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Petrology of the Rumble seamounts, southern Kermadec Ridge, southwest Pacific

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Abstract. The Rumble seamounts are major Quaternary submarine volcanoes which lie at the southern end of the Tonga-Kermadec island arc. Rocks dredged from three of the volcanoes are olivine and pyroxene phyric basalts and highly porphyritic plagioclase-rich basaltic andesites. Plagioclase phenocrysts display patterns of iron enrichment similar to those observed in rocks from other parts of the arc. Systematic major and trace element variations indicate that the specimens constitute a closely related suite of low-K arc-type rocks showing characteristic depletion in some large ion lithophile elements. They are closely comparable to basaltic rocks of the Kermadec Islands and their genesis may be linked to the currently active subduction system beneath the arc.

Introduction

The Rumble (I to IV) and Silent (I and II) seamounts (Fig. 1) are a group of six separate topographic features which rise from an ocean floor depth of about 2000 m to within 120 m of the ocean surface. They were discovered following a bathymetric survey by the Royal New Zealand Naval Fleet Auxiliary TUI of an area of acoustic disturbances interpreted as a series of explosive eruptions interspersed with emission of lava flows (Kibblewhite 1966, 1967; Hall 1985). As shown in Fig. 1, the seamounts are contained within a narrow latitudinal zone (35°-36°S) at the extreme southwestern end of the Kermadec Ridge and on the northeastern (oceanic) side of the Vening Meinesz Fracture Zone. Details of their locations as determined by Kibblewhite and Denham (1967) and from a survey by RNZFA TUI in 1967 are given in Table 1.

Bathymetric data produced for Silent I and II and for Rumble I, II and III by RNZFA TUI have been summarised by Kibblewhite and Denham (1967). Similar data for Rumble IV, presented here as Fig. 2, shows a north-south elongation with dimensions of 13 km by 10 km at the 1000 fathom contour. Rumble IV is similar in size and

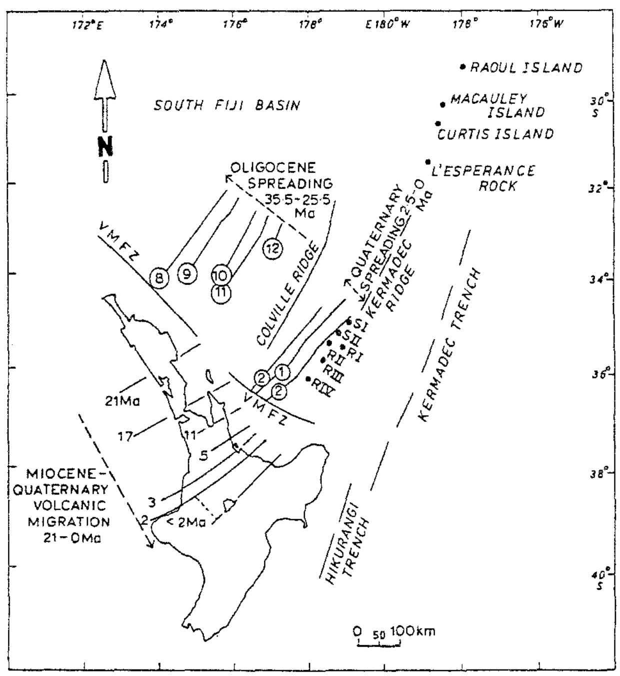

Fig. 1. Location and regional setting for the Rumble (R I, R II, R III, R IV) and Silent (S I, S II) seamounts off the North Island, New Zealand. Oceanic magnetic anomalies (1-2, 8-12) are from Malahoff et al. (1982) and North Island volcanic lineaments (21-0 Ma) are from Brothers (1986). *VMFZ* - Vening Meinesz Fracture Zone

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Table 1. Seamount locations, southern Kermadec ridge

Seamount	Latitude	Longitude	Minimum Depth
Silent I	34° 58.5′S	179° 17′E	266 fathoms (487 m)
Silent II	35° 10.5′S	178° 53′E	385 fathoms (705 m)
Rumble I	35° 30′S	178° 52.5′E	605 fathoms (1106 m)
Rumble II	35° 26′S	178° 39′E	496 fathoms (908 m)
Rumble III	35° 44.7′S	178° 28.7′E	65 fathoms (119)
Rumble IV	36° 08′S	178° 03′E	237 fathoms (434 m)

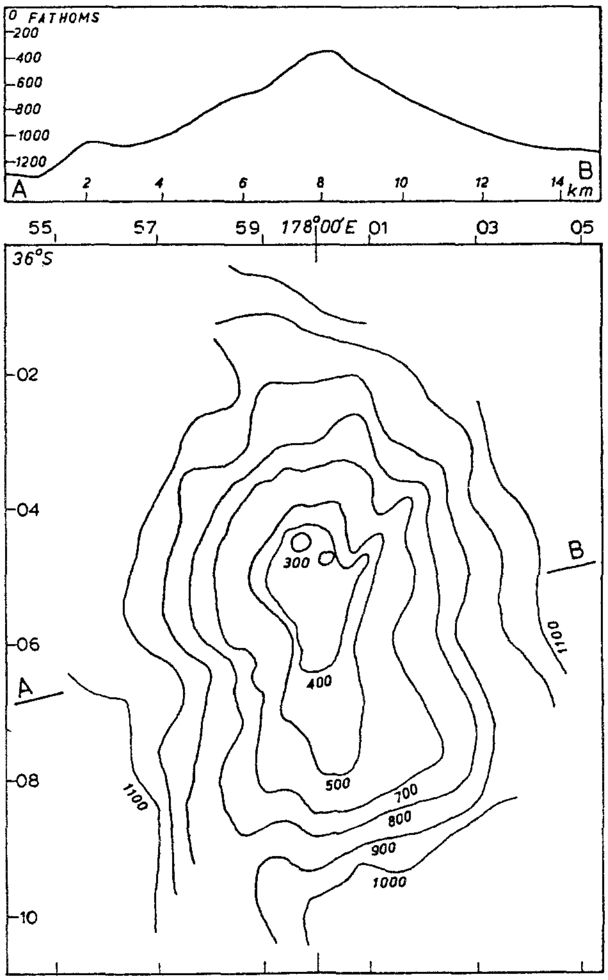

Fig. 2. Submarine topography of Rumble IV based on a radial pattern of 1009 soundings taken by RNZFA TUI in August 1967

shape to Rumble III, its nearest neighbour in the seamount group. All of the seamounts are major structures comparable in size with the subaerial volcanoes of the central North Isand, New Zealand.

Previously the only samples available from these seamounts were basalt fragments dredged from Rumble III (Brothers 1967; Ewart et al. 1977; Brothers and Hawke 1981). Recently, material has been dredged from near the summits of Rumble II, III and IV by RNZFA TUI, and the petrography and petrological relationships of these new samples are described in this paper. The work forms part of a continuing project on the petrology of volcanic rocks from the southern Kermadec ridge.

Petrography

Apart from coral and shell fragments, material dredged from the Rumble seamounts is exclusively volcanic sand, and boulders with aphanitic to strongly porphyritic textures. The material was dredged from five sites on Rumble III and one site on each of Rumble II and IV. Specimen numbers refer to samples in the petrology collection of the Geology Department at Auckland University. In the petrographic descriptions given below, modal percentages are estimates of volume within samples.

Rumble II

The dredged material from Rumble II consists mainly of coral and shell debris together with a small number of rock fragments. The largest is an angular block 8 × 8 × 15 cm, but the remainder are all less than 7 cm across and are slab-shaped. The large block (sample number 36982) has a dark grey-brown weathered rim about 1 mm thick; the smaller fragments, of which 36983 is typical, have rusty oxidised coatings about 2 mm in thickness. The interiors are fresh, apart from minor patches of rusty discolouration. Petrographically, the specimens from Rumble II are all essentially the same (Table 2). They are porphyritic and vesicular, with rounded vesicles (5%–10%) up to 9 mm across, but commonly only 1–2 mm across. Phenocrysts (up to 30%) are clinopyroxene (up to 6 mm, usually 1–2 mm; 15%–22%), plagioclase (typically 1 mm across; 8%–12%), olivine (up to 4 mm, mostly 1 mm; 2%–4%) and orthopyroxene (rarely to 4 mm, typically 1–2 mm; <2%). Modal proportions of representative specimens are presented in Table 2. The groundmass consists of brown glass containing plagioclase laths together with subordinate clinopyroxene and iron-titanium oxides.

Rumble III

The dredge samples from Rumble III were taken from five different localities near the summit of

Table 2. Modal phenocryst proportions in representative samples from the Rumble seamounts, calculated as percentages on a vesicle-free basis. Modes were determined in thin-section, with a minimum of 1000 points on a grid spacing of 0.3 mm

Seamount:	Rumble II		Rumble III			Rumble IV	
Sample:	36982	36983	36984	36986	36987	36990	36991
Plagioclase	9.5	11.1	22.4	14.7	12.2	18.2	47.9
Clinopyroxene	18.1	21.1	1.3	<0.1	0.2	<0.1	<0.1
Orthopyroxene	0.2	1.8	0.6	<0.1	<0.1	<0.1	<0.1
Olivine	3.9	2.3	0.6	0.5	0.2	2.0	4.1
Groundmass	68.3	63.7	75.1	84.8	87.4	79.8	48.0
Vesicles %	8.7	6.0	17.0	54.5	40.9	39.7	24.3

the cone. In each case the sample consists almost entirely of volcanic material ranging from sand-size fragments to blocks up to 50 cm across; the proportion of sand varies at different localities. The Rumble III specimens are all highly porphyritic and, with the exception of 36984, essentially similar. The larger blocks are characteristically sub-angular to sub-rounded with fresh broken surfaces and show an outer glassy selvage surrounding a more crystalline interior; their appearance suggests that they are fragments of small lava pillows. Petrographically, the blocks are dark grey to black porphyritic vesicular rocks with rounded- to oval-shaped vesicles (40%–55%) up to 1 cm across, but usually smaller. Phenocrysts (<10%) are predominantly plagioclase (6%–8%) forming clusters up to 3 mm and individual crystals typically 1 mm across, together with subordinate (<1%) olivine, clinopyroxene and orthopyroxene. Typically, the groundmass consists mainly of brown glass which contains plagioclase microlites together with variable proportions of clinopyroxene. Modal analyses of two representative specimens (36986, 36987) are presented in Table 2.

Sample 36984 is a rounded block 20 cm across of pillow-like form. The outer surface is glassy with sectors where the highly porphyritic interior appears to have extruded through the skin. Cracks and large vesicles are lined with glass. Apart from some minor patches of rusty discolouration on interior broken surfaces, the block is fresh. The specimen is dark grey to black, porphyritic and vesicular. Vesicles (17%) are rounded and up to 2 mm across, but mainly smaller. The phenocryst assemblage (21%) is dominated by plagioclase (19%) forming crystals up to 2 mm across and mostly 1–2 mm across. Clinopyroxene and orthopyroxene (each <1%) occur as large (up to 3 mm, typically 1 mm) phenocrysts and olivine (<1%) forms small crystals generally 0.5 mm across. The groundmass consists of plagioclase laths, clinopyroxene and iron-titanium oxides in brown glass.

Rumble IV

Two blocks recovered from the same site on Rumble IV (36990, 36991) are 10–20 cm across and consist of dark grey to black vesicular prophyritic rock. They have glassy outer surfaces and a sub-rounded form similar to the Rumble III specimens, but differ in their relative and absolute phenocryst abundances, and in their vesicle contents. Sample 36990 contains phenocryst clusters and individual phenocrysts of plagioclase (11%, up to 3 mm) and minor olivine (<2%, 0.5–1 mm) in a groundmass of plagioclase, clinopyroxene and glass. Vesicles are abundant (40%) and typically 0.5–1 mm in diameter. The other block (36991) is a strongly porphyritic rock containing irregularly distributed prominent (up to 8 mm) well-formed phenocrysts of plagioclase (34%) that locally form clusters and less abundant large (up to 3 mm across) olivine (2%) with a distinctly smaller (0.5–1 mm) generation of plagioclase (3%) and olivine (1%) phenocrysts. The groundmass consists of devitrified glass and iron titanium oxides. Vesicles represent 25% of the specimen.

Mineral compositions

The compositions of mineral phases, as determined by electron microprobe in representative specimens from the Rumble seamounts, are presented in Table 3 and these analyses were selected to illustrate the range of compositions observed in each of the Rumble volcanoes. Plagioclase is the major phenocryst phase in the specimens from Rumble III and IV, but is subordinate to clinopyroxene in the specimens from Rumble II.

Table 3. Chemical compositions of mineral phases in representative specimens from the Rumble seamounts

Plagioclase

	Rumble II			Rumble III									Rumble IV		
	(36982)			(36984)			(36986)			(36987)			(36991)		
	core	rim	gm.	core	rim	gm.	core	rim	gm.	core	rim	gm.	core	rim	gm.
SiO_2	45.7	46.8	51.4	46.9	47.8	52.1	47.0	48.9	53.0	47.5	48.5	52.2	45.3	46.4	49.0
Al_2O_3	33.3	32.3	28.4	32.8	32.0	28.1	32.4	31.7	27.9	33.0	32.1	29.2	34.4	33.7	31.6
Fe_2O_3	1.4	1.5	2.6	1.0	1.3	2.5	1.2	1.3	2.1	1.0	0.8	1.4	0.6	0.7	1.1
CaO	18.6	17.2	13.6	17.6	15.6	12.3	18.0	15.4	12.5	16.7	16.2	12.7	18.9	18.0	15.9
Na_2O	0.8	1.7	3.6	1.6	2.8	4.5	1.5	2.7	4.3	1.6	2.4	4.4	0.7	1.1	2.3
Total	99.8	99.5	99.6	99.9	99.5	99.5	100.1	100.0	99.8	99.8	100.0	99.9	99.9	99.9	99.9
%An	92.7	84.6	67.3	85.7	75.2	59.8	86.7	75.6	61.3	85.0	78.6	61.1	93.6	89.9	79.0

Clinopyroxene / *Orthopyroxene*

	Clinopyroxene								Orthopyroxene	
	Rumble II			Rumble III					Rumble III	
	(36982)			(36984)			(36987)		(36984)	
	core	rim	gm.	core	rim	gm.	core	gm.	core	rim
SiO_2	53.3	49.8	49.9	52.2	52.7	49.6	51.0	53.6	55.1	54.2
TiO_2	0.2	0.7	0.6	0.2	0.3	1.1	0.3	0.6	0.1	<0.1
Al_2O_3	2.0	4.5	3.7	2.1	2.3	4.8	2.5	2.2	0.9	1.1
FeO	5.0	8.0	10.7	9.1	9.4	17.8	9.6	15.3	15.6	15.9
MnO	0.2	0.2	0.4	0.3	0.2	0.5	0.2	0.4	0.6	0.3
MgO	17.3	15.4	15.7	16.8	15.5	12.1	16.6	19.5	25.9	25.4
CaO	22.3	21.2	18.4	19.2	19.3	13.5	19.0	8.3	2.0	1.9
Total	100.3	99.8	99.4	99.9	99.7	99.4	99.2	99.9	100.2	98.8

Olivine

	Rumble II		Rumble III							Rumble IV		
	(36982)		(36984)			(36986)		(36987)		(36991)		
	core	rim	core	rim	gm.	core	rim	core	rim	core	rim	gm.
SiO_2	39.3	37.9	40.4	37.8	38.8	38.6	38.2	38.0	36.8	39.5	40.0	39.6
FeO	14.5	21.3	15.2	24.4	23.6	24.1	24.7	23.5	26.5	17.9	18.3	18.8
MnO	0.4	0.5	0.2	0.3	0.4	0.5	0.7	0.5	0.4	0.5	0.3	0.2
MgO	45.3	40.0	43.4	37.2	36.7	36.5	36.2	37.9	35.9	41.8	41.2	40.6
CaO	0.3	0.1	0.4	0.2	0.2	0.2	0.3	0.2	0.4	0.3	0.3	0.6
Total	99.8	99.8	99.6	99.9	99.7	99.9	100.1	100.1	100.0	100.0	100.1	99.8
Fo%	84.8	77.0	83.6	73.1	73.5	73.0	72.3	74.2	70.7	80.6	80.1	79.4

Mineral compositions were determined with a Jeol JXA-5A electron microprobe fitted with a Link LZ-5 energy dispersive detector, together with a Link data reduction system using ZAF correction procedures. Core and rim designations refer to phenocryst compositions; gm. - groundmass phase

The plagioclases show systematic compositional patterns in terms of both crystallisation order and bulk compositon of the host rock (Fig. 3). Thus, phenocryst cores are characteristically more calcic than rims, and phenocrysts are more calcic than groundmass crystals; zoning appears to be regular and continuous. The range of anorthite content within phenocrysts in any one specimen is typically about 10%–15% and there is everywhere a distinct compositional gap between the most sodic phenocryst and the most calcic groundmass feldspar. The calcium contents of phenocrysts vary from specimen to specimen and are most calcic in host rocks with lower whole rock SiO_2 content (36982, 36983, 36991).

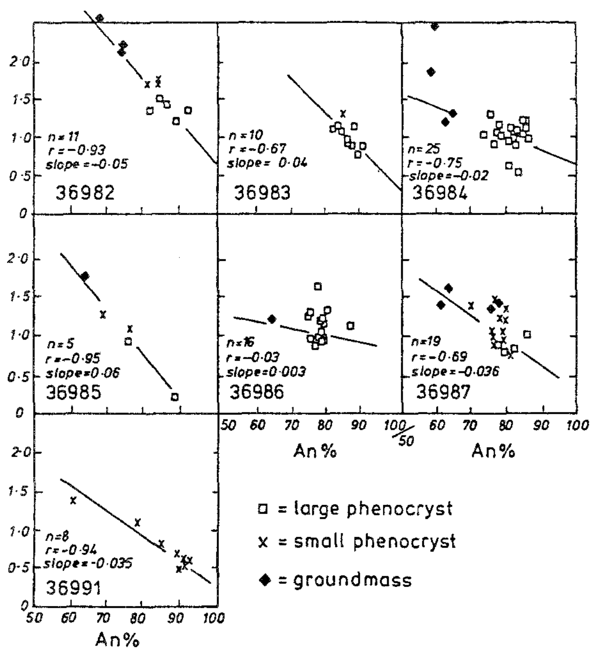

Fig. 3. Plagioclase compositions in rock specimens from the Rumble seamounts showing variation in iron content with respect to anorthite component. Lines through the data are drawn on the basis of least squares regression analysis (*n* - number of data points; *r* - correlation coefficient; *s* - slope). Rumble II - 36982, 36983; Rumble III - 36984 - 36987; Rumble IV - 36991

There is also a consistent relationship between the Fe content and An% of the plagioclase in each of the specimens (Fig. 3). The slope of the correlation varies; the steeper slope of the Rumble II specimens corresponds to lower host rock SiO_2 content and higher MgO contents, but does not appear to relate to total Fe content. Similar patterns in plagioclases have been described from basalt at Monowai seamount (northern Kermadec Ridge) by Brothers et al. (1980) and from basalts, andesites and dacites in the Kermadec Islands by Brothers and Hawke (1981) who observed that the extent of Fe enrichment in plagioclase appeared to be related to the crystallisation stage as well as to the degree of fractionation of the host rock. The range of rock types from the Rumble seamounts is much more restricted than in the Kermadec Islands and, except for the Rumble II specimens, the zoning pattern for Fe within plagioclases is not clearly correlated with host rock composition.

Clinopyroxene compositions show systematic zoning within phenocrysts and between phenocrysts and groundmass crystals (Fig. 4). Rumble II pyroxene phenocrysts have higher Ca contents than those of Rumble III and this difference is consistent with their contrasting whole rock compositions. Specimen 36987 from Rumble III has a greater range in Mg/Fe ratio in its phenocrysts and these coexist with groundmass sub-calcic augite (Fig. 4).

Olivine compositions vary regularly from Fo_{85} to Fo_{68} with cores being more magnesian, and higher overall Fo contents correlating with higher Mg-numbers for the host rock. The most forsteritic olivines are found in Rumble II specimens and also in 36984 (from Rumble III) which shows the greatest range of compositions (Fo_{84-69}).

Chemical compositions

Major and trace element analyses of ten specimens from the Rumble seamounts are presented in Table 4. In general, the analyses define a consistent trend on variation diagrams (Fig. 5). The Rumble II specimens plot separately to those from Rumble III and IV and have less fractionated compositions. Two specimens (36984 from Rumble III and 36991 from Rumble IV) have distinctive compositions which lie off the overall trend of the suite and therefore are discussed separately.

The lavas are all quartz normative. Apart from 36991, values for SiO_2 fall within a small range (50–53 wt %) and on this basis the rocks are basalts and basaltic andesites. Some ferromagnesian elements (Ti, Fe, Mn, V) together with Al, Zn, Cu

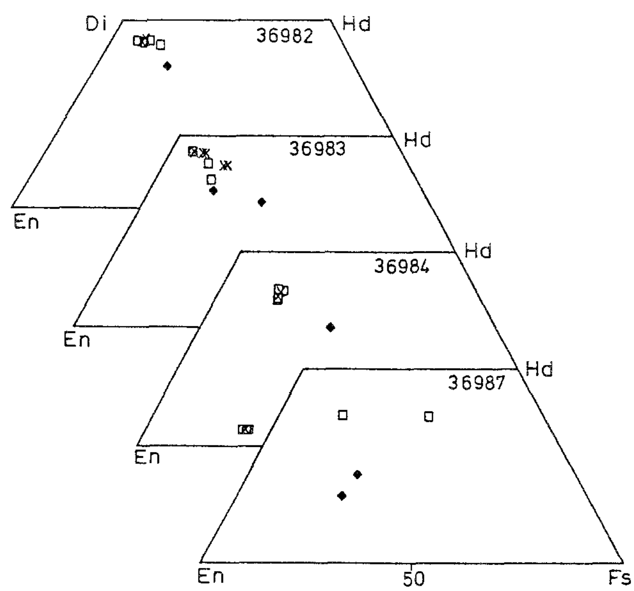

Fig. 4. Compositions of pyroxenes in rock specimens from the Rumble seamounts. Symbols as in Fig. 3. Rumble II - 36982, 36983; Rumble III - 36984, 36987

and some characteristically incompatible elements (Na, Ba, Zr, Y) have clear positive correlations with Si, whereas Mg, Ca, Sr, Cr and Ni show a negative correlation. Other elements exhibit no significant variation.

The positive correlation between the ferromagnesian elements and indices of fractionation, such as SiO_2 content, differentiation index, 1/Mg-number and Zr abundance, requires some explanation since it indicates a separation of the Fe group of elements from the Mg-Ca group. The explanation may be connected to the fact that the rocks are relatively Si-rich basalts and contain as their dominant near-liquidus phase a Ca-rich plagioclase together with subordinate Mg-rich olivine. Since these two phases are lower in SiO_2 than both the most mafic observed bulk rock composition and the likely primitive precursor magmas, their removal from parental compositions would lead to fractionates relatively depleted in Mg, Ca and related elements, but displaying the observed trend of enrichment in Fe and related elements. Within the suite, subtraction of clinopyroxene together with olivine and plagioclase from magma with the least fractionated compositions (Rumble II) can account for observed major element variations. Thus, although collected from three different centres, these Rumble specimens clearly belong to one magmatic association and can be modelled as such.

Two specimens plot away from the compositional trend defined by the suite as a whole. Specimen 36991 is distinctive in having low SiO_2 and high Al_2O_3 and CaO; trace element abundances, particularly Ba, Sr and Zr, are strongly depleted considering the SiO_2 content. The composition of 36984 is less extreme, but shows similar major element features. Both samples are highly porphyritic and contain a large proportion of plagioclase (Table 2). Their petrographic features suggest that they are partial cumulates.

Table 4. Major and trace element analyses of specimens from the Rumble seamounts

Seamount:	Rumble II		Rumble III						Rumble IV	
Sample:	36982	36983	36984	36985	36986	36987	36988	36989	36990	36991
SiO_2	50.83	50.43	53.19	53.21	51.69	52.74	53.04	52.34	52.94	48.40
TiO_2	0.61	0.59	0.68	0.84	0.71	0.79	0.82	0.82	0.80	0.38
Al_2O_3	13.70	13.71	18.06	15.64	15.19	16.46	15.84	15.61	16.20	21.04
FeO*	9.23	9.28	9.46	11.48	10.00	10.91	11.46	11.44	11.27	8.97
MnO	0.18	0.18	0.18	0.21	0.20	0.20	0.22	0.21	0.21	0.15
MgO	9.22	9.26	3.95	4.58	6.47	4.24	4.51	4.51	4.40	5.96
CaO	12.97	12.84	10.57	9.91	11.08	10.01	9.86	9.81	9.92	14.41
Na_2O	1.45	1.44	2.64	2.63	2.42	2.71	2.69	2.64	2.65	1.41
K_2O	0.53	0.54	0.53	0.60	0.47	0.60	0.59	0.59	0.58	0.14
P_2O_5	0.15	0.13	0.10	0.12	0.11	0.12	0.12	0.12	0.13	0.05
H_2O—	0.17	0.21	0.08	0.07	0.25	0.24	0.35	0.40	0.03	0.03
LOI	0.26	0.30	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total	99.30	98.91	99.44	99.29	98.59	99.02	99.50	98.49	99.13	99.94
ppm										
Ba	226	233	336	276	194	310	279	267	272	19
Rb	8	3	3	9	5	8	6	8	5	2
Sr	344	340	271	240	230	251	245	243	248	202
Th	7	6	6	9	8	<5	<5	8	<5	5
Zr	32	38	54	58	49	56	57	56	56	18
Nb	2	3	2	2	2	2	2	3	3	2
Y	15	13	21	23	19	21	23	21	25	11
La	6	6	<5	9	7	6	5	6	6	<5
V	246	248	224	289	253	283	277	275	280	155
Cr	293	319	30	19	151	13	17	21	13	31
Ni	69	71	17	14	47	13	17	15	9	34
Cu	129	107	129	158	131	157	149	148	153	89
Zn	75	76	86	104	87	101	99	100	101	57

Analyses by X-ray fluorescence using standard techniques, (Norrish and Chappell 1977; Parker 1978) with H_2O and loss on ignition (LOI) by gravimetry. Total Fe expressed as FeO* Before preparation for analytical work, all specimens were flushed with distilled water to remove any surficial contamination due to immerison in sea water

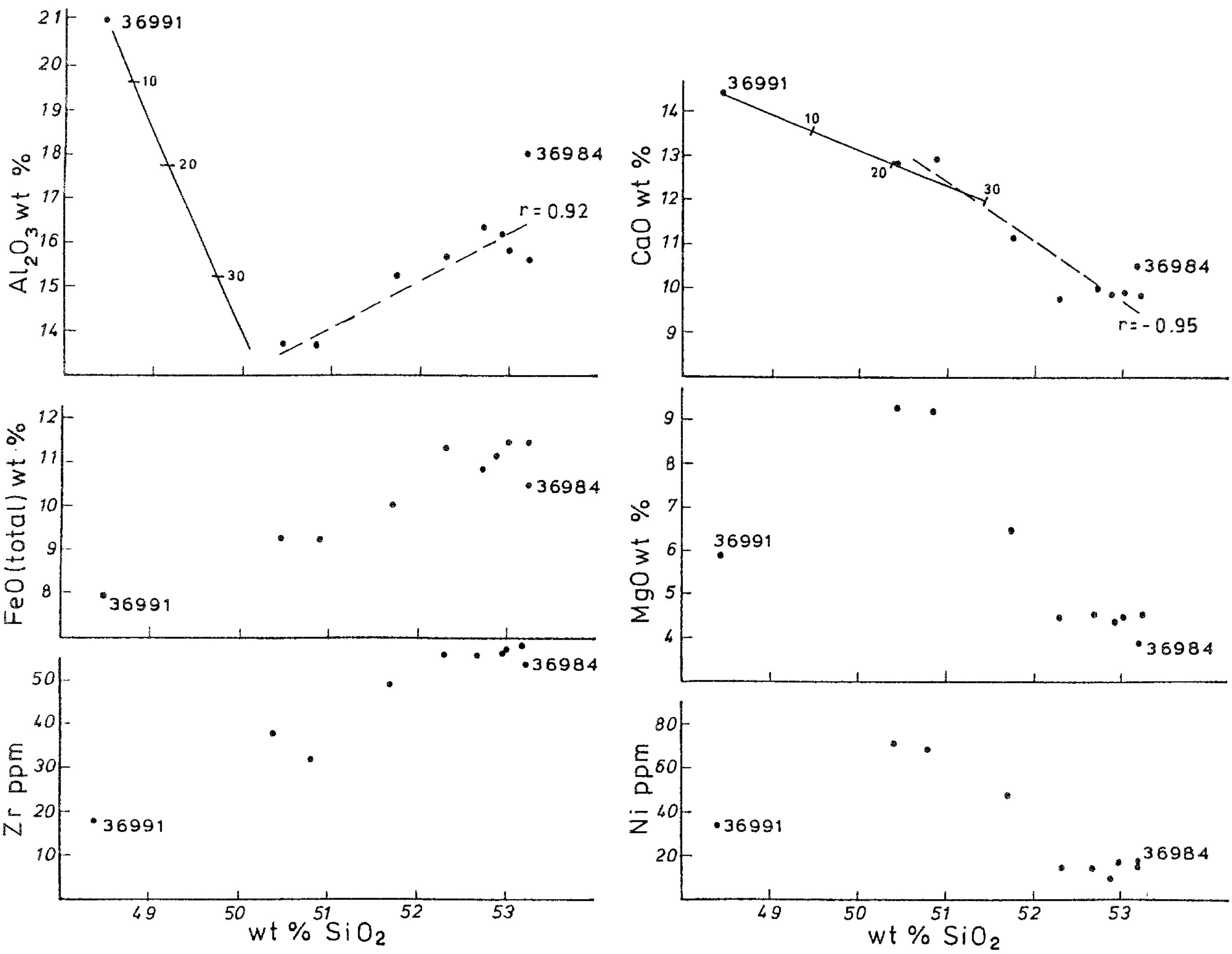

Fig. 5. Variation diagrams for the main compositional features of the Rumble seamount rock suite. In the Al_2O_3 and CaO diagrams, *broken lines* are regression curves (*r* - correlation coefficient) for the suite, but excluding samples 36984 and 36991. *Solid lines* are calculated trends illustrating subtraction of 10%, 20% and 30% plagioclase from magma of sample 36991 composition

Discussion

The Rumble seamounts are major undersea volcanoes comparable in size to the larger andesitic volcanoes of the New Zealand mainland. Clearly, the limited sample collection described in this paper may not be representative of their compositions, but nevertheless some conclusions can be drawn from the data presented here.

Reports of recent volcanic activity from Rumble III (EOS 67: 675–676) are consistent with the very fresh nature of all samples obtained from the volcano. The Rumble IV samples are similar in nature, suggesting that this volcano may also be active. In contrast, the appearance of the Rumble II specimens, together with the abundance of biogenic material in the dredge haul, indicates that at least the sampled part of the volcano is older.

The rocks from the Rumble seamounts are characterised by relatively simple anhydrous mineral assemblages dominated by calcic plagioclase with subordinate magnesian olivine. The most primitive rock specimens, from Rumble II, are depleted in Ti, Y, Rb, Zr and Nb, but enriched in Ba, Th, La and K, relative to N-type MORB. These features are characteristic of low-K arc-type rocks found associated with simple subduction systems (e.g. Thompson et al. 1984) and are consistent with the tectonic setting of the Rumble seamounts.

The Rumble seamounts lie at the southern end of the island arc extending southward from the Tonga Islands through the Kermadec Islands to the North Island of New Zealand, and are situated on the ocean basin side of the Vening Meinesz Fracture Zone (Van der Linden 1967; Malahoff et la. 1982; Davey 1982). This zone (Fig. 1) is

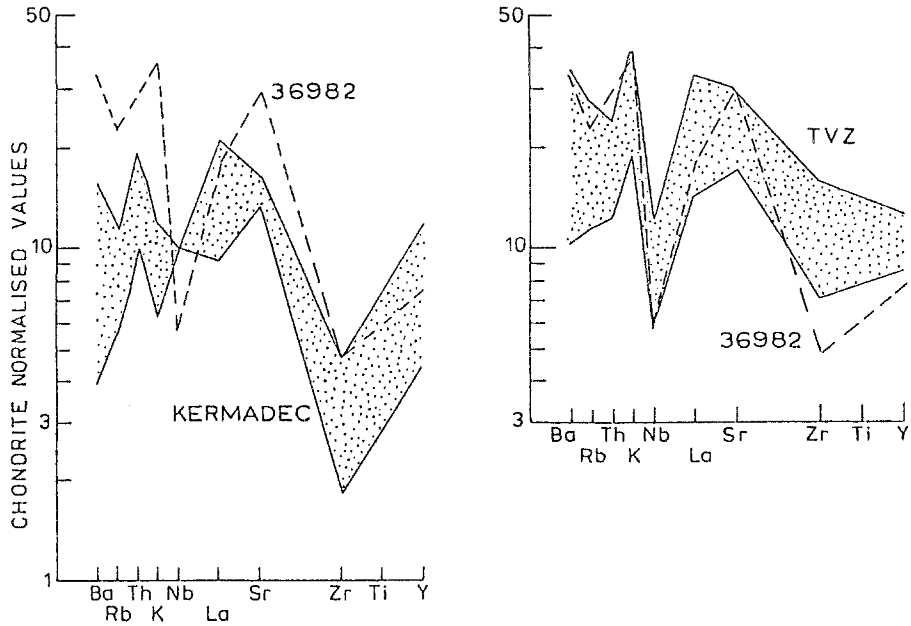

Fig. 6. Chondrite normalised concentration fields *(stippled)* for basaltic specimens (Mg-number >65) from Taupo Volcanic Zone *(TVZ)* and the Kermadec Islands, compared with sample 36982 from Rumble II *(broken line)*. Chondritic factors from Thompson et al. (1984), Kermadec data from Ewart et al. (1977), Rumble II and Taupo Volcanic Zone data from Gamble et al. (in preparation)

described by Brothers and Delaloye (1982) and Eade (in press) as an old rifted margin, possibly transform in character, separating the continental-type rocks of New Zealand from the sea-floor crust of the Pacific Basin. The Rumble seamounts are the oceanic volcanoes closest to the on-land eruptive centres of the North Island and lie seaward of the continental shelf.

Most of the rock specimens described in this paper are fractionated to some degree and we have suggested that compositional trends displayed by non-cumulate samples can be attributed to fractionation of observed phenocryst phases. The least fractionated samples are those from Rumble II (36982, 36983). Analytical data for sample 36982 show that the Rumble rocks essentially resemble basaltic rocks of the Kermadec Islands, but are geochemically more evolved (Fig. 6). They are also comparable in some respects to the basaltic component of Taupo Volcanic Zone in the central North Island, but are lower in Al, Na, K and incompatible trace elements for equivalent degrees of fractionation, and have pronounced Zr depletion.

The Rumble seamounts lie close to, but on the oceanic side of, a location of critical petrological importance where the Tonga-Kermadec volcanic arc intersects the New Zealand continental crust (Fig. 1). Our data indicate that Rumble rocks are geochemically most similar to basic members of the Kermadec suite and therefore logically should be related to the currently active oceanic subduction system. However, their apparently more evolved character also suggests a petrogenetic status transitional between Kermadec and central North Island magmas.

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