.58	.56	29.75	14.90	45.92	.37	.34	.94
CaO	9.74	12.41	12.78	1.02	18.62	.29	9.03	10.22	1.36
MgO	13.51	.10	.10	.66	11.91	19.58	.05	.04	.01
MnO	.50	.00	.00	.00	.90	1.63	.00	.00	.00
Na_2O	.30	4.37	4.36	.19	.34	.01	6.42	4.75	3.51
K_2O	.01	.08	.08	.32	.00	.00	.23	.14	2.00
Cr_2O_3	.02	.02	.00	.00	.00	.02	.02	.06	.01
BaO	.00	.00	.01	.00	.00	.00	.04	.00	.00
NiO	.07	.00	.00	.01	.04	.05	.00	.00	.00

* Total iron

1. Groundmass pyroxene
2. Core of plagioclase phenocryst
3. Margin of plagioclase phenocryst
4. Red weathering product within plagioclase phenocryst
5. Pyroxene phenocryst
6. Olivine phenocryst
7. Core of plagioclase phenocryst
8. Margin of plagioclase phenocryst
9. Groundmass

Figure 6. Ca-Mg-F^{2+} composition of monoclinic pyroxenes and the positions of microprobed pyroxenes from Tikopea (triangle) and Anuda (cross) Islands.

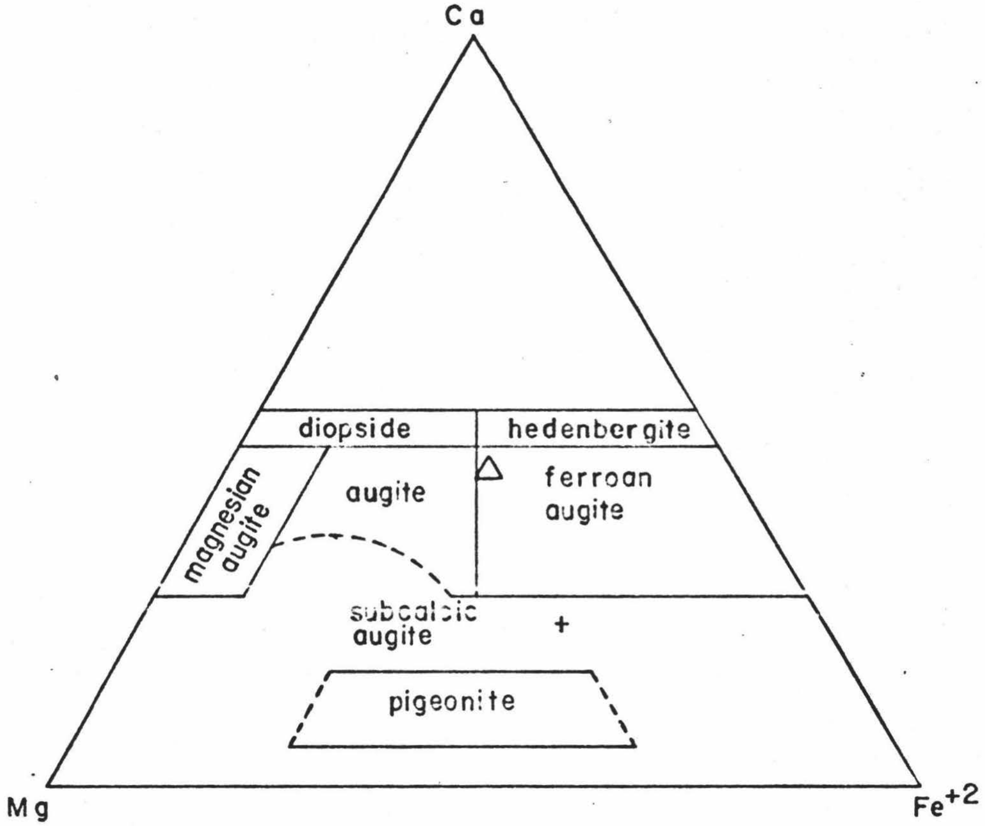

Ca
diopside
hedenbergite
magnesian augite
augite
ferroan augite
subcalcic augite
pigeonite
Mg
Fe+2

Figure 6

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