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PETROCHEMICAL GROUPING OF QUATERNARY BASALTS, NORTHLAND, NEW ZEALAND: A REASSESSMENT AND RELATION TO NGAWHA GEOTHERMAL SYSTEM.

Malcolm E Cox

Geothermal Institute and Geology Department,
University of Auckland

ABSTRACT

The petrochemistry of basaltic rocks in the Kaikohe–Kaeo areas around Ngawha is reassessed to determine if chemical variations would confirm the apparent association of age and location of the youngest volcanism with the identified Kaikohe structural block, within which the Ngawha geothermal system is located. The outcome of this reassessment is the indication of an apparent change in chemical composition of the Kaikohe lavas from early (Horeke) high-Al to later (Taheke) alkali, the reverse of that previously reported. Comparison of basalts from the Kaeo area to the north of Kaikohe indicates volcanism forming the majority of the basalts there was alkalic and, at least, partly contemporaneous with the older high-Al volcanism in the Kaikohe block. A similar approach to basalts in the Whangarei and Puhipuhi areas to the south of Kaikohe suggests a compositional change from earlier tholeiites to younger high-Al and alkali basalts. The age relations in those areas are, however, less clear. Petrochemistry of these Northland basalts indicates an increasing depth of formation northward for the initial magma type in each area.

INTRODUCTION

The Quaternary basalts in the northern part of Northland (Fig 1) have been described as comprising two volcanic fields, the most northern the Kaikohe–Bay of Islands and that further south, at Whangarei including the basalts of the Puhipuhi area (e.g. Heming, 1980a, b). Volumes of erupted lava are c. 20km^3 and c. 10km^3, respectively (Heming, 1980, a). The Quaternary volcanism of the northern field flanks the Ngawha geothermal area (Fig 2) and is intimately associated with that active hydrothermal system. It was, therefore, considered that the spatial distribution of this volcanism and its temporal history may assist in understanding the formation of the Ngawha system. This was approached from an assessment of the chemistry of the lavas from available data (Bell and Clarke, 1909; Mulheim, 1973; Heming, 1980, a) as well as some new analyses. Such an assessment was further considered worthwhile due to the very small number of determined ages for the Quaternary volcanic rocks of the area (Wellman, 1962; Stipp and Thompson, 1971).

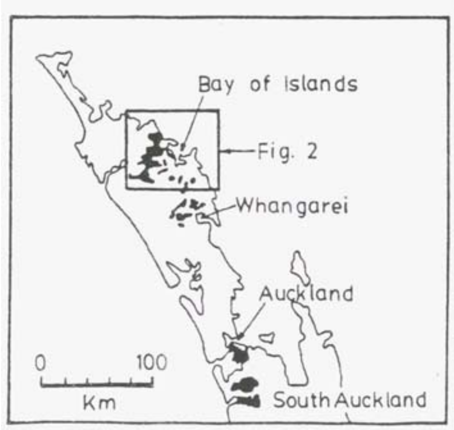

Fig. 1. Location of Quaternary basalt fields in Northland.

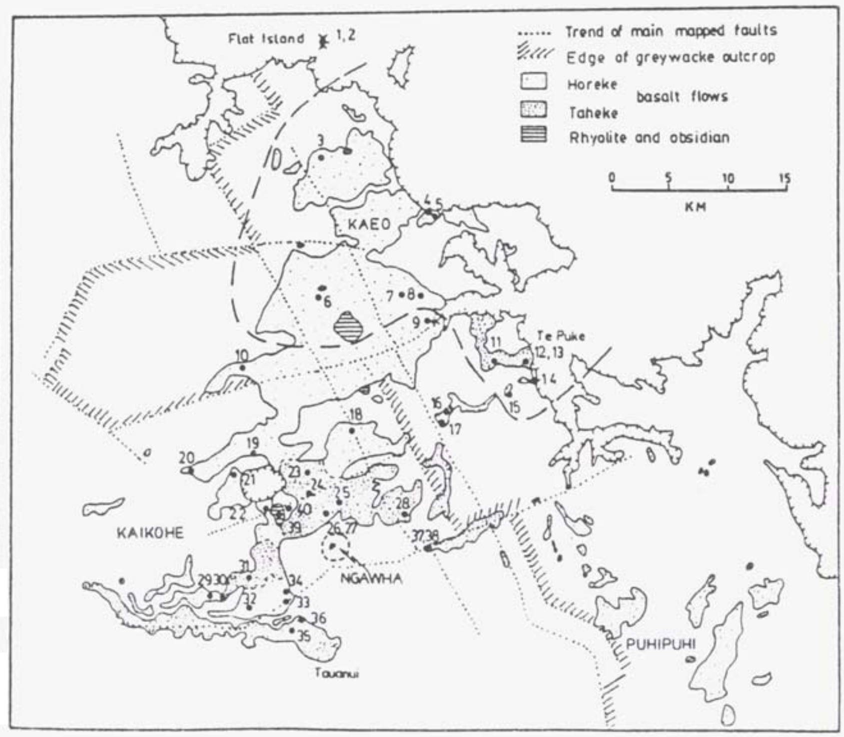

Fig. 2. Karo, Kaikohe and Puhipuhi basalt fields showing locations of samples in Tables 1&2. Extent of the indicated Kaeo volcanism is shown by broken line.

PREVIOUS WORK: APPROACH AND CONCLUSIONS

In an early reference to the Quaternary basalts (Marshall, 1907) both the Horeke and Taheke lavas were described as basanites. An early comprehensive study of volcanism in the area (Bell and Clarke, 1909) concluded that three groups of volcanic rocks existed:

1) the Kerikeri Series - dolerite (basalt) and minor andesite flows;
2) acidic igneous rocks - rhyolite domes and scattered blocks of obsidian;
3) later basic volcanics - basalts with andesitic character, gradational from the Kerikeri Series.

Perrar (1925) described the range of volcanic rocks as olivine basalts and andesitic basalts to olivine andesites. He proposed that the acidic volcanic rocks and later basic volcanics vere continuous with the Kerikeri Volcanic Group and part of it. From mapping in the southern part of the area, Hay (1960) considered that the Kerikeri Volcanics were a single lithological unit, and divided the flows into basalt fields. Mason (1953) first proposed subdividing the Kerikeri Volcanic Group on a relative age basis into Taheke and Horeke flows; the Taheke being younger, with preserved scoria cones. This relative age distinction was expanded (Kear, 1961; Kear and Hay, 1961) utilizing the degree of erosion and preservation of volcanic features. Further detail in mapping and petrography of the area were produced by Skinner (1966).

The rhyolitic rocks of northern Northland with their associated halloysite clays were studied by Bowen (1974) and were classified as part of the Pliocene-Pleistocene Parahaki Volcanic Group. Other work (e.g. Skinner, 1966; Mulheim, 1973; Heming, 1979; Letelier, 1979) indicates the rhyolites to be genetically different, much younger and should be considered part of the Kerikeri Volcanic Group.. Analyses of the Putahi rhyolite (Table 2) provide a molar $(Na_2O+K_2O)/Al_2O_3$ = 1.04. This and the presence of riebeckite suggest that the rhyolite is marginly peralkaline. Smith et al. (1977) consider the minor alkaline and peralkaline rhyolites of the area are likely to be evolved from a parent basalt magma by crystal fractionation. Heming (1980, a) considered a formation of partial melting of the base of the crust, a genesis similar to that considered to form the rhyolites of the Taupo Volcanic Zone (e.g. Ewart and Stipp, 1968; Cole, 1981). Trace element data for the young Northland rhyolites, however, suggests fractional crystallisation played an important role in their formation (Stipp, 1968).

Radiometric dating of Northland volcanic rocks was carried out by Stipp (1968) and Stipp and Thompson (1971) but only five ages for Quaternary basalts were produced. Kaikohe-Bay of Islands: two Horeke (1.27 and 1.24 m.y.) and one Taheke (0.017 m.y.); the latter is possibly of low accuracy due to air argon contamination (Stipp and Thompson, 1971). Whangarei: one Horeke (2.30 m.y.) and one Taheke (0.521 m.y.). Wellman (1962) reported a ^{14}C age of 1300-1800 yrs for carbonised wood from a flov from Te Puke cones (the same source as the 0.017 m.y. dated flow).

Mulheim (1973) classified the volcanic rocks from the Kaikohe area into five petrographic groups: olivine basalt with augite phenocrysts, olivine basalt, ophitic basalt, hypersthene-augite andesite, and sanidine-riebeckite rhyolite. She describes the basaltic rocks around Kaikohe as being mineralogically and chemically gradational betveen high-alumina and alkali olivine basalt suites.

Heming (1980,a) presented major and trace element analyses for 45 basalts from both the Kaikohe- Bay of Islands and the Whangarei areas. From this study, he concluded that volcanism in northern Northland over the last 2-3 m.y. has produced tvo volcanic fields containing alkalic, transitional (high-Al) and tholeiitic basalts. He agreed with Mulheim that petrographic variation is small, variation in major chemistry is limited, and that all lavas are distinctly aluminous (15.5-18.6% Al_2O_3). Quaternary alkalic and high-Al basalts from the Auckland and South Auckland volcanic fields of southern Northland (Fig 1) have Al_2O_3 contents of 12.3-15.7% (Rafferty and Heming, 1979). Heming (1980,a) concluded that in the northern Northland fields the older lavas tend to be ophitic and are predominantly alkalic, while the younger lavas are porphyritic and of tholeiitic composition.

Stipp (1968) noted that Northland volcanics differ chemically from Taupo Volcanic Zone rocks, with higher alkalis relative to silica. The Northland basalts and andesites have higher K and Sr contents and Rb/Sr ratios. Be proposed that both tholeiitic and alkali basalts of the North Island (Including Northland) were derived by partial melting of mantle peridotite based on the model of Green and Ringwood (1967). The degree of partial melting and consequent variation in basalt type may be depth dependent as suggested occurs in Japan (Kuno, 1960). A variety of tectonic models have been proposed for the North Island (e.g. Brothers, 1974; Ballance et al., 1982; Brothers, 1984). One aspect not clarified is the relationship of the Quaternary volcanism in northern Northland to the currently active NW-dipping subduction below the TVZ, and whether it is related, or represents continental "intraplate" volcanism. In this respect, Heming (1980,a; b) proposed a model of upwelling diapirs to the rear of the TVZ from a zone of partial melting within the upper mantle. The resulting basalts are explained as products of progressive melting at depths of 70-120 km with mantle diapirs formed by convection in the mantle wedge.

GEOLOGICAL SETTING

Studies of the Ngawha geothermal system and surrounding area demonstrate the importance of structural control on the location and form of the geothermal system (e.g. Skinner and Grindley, 1980). This aspect of Ngawha and the Quaternary volcanism of the area have been previously noted (e.g. Kear, 1961). Current assessment of the regional structure shows that one of the basic characteristics is the fault control of the uplifted and outcropping greywacke basement rocks, and the location of Ngawha and most younger volcanic centres within an ENE trending structural block (Fig 2). Within the block there is some apparent fault control over volcanic centre locations and orientation, producing in part the NE and NNW alignment noted by Kear (1961). The block itself is bounded by faults (except to the west) on which significant vertical displacement of the basement (to several hundred metres) has occurred. Such displacement was further confirmed by drilling at Ngawha. Other important features related to this structural block are the western extent of Quaternary volcanism vithin it, the range of rock types and the apparent youth of the Putahi rhyolite dome, based on geologic-geomorphological reasonfng (e.g. preservation of gas vents and limited erosion (Letelier, 1979)) compared to other Quaternary rhyolites of northern Northland.
It is difficult to assess the respective volumes of Roreke and Takeke basalts within the Kaikohe block. Broadly, the area covered by each is similar, but the observed greater thickness of Horeke flows suggests the earlier volcanism was more voluminous.

Heming's (1980,a) approach was to examine together all the analysed basalts for Whangaref, Puhipuhi, Kaikohe and Bay of Islands areas. Although he addresed the age distinction, plotting of the data together apparently masked some of the petrochemical trends within individual areas and interpretation appears to have been biased by the Whangarei data. This reassessment is directed towards the Kaikohe-Bay of Islands volcanics, but the Whangarei-Puhipuhi volcanics are also considered as a comparison. Both areas of Quaternary volcanism are the subject of a current, more detailed, thesis study (J Ashcroft, Geology Department).

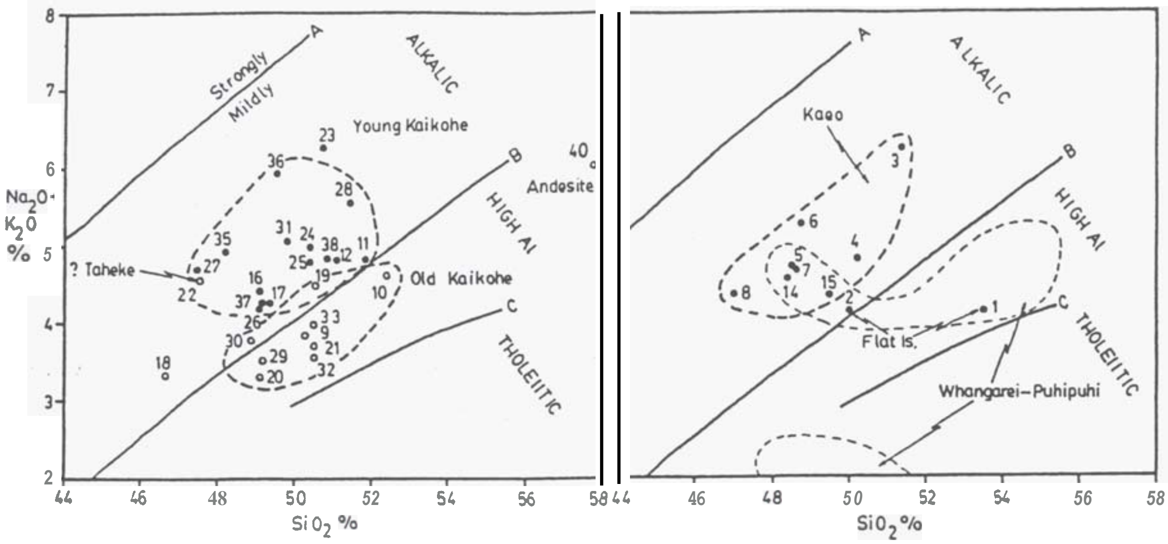

Fig.3 a,b. Alkali– silica variation diagrams showing alkalic,' high–Al and tholeiitic basalt fields. Grouping of Whangarei–Puhipuhi basalts is based on analyses of Ferrar (1925) and Heming (1980,a). Samples 1,2 ,18 and 23 are Bell and Clarke (1909) analyses.

PETROCHEMISTRY

Major Elements

The data were plotted on alkali– silica variation diagrams (Fig 3a ,b); basalt type boundary lines used are: strongly–mildly alkalic (Saggerson and Williams, 1964), alkalic– tholeiitic (Macdonald and Katsura, 1964) and high–Al— tholeiite (Kuno, 1960). Distribution on alkali–silica variation diagrams shows that within the Kaikohe block (Fig 3a) the early basaltic volcanism ("old Kaikohe" i.e. Eoreke) was primarily high–Al, or transitional, in character. The later basaltic volcanism within the block ("young Kaikohe" i.e. Taheke) was (mildly) alkalic. The plot of basalts from the north of the Kaikohe block (Fig 3b) shows them to be (mildly) alkalic. These basalts are referred to here as belonging to "Kaeo volcanism", and have been mapped as of Horeke age. Results indicate that the Kaeo volcanism probably extended Into the eastern end of the Kaikohe block (Fig 2). It should be noted that some lavas spatially marginal to the Kaikohe block are petrochemically gradational between Kaeo and Kaikohe (Horeke) volcanism. The alkali–silica diagrams show that no tholeiites were erupted in these areas. Variation diagrams for major elements versus MgO are shown in Figure 4. Those for CaO, Na_2O and K20 tend to reflect a compositional series in which the Te Pua andesites is related to the Kaikohe basalts. The Bell and Clarke (1909) analyses are not included as they tend to be highly variable. Their analyses for Flat Island, however, indicate the lavas are andesite and not Horeke basalts as mapped. It is probable they are part of the Miocene Wairakau Andesite group.

A plot of Al_2O_3 vs K_2O for Kaikohe and Kaeo basalts demonstrated their similar Al content, but a variation in K content. Kaikohe lavas have a wide range of K20 values, older (.2–1.0%) being lower than younger (.75–2.4%) lavas. The Kaeo lavas have a relatively consistent K_2O content (1.45–2.0%). The Kaihoke lavas have little variation in Si02 content *(47–52%)* and are mostly sodic. The old Kaikohe high–Al basalt have a wide scatter of Na_2O/K_2O ratios, mostly 3–8, but up to 17; young Kaikohe alkali basalts have a more consistent ratio of *2–5*. The Kaeo alkali basalts are generally a lower soda type with Na_2O/K_2O ratios of 1–2.5.

Similar treatment of the Whangarei data Lndicates that lavas mapped as Horeke (Kear and Hay, 1961) are mostly tholeiites and those mapped as Taheke are mostly high–Al basalts (Fig 3b). One Horeke lava plotted within the alkali field. Of the Whangarei lavas

TABU 1: SAMPLE LOCATIONS *AND* AGES.

Map No	Ref No	Map Ref	Location	Age	Ref
1	BC1	N8	Flat Is, upper flow	H	A
2	BC2	N8	Flat Is, lower flow	H	A
3	NAH60	N11,362753	Otoroa, flow	H	a
4	NAH64	R11.474698	Taronui Bay, flow	E	B
5	NAH66	111.483686	- - -	H	B
6	NAH75	N11,362614	Pungare, flow	H	a
7	NAH58	N11,447613	Rangitane, flow .	H	B
8	NAH69	111,449615		H	B
9	NAH57	111,469978	Kerikeri Falls, flow	H	a
10	NAT94	111,284533	Puketi, flov	H	a
11	NAT19	N11,536540	Te Puke, cone	T	B
12	UT22	N11,580538	Te Puke, flow	T	B
13	B12	N11,580538	Te Puke, flow	T(0.017 m.y.)	C
14	N8	N11,591521	Waitangi, flow	H	E
15	NAH56	N11,558505	Haruru Falls, flow	n(1.24 m.y.)	B,C
16	NAH25	N15,493496	Puketona, cone	T	B
17	NU27	N15,487486	Puketona, flow	T	B
18	BC3	N15,400475(?)	Waimate N, flw	H	A
19	17634	N15,295447	Okaihau, flw	H	D
20	NAH100	N15,224431	Okaihau, come	H	B
21	NAH99	N15,277426	N.W.Omapere, flow	H	a
22	N15	N15,315388	S.Omapere, flow	H(?) possible T	E
23	BC4	N15,350428	Te Ahuahu, flov	T	A
24	17632	115,348402	Waimimiti, flw	T	D
25	17633	N15,385391	Maungaturoto, flow	T	D
26	17640	N15,372388	Waimimiti, flow	T	D
27	N31	N15,372389	Ngawha Pt quarry, flow	T	E
28	UT29	N15,450381	Pouerua, flw	T	B
29	N41	N15,245300	Raukauwahia, flow	H	t
30	17638	115,263298	■ flow	H	D
31	17639	N15,292323	Kaikohe, flow	T	D
32	17637	N15,294281	Te Iringa, flow	H	D
33	17635	N15,335291	Ngapuhi, flov	H	D
34	B8	N15,335305	Kaikohe quarry, flov	H(1.27 m.y.)	C
35	NAT95	N15,347256	Taupoui,flow	T	B
36	N30	N15,346273		T	E
37	NAT30	115,472348	Kawiti,flow	T	B
38	N33	N15,474398	Kawiti,cone	T	E
39	N36	N15,324382	Putahi Ryolite	T	&
40	N11	N15,333389	Te Pua andesite,flow	H(?)	E

A: Bell & Clarke. 1909. B: Heming, 1980,a. C: Stipp, 1968.
D: Mulheim, 1973. E: This study (Table 2).

considered, 86% of the Horeke are tholeiites and 73% of the Taheke are high–Al. For the basalts in the Puhipuhi area, north of the Whangarei field, all are mapped as Horeke; of 7 analyses, 3 are tholeiites, 2 are high–Al and 2 are alkalic. The Whangarei–Puhipuhi basalts are more saturated than those further north, with SiO_2 contents of 48–55%. The strongly tholeiitic Lavas have low Na_2O/K_2O ratios, mostly less than 1.5, and the high–Al and alkali basalts are more sodic vith a ratio range mostly between 4.5–15.0. No analyses are available for the two dated Whangarei lavas, and it is apparent that further dating of

TABLE 2: ROCK ANALYSIS

Map No:	14	22	27	29	36	38	39	40
Ref NO:	N8	N15	N31	N41	N30	N33	N36	N11
SiO_2	48.40	47.58	b7.48	49.21	49.56	50.87	76.02	57.89
TiO_2	2.03	1.64	1.72	1.21	2.10	1.62	.11	.98
Al_2O_3	16.70	16.52	16.91	17.79	17.13	17.36	11.70	17.34
Fe_2O_3	10.93	11.89	9-89	8.71	11.13	9.71	2.32	7.29
MnO	.17	.24	.16	.14	.17	.14	.03	.15
MgO	5.62	5.88	7.21	8.48	4.52	5.54	.04	3.00
CaO	9.0S	9.03	10.10	10.57	6.98	9.40	.06	6.01
Na_2O	3.87	3.97	3.77	3.36	4.52	3.70	4-67	4.41
K_2O	.77	.61	.94	.20	1-46	1.15	4.18	1.59
P_2O_5	.41	.34	.40	.14	.50	.34	.05	.31
H_2O^-	1.12	.22	.67	.42	1.02	.46	.64	.64
LOI	.22	1.91	.14	.17	1.00	0	s7	.42
Total	99.30	99-81	99.39	100.40	100.08	100.29	100.39	100.03
Nb	21.6	15.2	28.0	8.2	35.2	23.4	143.8	17.0
Zr	17f.2	159.6	134.b	83.1	225.1	136.7	868.3	242.4
Y	29.8	25.8	22.1	20.6	24.6	21.0	5.9	55.4
Sr	395.6	315.6	504.4	283.7	382.3	399.2	1.3	269.4
Rb	9.4	13.5	17.3	5.8	24.1	29.6	416.3	46.4
Th	.3	n.d.	n.d.	1.2	8.2	2.8	73.0	5.1
Pb	2.0	n.d.	2.0	1.6	14.7	3.1	26.8	8.0
As	n.d.	1.0	n.d.	1.4	.8	1.4	12.5	3.8
Zn	83.8	67.4	60.7	61.8	97.2	80.2	128.6	83.1
Cu	33.9	45.8	47.3	73.9	18.6	33.8	1.5	38.5
Ni	27.2	101.3	62.1	154.1	43.1	40.1	6.9	24.0
Cr	42.1	171.1	100.6	315.8	82.0	84.9	5.4	26.5
Ba	38.5	34.1	68.5	255.0	192.5	111.4	n.d.	129.0
V	223.2	164.8	189.0	137.2	197.2	189.6	2.1	101.4
La	21.7	22.8	32.1	15.5	33.9	31.5	9.3	30.5

Major elements am wt%; trace elements as ppm.
Analyses by Xray fluorescence. n.d. = not detected
Total FeO + Fe_2O_3 expressed as Fe_2O_3.

lavas in both these areas is needed to confirm age-petrochemical trends. However, at least at Whangarei, the older lavas (one date of 2.3 m.y.) appear to be partly contemporaneous with old Kaikohe volcanism, but of tholeiitic composition. This is considered as evidence for a separate magma source for Whangarei volcanism, the onset of which may pre-date that of Kaikohe.

Trace Elements

To provide further support for the age-petrochemical trends indicated by alkali-silica diagrams a series of plots of various trace elements vas made. The most useful elements in defining basalt groups were the incompatible elements notably Sr and Rb, and their relation to K and Ca. Chemical trends of different basalt groups were not always apparent from assessment of calculated ratios alone (e.g. K/Rb, K/Sr, Rb/Sr, Ca/Sr).

Distinct grouping of basalts vas found plotting Sr vs K/Rb (Fig 5). For Kafkohe volcanism K/Rb ratios are similar (300-450), but Sr is enriched in the younger (alkalfc) basalts. A similar trend is evident for Whangarei basalts, with the (?) younger more alkalfc basalts being enriched in Sr. From both alkali-silica and Sr vs K/Rb plots the Te Pua andesite appears to have a petrochemical relation to the older (high-Al) Kaikohe basalts. The Kaeo volcanism basalts have similar Sr contents to younger Kaikohe (and Whangarei) but have very high K/Rb ratios and are distinctly enrfched in K and depleted in Rb. Whangarei lavas have the lowest K contents, as noted by Heming (1980,a). Kaeo samples 6 and 14 and young Kafkohe sample 36 have marginal K/Rb ratios; 6 and 36 are at the peripheries of the Kaikohe block, and 14 is at its eastern extremity. Sample 21, a Kaikohe Horeke flow plots as high-Al in Ffgure 3a, but in Figure 5 falls within the young Kaikohe group. This could possfbly suggest that it is temporally transitional between old and young Kafkohe. Most Northland Quaternary basalts tend to fall along a constant Sr vs K/Rb trend (Fig 5); those from the South Auckland field (Rafferty and Heming, 1979) fall on this line at higher values (Sr=700-1100 and K/Rb = *450-650).*

The plot of Ca/Sr vs K (Pig 6) shows similar grouping. Young and old Kaikohe have similar Ca contents, but Sr is lover (? depleted) in old Kaikohe high-Al basalts. Relative K contents are evident, and the higher K Kaeo basalts appear depleted in Sr. The old Kaikohe (high-Al) lavas fall within the field of most continental tholeiites (from Lo and Coles, 1976) and the young Kaikohe alkalic basalts are gradational between fields for continental tholeiites and alkali basalts. The Kaeo lavas are again anomalous (higher K and lower Sr). Again, the plot of samples 6 and 36 (? 28) suggests some marginal, or transitional formation; Te Pua andesite falls with these marginal basalts. Horeke sample 14 (Waitangi) appears marginal between Kaeo aad old Kaikohe. The (?) older Whangarei tholeiites plot low in the figure showing law relative K and Sr contents and higher Ca. The (?) younger Whangarei high-Al basaltr plot similarly *to* the old Kaikohe high-Al basalts.

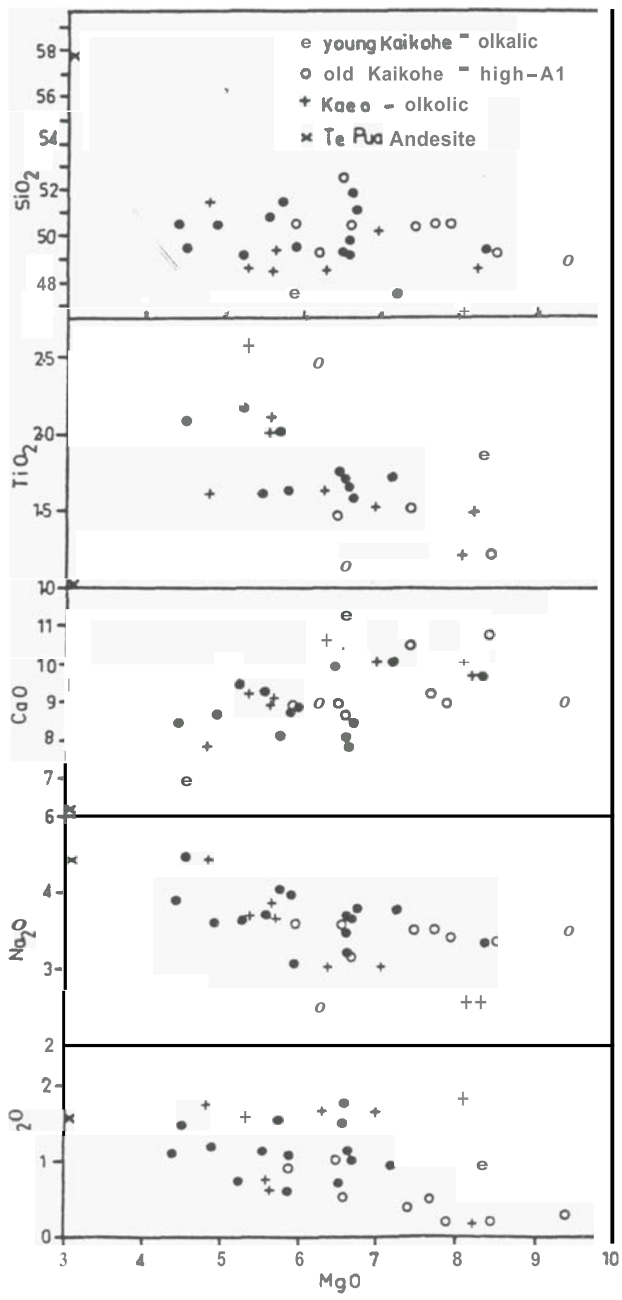

Fig.4. Variation diagrams for major oxides vs MgO for samples in Table 1. Bell and Clarke (1909) analyses are not included, nor TiO_2 analyses of Mulheim (1973), which are systematically low.

Assessment of Ba contents and K/Ba ratios shows that the Kaikohe basalts have similar values but that the Kaeo basalts are depleted in Ba. Ba contents in Kaikohe basalts are typically 40-250 ppo and in Kaeo basalts 0-80 ppm. Ba contents in Whangarei-Puhipuhi basalts do not show a consistent trend between tholeiites and more alkalic basalts, and range from 0 to 234 ppm.

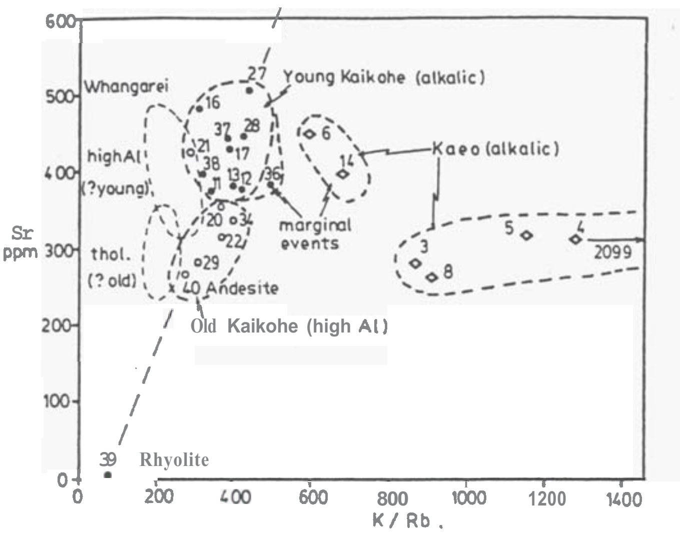

Fig.5. Sr vs K/Rb plot for Kaikohe and Kaeo samples. Grouping of Whangarei samples is based on analyses from Heming (1980,a).

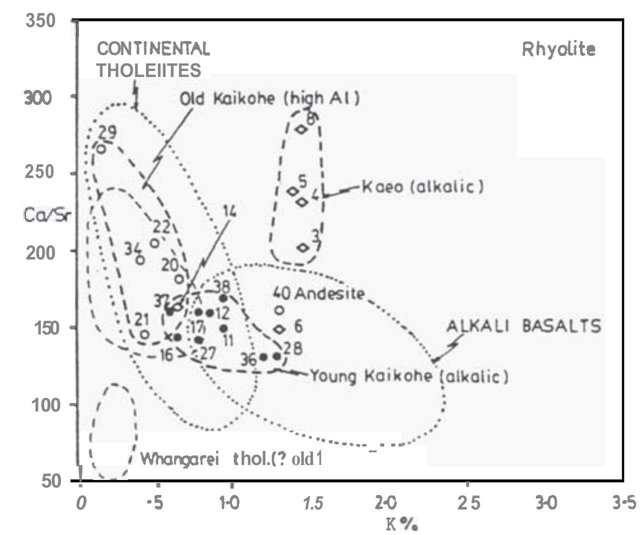

Fig.6. Ca/Sr vs K plot for Kaeo and Kaikohe samples. Grouping of Whangarei samples is based on analyses from Heming (1980,a); the (?)younger high-Al and alkalic sample group partly overlaps the Kaikohe samples. Grouping of continental tholeiites and alkali basalts is from Lo and Goles (1976).

DISCUSSION

For the Kaikohe area the petrochemical characteristics shown above tend to confirm the relative ages assigned to the lavas by previous mapping. The order of ages at Whangarei-Puhipuhi is less clear and still open to examination, the basalts in these areas being more complex chemically. On a broader scale the compositions of the indicated early basalts in each area presumably reflect that of the supplying magma (assuming, as considered by Stipp (1968) and Heming (1980,a) that crustal contamination is minimal). An initial interpretatton is of partly contemporaneous volcanism (Horeke) within the Kaikohe block and the Kaeo area. Age considerations suggest that Kaeo volcanism then waned, but there was a resurgence of Kaikohe volcanism (? less than 0.5 m.y. ago) with a compositional change from high-Al to alkali.

Magma batches of different composition are consistent with the upwelling diapir model proposed by Heming (1980, b). However, this current assessment indicates a reverse order in time of basalt composition to that described by Heming (1980,a) of older lavas as predominantly alkalic and younger as tholeiitic.

Considered of importance is the spatial association of the eruptive areas to major structures on which significant vertical movement has taken place. A general scheme of evolution proposed is of mantle upwelling below the whole area followed by the onset of tensional stresses along fault systems allowing the formation of possibly three mantle diapirs. Melts of basaltic composition rising in the diapirs below Whangarei and Kaikohe may have resided temporarily in small "magma chambers' before passing through shallower conduits to erupt at the surface.

Within the Kaikohe block a compositional sequence of eruptions is indicated: high-Al basalt, high Al_2O_3 hypersthene-augite andesite, alkali basalt and finally peralkaline rhyolite. The change in composition of the basaltic magma could be produced by varying degrees of partial melting at increasing depth; the andesite and rhyolite resulting from fractionation within chambers in the diapir of high-Al and alkalfc magma, respectively. A fractionation formation of rhyolite is supported by the very low content of Sr, absence of Ba and high contents of incompatible elements such as Th (e.g. Smith et al., 1977). Rhyolite emplacement was possibly contemporaneous with isolated alkali-basalt eruptions at the peripheries of the block (Tauanui to the south, and Te Puke in the east). The conclusion of Heming (1979) that the most feasible heat source for Ngawha is an unerupted rhyolite mass, younger than the Putahi rhyolite is considered valid. The existing thermal regime at Ngawha and the young determined Taheke age of Te Puke indicate that the most recent volcanism in northern Northland was within the Kaikohe block.

For the Kaeo volcanism, the available data suggest one petrochemical episode of limited partial melting derived from a mantle diapir already depleted in the dispersed elements such as Rb, Ba and Sr. These Kaeo basalts do not follow trace element trends of most continental tholeiites and alkali basalts (e.g. Lo and Coles, 1976). A compositional sequence of eruptions is also evident for Whangarei and Puhipuhi, but of a more complex nature, as tholeiites, high-Al and alkali basalts apparently occur in both areas. Additionally, a rhyolite of probable Quaternary age occurs at Puhipuhi.

The overall high Al_2O_3 contents of all these basalts suggests the melts were derived from relatively shallow depths (e.g. Green, 1970) which is considered the case by Heming (1980,a). The indicated general trend based on petrochemical type of the earliest basalt in each area is of a change from south to north from tholeiite, to high-Al, to alkali composition. Such a compositional change was found in Japan to be related to distance from the trench and an associated increase in depth to the Benioff zone (Kuno, 1960). Experimental work (e.g. Green, 1970; Ringwood, 1975) also supports a likely Increasing depth of formation for basalt types in this order, here south to north. Such an increase in depth for these areas may also be reflected by the increase northward in the K/Rb ratio: Whangarei-Puhipuhi=200-300, Kaikohe-300-500 and Kaeo-600-2099. The younger basalts in both Kaikohe and Whangarei-Puhipuhi areas tend to have slightly higher K/Rb than the older lavas.

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CONCLUSION

In summary, it can be shown that the youngest volcanism in northern Northland is associated with an ENE- trending structural block, bounded by major faults on which significant vertical movement has taken place. Petrochemistry of these volcanic rocks indicates that they are derived from a separate magma to the basalt fields to the north and south. Partial melting at different depths is considered to be the dominant process producing the observed sequence of magma types. For Kaikohe volcanism crystal fractionation of the resulting different magmas is considered the probable mechanism which produced the Te Pua andesite and Putahi rhyolite. The youngest activity was possibly contemporaneous intrusion of rhyolites in the centre of the structural block, and alkali basalt eruptions in several peripheral locations. This young activity is evidenced by the current thermal regime which has formed the Ngawha geothermal system, which is considered to result from remnant heat in a solidified, unerupted rhyolitic body. The depth of formation of initial magma types for Whangarei-Puhipuhi, Kaikohe and Kaeo volcanism is indicated to become deeper northwards.

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