Final Report

Project: The evolution of basaltic volcanism in Northland in space and time
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Phil Shane
School of Environment, University of Auckland, Private Bag 92019, Auckland
pa.shane@auckland.ac.nz

Layman abstract

New radiometric ages determined on basalt lava flows at Kaikohe and Bay of Islands in Northland, New Zealand demonstrate that volcanoes were active as recently as about 70,000 and 40,000 years ago, respectively. These new ages are more accurate than those of previous studies. New ages determined on some of the oldest basalt rocks show that these volcanic regions have been active for millions of years, and thus, there is no reason to believe the region is now extinct. Volcanoes in northern Northland are capable of new eruptions that could include the formation of small scoria cones and shield volcanoes, and far-travelled lava flows. Future regional hazard assessments need to consider such phenomena.

Abstract

New ^{40}Ar-^{39}Ar step-heated laser and furnace ages on groundmass samples from basaltic lava flows in the Kaikohe and Bay of Islands volcanic field, and the Whargarei volcanic field, provide robust constraints on the longevity of volcanic activity and the timing of most recent eruptions. The samples returned excellent plateau and isochron age spectra, and show no significant evidence of alteration or geologic contamination. Duplicate laser fusion and furnace step-heating of sample aliquots returned the following weighted mean plateau ages on the youngest lavas: Piccadilly Road (Kaikohe) = 43 ± 10 ka; Te Puke (Bay of Islands) = 75 ± 12 ka and Whangarei (Whangarei city) = 319 ± 31 ka. We consider these to represent the best constraints on the most recent volcanism in these regions. The data confirms the youth of several volcanoes. One of the oldest lava flows, the Te Rahui lava flow (Bay of Island field), produced a robust plateau age of 10.37 ± 0.13 Ma, confirming the prolonged longevity of basaltic volcanism in the region (more than 10 million years). It is possible that the frequency of basaltic activity is low (on the order of an event every 10,000 to 50,000 years), but the volcanic fields are not extinct. We strongly recommend further Ar-Ar chronological studies of volcanoes in Whangarei and Kaikohe-Bay of Islands Fields to better constrain the frequency of past volcanism and hence likelihood of future activity.

Original Objectives

There are two primary objectives of this investigation: (1) assess the time-dependant behaviour of basaltic eruptions in the Kaikohe-Bay of Islands, and Whangarei volcanic fields, Northland, New Zealand using high-precision ^{40}Ar-^{39}Ar dating. (2) Examine the tectonic and magmatic association between all late Cenozoic basaltic volcanism in Northland and Auckland using isotope geochemistry, to assess the broader spatial-temporal pattern and context of volcanism in the region.

Modified Objectives

Funding and sampling greatly limited the number of samples that could be analysed for radiogenic isotopes, namely Sr, Nd and Pb -isotopes. Coupled with the heterogeneity of the isotopic signals in the basalts, the isotopic interpretation of tectonic settings was not feasible. Such a study would require a significantly larger suite of samples (>50), and associated laboratory time at the Australian National University, which would involve a collaborative agreement. Thus, we focussed on assessing the age of basalt volcanism in Northland from ^{40}Ar-^{39}Ar dating, and its implications for hazards.

Background and rationale

Terrestrial basaltic volcanic fields consist of tens to hundreds of monogenetic volcanoes, usually cinder cones, tuff rings, maars, and associated lava flows, spread over wide areas. In general, eruption recurrence rates are low (10^{-4}–10^{-5} vents/yr) compared to the longevity of the fields (10^{5}–10^{6} yr) (e.g., Condit and Connor, 1996; Conway et al., 1998). Despite their low eruption frequency, the spread of human infrastructure into basaltic volcanic fields necessitates a better understanding of future hazards. For example, Auckland City, New Zealand is large metropolitan area built on a basaltic volcanic field that has been active during the last 10,000 years (Kermode, 1992). An assessment of the likelihood of future volcanic activity requires an understanding of the frequency of previous eruptions. This can be based on geochronology of volcanic deposits. The broad pattern of volcanism can be deciphered from a plate tectonic understanding of the controls.

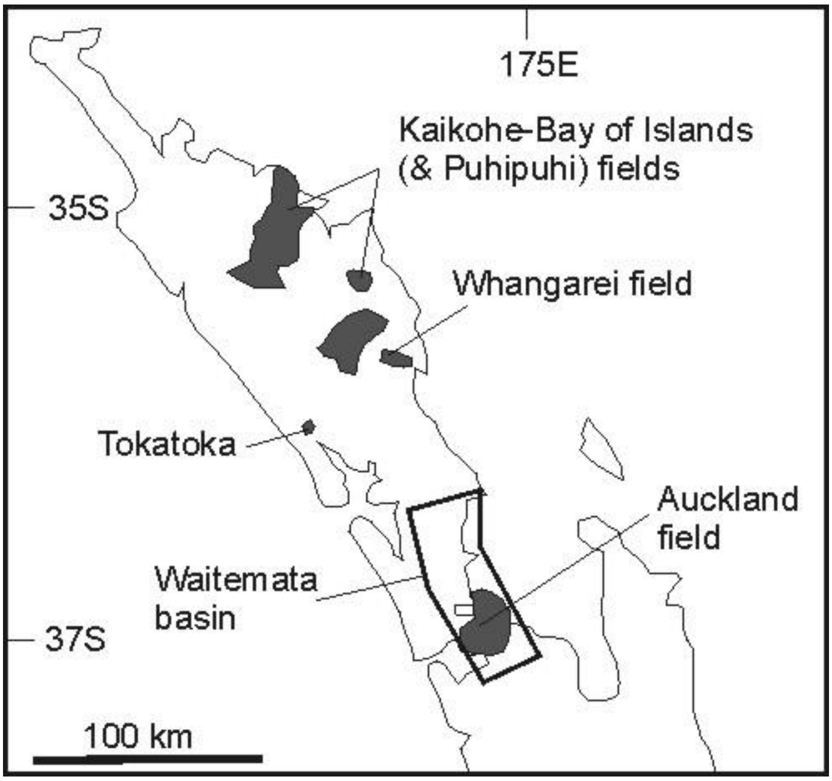

Figure 1 Map showing basaltic fields in Auckland and Northland, and other localities mentioned in text.

Terrestrial basaltic fields occur in Northern New Zealand (Fig. 1) and have been active since about 10 million years ago (Smith et al., 1993). The Auckland field, currently the focus of the DEVORA programme, is being studied in some detail. However, the Kaikohe-Bay of Islands, and Whangarei volcanic fields have received less attention, although they could also be a future hazard to local and regional communities. A chronologic framework for the past activity of the Northland fields has been established by Smith et al. (1993), based on whole-rock K-Ar ages, and the youngest known lava flows in these fields are <60,000 years old. However, ^{40}Ar-^{39}Ar isotope studies in the Auckland field demonstrate the potential for erroneous ages arising from excess Ar in the K-Ar system (e.g., Cassata et al., 2007). It is unknown whether this is a problem for basalts of the Northland fields. In addition, it is difficult to obtain high precision ages on the youngest lava flows (<100,000 years) via the K-Ar method. Thus, it is difficult to confirm the age of the most recent activity in these fields.

Basalt samples selected

To test the accuracy of the previous K-Ar age framework (Smith et al., 1993), we selected both the youngest and oldest lava flows from the Kaikohe, Bay of Islands, and Whangarei fields for ^{40}Ar-^{39}Ar dating. In addition, we selected two very old samples (Todds Quarry and Reserve Point) from intra-plate basalt Tokatoka volcanic centre, to test the previous assumption that is deposits were not part of the Quaternary activity of the region.

Table 1. Basalts examined in this study. Ages represent previous determinations based on the K-Ar method.

Sample	Grid ref	Location	Age (Ma)	Reference
44032	P06/835356	Tauanui, Piccadilly Rd	0.06 ± 0.05	Smith et al. 1993
44060	P05/042643	Te Puke, Kerikeri Inlet Rd	0.14 ± 0.06	Smith et al. 1993
44030	Q07/296089	Whangarei	0.26 ± 0.12	Smith et al. 1993
37687	Q07/210914	Maungakaramea	0.31 ± 0.06	Smith et al. 1993
44042	PO5/730537	Cook Rd	8.10 ± 2.70	Smith et al. 1993
44034	PO5/717716	Te Rahui	9.35 + 0.49	Smith et al. 1993
Todd	P08/999763	Todd Quarry	~13	Hayward et al. 2001
Reserve	Q07/433996	Reserve Point	Eocene	Smith pers com

Grid Reference from the NZ 1:50,000 metric map series.

^{40}Ar-^{39}Ar Ages of basalts

Method

The groundmass of basalt lava was targeted for geochronological investigation because it is least likely to contain volumetrically significant phenocrysts or xenocrysts that potentially retain excess Ar. Groundmass aliquots of 75–350 mg were separated from the 250–500 mm size fraction of crushed basalt samples. Phenocrysts and weathered or alteration products were removed by hand picking under a binocular microscope. The resulting groundmass aliquots comprise glass and micro-crystalline groundmass. The groundmass aliquots were shipped to the University of Wisconsin–Madison for packaging for irradiation. The samples were irradiated in the cadmium- lined in-core irradiation tube (CLICIT) at the Oregon State University TRIGA reactor.

The Ar isotope analyses involved the step-wise release of Ar gas from the sample via heating. This produces an Ar spectrum that allows an assessment of eruption age, and any influences of alteration or geologic contamination that could affect the results. The samples step-wise heated for Ar release using a CO2 laser at the University of Wisconsin–Madison

Rare Gas Geochronology Laboratory. Radiation procedures, standards and data reduction were similar to that described by Hora et al. [2007]. Experiments on some samples also involved incremental heating in a double-vacuum resistance furnace. Prior to each furnace step-heating experiment, samples were heated at 450–650 °C and pumped to remove potentially large amounts of water and atmospheric Ar. Experiments consisted of 5 to 15 steps in the temperature interval between 650 and 1400 °C.

Results

The results of step-heating experiments were examined following two standard procedures (e.g., Allegre, 2008). Data was plotted as age spectra against percentage gas released to investigate the presence of a plateau that could represent the eruption age of the sample (Fig. 2). A plateau in ages across a wide part of the heat release spectrum is normally considered a good indicator of eruption age. In addition, isotope ratios of Ar gas were plotted as an 'inverse' isochron where the slope of the best fit line is a function of age and the line intercept on the 40Ar/36Ar axis gives the initial Ar gas ratio of the sample (Fig. 3). This value should be close to atmospheric values if the sample was completely de-gassed prior to eruption and did not contain any contaminant Ar. Both approaches allow for the identification of anomalous gas releases in parts of the spectrum that could result from excess Ar (incomplete de-gassing before eruption), and post-eruption alteration. The spectrometer measurements also give an estimate of K/Ca composition ratio of the sample. This can be used to interpret what minerals or groundmass in the sample is releasing the Ar gas. This in turn can be used to assess whether the components releasing the Ar gas are consistent with magmatic compositions rather than alteration compositions.

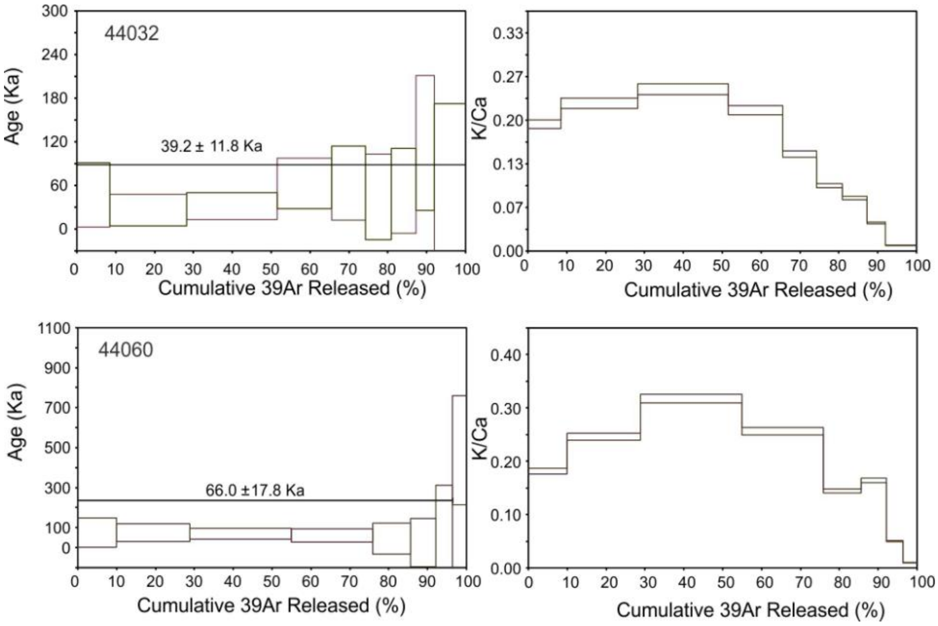

Figure 2. Examples of Ar-Ar plateau age spectra from two of the basalts studied (Table 1). Robust age plateaus are shown (Left). An indication of the composition of the components releasing the Ar is shown (Right).

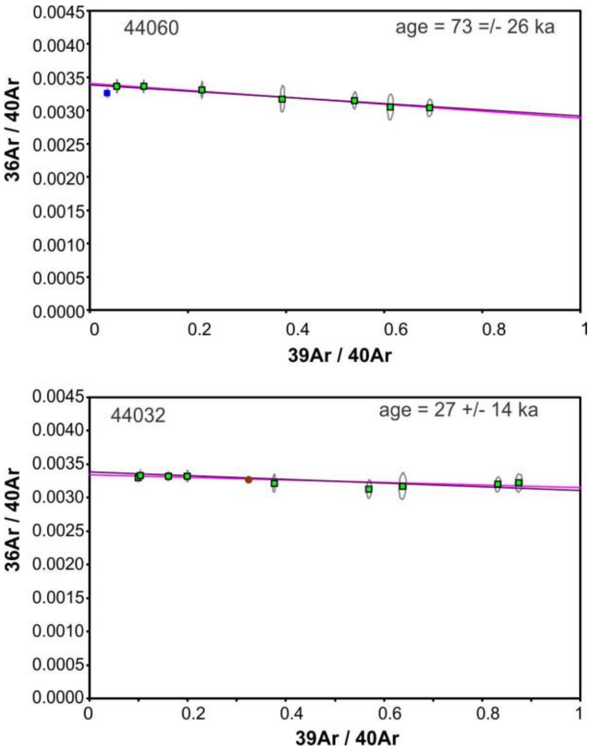

Figure 3. Examples of Ar-Ar inverse isochron plots for two samples of basalt dated in Figure 2. The heated steps form statistically robust isochrons (Table 3).

The groundmass of basalt samples produced simple apparent age spectra from the Ar release experiments. Many of the samples display very flat apparent age plateaus between the release of 10% to 90% 39Ar (Figure 2; Table 2,3). The use of heating steps in the plateau part of the spectra resulted in mean square of weighted deviates (MSWD) values less than 1 (Table 2), indicating no systematic errors in the expected distribution. The age spectrum of each sample produced an age concordant with the inverse isochron plot of the age data (Table 2,3). Inverse isochron plots produced initial 40Ar/36Ar ratios indistinguishable from that of atmospheric Ar (Table 3). Isochron regressions produced MSWD values less than 1. These data indicate no evidence for excess Ar. Although K/Ca ratios for the plateau steps showed various patterns, high ratios were characteristic of the early and middle steps of the spectra and low ratios dominated the last steps (Figure 2). Since the groundmass comprises basaltic glass, and plagioclase and clinopyroxene microcrystals, the Ar release pattern is likely to reflect first glass, followed by increasing contributions from groundmass crystals. Thus, the plateau ages should reflect eruption ages. Replicate experiments (2-3) were performed on separate aliquots of each sample to test reproducibility. They produced statistically identical results and improved the precision of the results (Table 3).

For three samples (44032, 44060, 44030), Ar release via both laser and furnace was attempted on different aliquots (Table 3). The individual ages are in good agreement and the furnace ages display better precision. This is common for young basalts and reflects the larger samples used and the more sensitive vacuum and extraction system.

Table 2. Summary of $^{40}Ar/^{39}Ar$ laser heating experiments

Sample #	Material	K/Ca total	Total fusion Age (Ma) ± 2σ	$^{40}Ar/^{36}Ar_i$ ± 2σ	MSWD	Isochron Age (Ma) ± 2σ	N	^{39}Ar %	MSWD	Plateau Age (Ma) ± 2σ
44034	groundmass	0.16	10.15 ± 0.17	295.3 ± 5.3	1.08	10.38 ± 0.25	11 of 12	97.3	0.97	**10.37 ± 0.13**
Todd	groundmass	1.17	14.43 ± 0.17	295.9 ± 1.1	0.46	14.38 ± 0.17	10 of 10	100.0	0.49	**14.44 ± 0.10**
Reserve	groundmass		total fusion age ~40 Ma. No plateau							

Sample #	Material	K/Ca total	Total fusion Age (ka) ± 2σ	$^{40}Ar/^{36}Ar_i$ ± 2σ	MSWD	Isochron Age (Ma) ± 2σ	N	^{39}Ar %	MSWD	Plateau Age (ka) ± 2σ
44032	groundmass	0.16	86.4 ± 63.4	304.4 ± 22.5	0.06	43.5 ± 86.0	7 of 7	100.0	0.16	77.0 ± 56.3
	groundmass	0.15	54.2 ± 27.4	298.7 ± 13.1	0.75	35.6 ± 31.0	7 of 7	100.0	0.67	49.3 ± 22.8
						Weighted mean plateau age from 2 experiments:				**53 ± 21**
44060	groundmass	0.21	89.8 ± 46.6	291.0 ± 19.8	0.29	108.2 ± 75.4	8 of 8	100.0	0.28	90.5 ± 40.0
	groundmass	0.21	83.3 ± 21.6	298.0 ± 5.5	0.16	71.0 ± 30.2	8 of 8	100.0	0.26	81.9 ± 18.8
						Weighted mean plateau age from 2 experiments:				**83 ± 17**
44030	groundmass	0.06	367.2 ± 153.4	304.4 ± 12.6	0.53	257.8 ± 126.4	9 of 9	100.0	0.74	326.0 ± 106.1
	groundmass	0.06	345.5 ± 70.7	291.6 ± 11.4	0.40	366.9 ± 147.9	6 of 8	91.1	0.41	319.4 ± 67.0
						Weighted mean plateau age from 2 experiments:				**321 ± 56**

J-value calculated relative to 28.201 Ma for the Fish Canyon sanidine
Age in **bold** is preferred

Table 3. Summary of combined laser and furnance heating $^{40}Ar/^{39}Ar$ experiments

Sample #	Material	K/Ca total	Total fusion Age (ka) ± 2σ	$^{40}Ar/^{36}Ar_i$ ± 2σ	MSWD	Isochron Age (ka) ± 2σ	N	^{39}Ar %	MSWD	Plateau Age (ka) ± 2σ
44032	groundmass	0.16	86.4 ± 63.4	304.4 ± 22.5	0.06	43.5 ± 86.0	7 of 7	100.0	0.16	77.0 ± 56.3
	groundmass	0.15	54.2 ± 27.4	298.7 ± 13.1	0.75	35.6 ± 31.0	7 of 7	100.0	0.67	49.3 ± 22.8
	groundmass	0.18	47.8 ± 14.8	299.5 ± 4.1	0.65	27.3 ± 14.0	9 of 9	100.0	1.05	39.2 ± 11.8
						Weighted mean plateau age from 3 experiments:				**43 ± 10**
44060	groundmass	0.21	89.8 ± 46.6	291.0 ± 19.8	0.29	108.2 ± 75.4	8 of 8	100.0	0.28	90.5 ± 40.0
	groundmass	0.21	83.3 ± 21.6	298.0 ± 5.5	0.16	71.0 ± 30.2	8 of 8	100.0	0.26	81.9 ± 18.8
	groundmass	0.24	78.4 ± 23.6	293.2 ± 6.4	0.15	73.0 ± 26.2	7 of 8	96.5	0.20	66.0 ± 17.8
						Weighted mean plateau age from 3 experiments:				**75 ± 12**
44030	groundmass	0.06	367.2 ± 153.4	304.4 ± 12.6	0.53	257.8 ± 126.4	9 of 9	100.0	0.74	326.0 ± 106.1
	groundmass	0.06	345.5 ± 70.7	291.6 ± 11.4	0.40	366.9 ± 147.9	6 of 8	91.1	0.41	319.4 ± 67.0
	groundmass	0.06	340.3 ± 53.6	294.4 ± 51.6	0.64	294.4 ± 51.6	10 of 10	100.0	0.76	317.3 ± 39.0
						Weighted mean plateau age from 3 experiments:				**319 ± 31**

J-value calculated relative to 28.201 Ma for the Fish Canyon sanidine
Age in **bold** is preferred

Discussion

It is common to obtain discordant results from K-Ar and 40Ar-39Ar methods on young (< 1 Ma) basalt samples due to heterogeneity in the rock. The large samples and separate sample splits required for K and Ar measurement in the K-Ar technique makes it prone to sample alteration and/or contamination by xenoliths or xenocryst materials. The small samples used in the Ar-Ar method allow microscopic examination and selection of material for dating. There is an order of magnitude agreement between previously published K-Ar ages and the new Ar-Ar ages (Table 1,2,3), but the determinations by the two techniques do not always overlap at the 1 sigma error. For some samples, the Ar-Ar age is older than that determined by K-Ar. For example, Te Rahui basalt (44034) (K-Ar = 9.35 ± 0.49 Ma K-Ar and Ar/Ar = 10.37 ± 0.13 Ma); and Whangarei basalt (44030) (260 ± 12 ka; 319 ± 31 ka). Younger ages from the K-Ar method can result from loss of Ar via alteration or incomplete Ar degassing in the laboratory. In some samples, the Ar-Ar age is within error of the K-Ar determination but at a higher precision because duplicate analyses were made. For example, Te Puke basalt (K-Ar = 140 ± 60 ka; Ar-Ar = 75 ± 12 ka). In young basalts it is not uncommon for the two techniques to produce apparently discordant results due to low K contents.

Northland volcano age implications

The study demonstrates that application of the 40Ar-39Ar technique and the careful preparation of basalt groundmass samples can produce robust eruption ages for basalt lavas younger than 100,000 year old. This provides better insight the chronology of volcanism in Northland.

One of the prime objectives was to accurately determine the age of the most recent volcanism in the Kaikohe- Bay of Island field and the Whangarei Field. Based on previous stratigraphic and chronologic data (Smith et al., 1993), we selected the Piccadilly Road lava flow (44032) near Kaikohe, Te Puke lava flow (44060) in the Bay of Islands, and Whangarei lava (44030) in Whangarei. Duplicate laser fusion and furnace step-heating of sample aliquots resulted in robust plateaus and inverse isochrons (Table 2,3), and returned the following weighted mean plateau ages: Piccadilly Road = 43 ± 10 ka; Te Puke = 75 ± 12 ka and Whangarei = 319 ± 31 ka. We consider these to represent the best constraints on the most recent volcanism in these regions. The data confirms the youth of several volcanoes.

We targeted the Te Rahui lava flow (Bay of Island field) because it is considered startigraphically old in previous studies, and hence gives some indication of longevity to the volcanism. The sample produced a robust plateau age of 10.37 ± 0.13 Ma.

The new age data confirms the prolonged longevity of basaltic volcanism in the region (more than 10 million years). Therefore, the ages on the Piccadilly Road and Te Puke lava flows should not be interpreted as evidence for the termination of volcanism to the region. Instead, the new data shows that basaltic fields in northern Northland are capable of producing new volcanoes including small scoria cones and shield volcanoes, and far-travelled lava flows. It is possible that the frequency of such activity is low (on the order of an event every 10,000 to 50,000 years). However, the frequency is difficult to verify without additional dating studies on other lava flows.

We strongly recommend further Ar-Ar chronological studies of volcanoes in the Whangarei and Kaikohe-Bay of Island Fields to better constrain the frequency of past volcanism and hence likelihood of future activity.

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