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GEOCHEMICAL CHARACTERISTICS OF THE TAHANGA ARCHAEOLOGICAL QUARRY COMPLEX

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INTRODUCTION

This paper reports the results of research conducted in 1993, and is presented substantially without alteration as written at that time. One current objective of publication is to provide an example of a multivariate source-discriminant approach to geochemistry of basalt artefacts, possible where sources have been sampled, as distinct from the more widespread use of multivariate clustering/grouping approaches, applicable where source samples are unavailable. The latter, more common approach, is used sometimes even where source samples are available (eg Sheppard *et al* 1997), and the present paper seeks to demonstrate the utility of the alternative discriminant approach in such circumstances.

Identification of artefact raw material sources has become an important component of archaeological research around the world. Where artefacts made from a distinctive lithic material are found to be widely distributed, archaeologists may attempt to infer the type of social transactions and means of transportation that have resulted in the archaeological pattern (Green 1987, Hunt and Graves 1990, Sheppard *et al* 1997, Torrence 1986, Weisler 1997). Establishing the cultural distribution of lithic materials involves techniques of characterization imported from geology and recognized as a branch of archaeological science (Ward 1974). Characterization of lithic and ceramic artefacts has two aims: to identify the products of known quarries, and to acquire data leading to the discovery of previously unknown sources of raw material (Cummins 1983: 171). Known quarries must be adequately characterized in relation to other possible sources for artefacts to be assigned to raw material source.

Methods of characterization range from examining the artefact with the naked eye, through various tests of physical properties like hardness and specific gravity, to thin section petrography and quantitative analysis of geochemical composition. If sources differ visibly, more complex methods of artefact analysis may not be necessary; however, artefacts from archaeological contexts may show the effects of weathering, which vary with soil pH, mineralogy, and prehistoric burning (Sheppard and Pavlish 1992); these effects may create or obscure the visual characteristics of raw material sources. Where raw materials from more than one source are similar in appearance and physical properties, thin section petrography or geochemical analysis is required to differentiate sources and artefacts (Green1987).

Analysis of rock chemistry, yielding a list of concentrations of the major and trace elements present, is the most complex and expensive set of techniques of lithic characterization. The need to enlist the aid of technical specialists and in some cases perform involved sample preparation is offset by the precise results, often capable of separating very similar rocks into source groups, that can be attained using some of these techniques. Basalt artefacts have observable mineralogy, and are therefore more amenable to thin-section petrographic sourcing work than the glassy obsidians, and are less commonly analyzed using geochemical techniques than obsidian. A major benefit of using compositional analysis rather than thin-section petrography alone is the success with which individual basalt flows can be identified in artefact composition (eg Best *et al* 1992). For a quarry complex like Tahanga, this allows the archaeologist to ask not only whether an artefact is from Tahanga or not, but also to ask from which part of the complex the artefact comes.

The Tahanga pre-European quarry complex was found in the hills above Opito Bay (Figure 1) in 1962 (Shaw 1963). Basalt plug outcrops, clastic dikes and boulder fields have been extensively quarried in the past over an area of several square kilometres (Best 1975, Kronkvist 1991: 31-33, Moore 1975, Moore 1976, Shaw 1963, Turner 1992: 86). Flakes and adze preforms at Tahanga exhibit selection in the past of the finest grained rock present for adze manufacture (Turner 1992). This material is a high-alumina calc-alkaline basalt with a sub-trachytic matrix of plagioclase feldspar, pyroxene, and opaques having numerous small phenocrysts of altered olivines and augite (Moore 1975). Green (1963) attributed most of the archaic adze material from the Coromandel coast to the Tahanga basalt source. Moore (1975) found that the Tahanga material could be recognized among artefact collections with some confidence, and proposed a more widespread distribution, in which adzes and
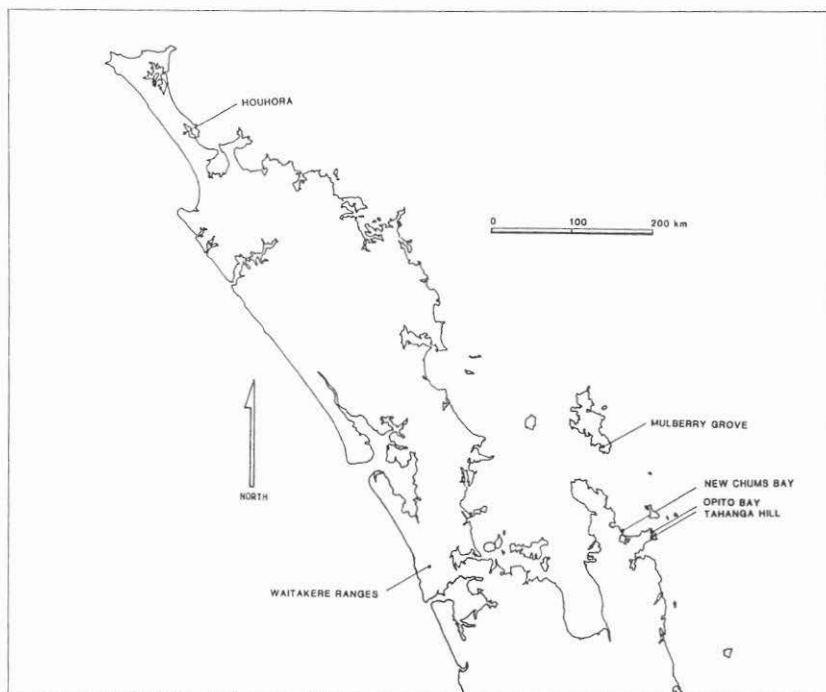
Figure 1. Map showing areas from which basalt samples were taken.

flakes from many parts of the North Island were sourced to Tahanga. Moore's distribution by this time included the bulk of the basalt adzes from the Auckland province, and adzes from as far afield as Cape Reinga, East Cape, and Wellington, as probably of Tahanga basalt. This distribution was based primarily on macroscopic examination of adzes.

Best (1975) set out to test Moore's distribution by subjecting a sample of artefacts to thin-section petrographic analysis and comparing these with quarry samples from Tahanga. He found that materials from as far away as Houhora/ Mount Camel in the far north did match the quarry samples (Best 1975: 15). Best examined geological theses from the North and rock samples held in the Geology Department of Auckland University and found nothing that could be confused with Tahanga basalt; he pointed out though that many areas remain unexamined (Best 1975: 19). This thin-section work confirmed for Moore that Tahanga basalt was in widespread use:

> Adzes, roughouts,and flakes of this basalt are common in early sites along the east coast of the peninsula, and adzes are widely distributed throughout the North Island. The Tahanga source was the focus of a major industrial centre along the eastern Coromandel coast during the Archaic, and probably Classic Maori periods. (Moore 1976)

Best (1975) and Moore (1976) both discussed the possibility of there being other similar sources of fine-grained basalt on the Coromandel peninsula or elsewhere in the North Island. Recently Bonica (pers. comm. 1993) has located geological sources of basalt in the Waitakere Ranges that are similar in macroscopic appearance and working properties to the rock found at Tahanga. Geological reports on this region (Wright and Black 1981) indicate there is a high probability that there are many more such sources of fine-grained adze-quality basalt on the west coast of the North Island between the Manukau and Hokianga harbours. It is not known at present how easily these can be distinguished from Tahanga basalt in thin-section or using geochemical methods of characterization.

A motivating factor in undertaking XRF geochemical characterization of the Tahanga complex for sourcing purposes is the possibility that this work will provide a clear indication of the analytical accuracy required to ascribe artefacts to this source and to sub-areas of this source. This information will be useful for evaluating the utility of non-destructive chemical analytical techniques, for example proton-induced X-ray emission spectroscopy (PIXE).

The primary aim of the present research was to obtain samples from the various basalt outcrops and flaking floors at the Tahanga quarry complex, and using these, to characterize the quarry and quarry subsources in terms of geochemical composition. Secondary aims were to investigate the geochemical relationships between Tahanga and other areas, and between Tahanga quarry geochemistry and artefact geochemistry. By including XRF analysis of some artefacts from the Houhora collection, the subject of previous investigation by Best (1975), it was hoped that some insight could be gained into the effects geochemical analysis might have on the presently understood distribution of Tahanga basalt.

METHODS AND MATERIALS
The main phases of the research were sample collection, thin section petrographic analysis of samples, XRF sample preparation and analysis, and finally the development of discrimination models for chemically identifying the

geological origin of artefact raw materials. Methods used in each of these phases are reported below.

Sample collection
The sample collection program had three main aims.
1. A representative sample of variation at the Tahanga quarry was required, including several samples from each basalt intrusion.
2. Other regions needed to be sampled for comparison and contrast with Tahanga.
3. Some basalt artefacts from museum collections were included in the sample to test the effectiveness with which artefacts could be assigned to source using chemical data.

The sampling program was conducted with the knowledge that only a subset of the samples would be submitted for XRF analysis, as sample preparation and analysis is labour intensive.

Seventy samples were collected from Tahanga (Figure 2, Table 1) and thirty of these were submitted for XRF analysis. Several samples were taken from each sample location, in an attempt to capture the range of macrosopic variation present at each location. In general, it was deemed desirable to have a series of sample locations for each intrusive centre at Tahanga. The XRF technique used required only a few grams of rock per sample, but in general it was found that a hand-sized flake or cobble taken entire provided enough material for XRF, thin sectioning, and a leftover piece for addition to a reference collection. The seventy samples taken left the Tahanga quarry complex effectively unaltered in terms of present archaeological techniques of information recovery. Locations from which Tahanga samples were taken are shown in Figure 2.

Although archaeological quarry sites are not recorded for the Waitakere region, experimental basalt procurement by adze maker Dante Bonica suggested fine-grained basalts with working properties similar to those of rock from Tahanga were present in the area (Bonica, pers. comm. 1993). Basalt boulders and cobbles occur along with a range of other rock types in stream beds and on boulder beaches, and have characteristic shape and colour that suggest good working properties. These high-energy environments are unlikely to preserve lithic procurement debris, so the absence of archaeological evidence at these locations can not be taken as proof that they did not form significant sources of adze basalt in the past. Future investigations of museum adze and flake collections may give a clearer indication of the past importance of such sources.
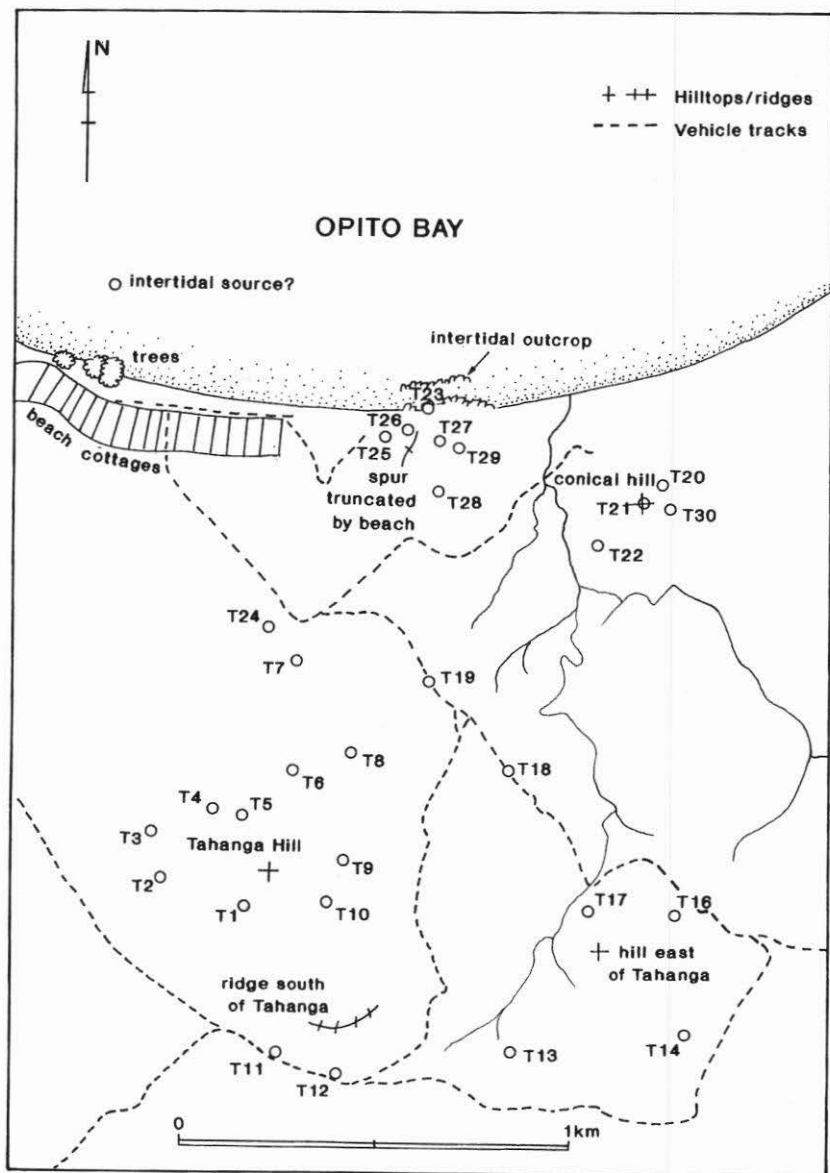
Figure 2. Map showing locations from which Tahanga samples were taken.

Locations of areas sampled are shown in Figures 1-3.

A reconnaissance survey of lithic resources of the northern Coromandel coast was made and samples of flakeable basalts were taken from several locations for reference purposes (Figure 1). None of these were analyzed using XRF, but thin-sections of all samples were prepared.

Five flakes from the Houhora collection at the Auckland Institute and Museum were released for analysis. This material was included in the sample for analysis to provide a test of the thin-section characterization procedure as used by Best (1975). If the Houhora material did turn out to be from Tahanga, the XRF results could then be used to find out how well archaeological materials could be assigned to subsources of the Tahanga quarry complex.

Two cobbles from a stream bed near a recorded quarry site (Clough, pers. comm.) in the Mulberry Grove area, Great Barrier Island, were included in the analysis. These were dissimilar to most of the other samples in macroscopic appearance and flaking qualities, having visible phenocrysts of plagioclase feldspar and a toughness and platy fracture that is undesirable for adze manufacture. These were included to provide a further benchmark for evaluating the effectiveness with which the XRF technique and elemental composition could be used for characterizing source areas and assigning artefacts to source.

Sample numbers were assigned an alphabetic prefix indicating the general geographic origin as follows: 'W' for Waitakere Ranges, 'T' for Tahanga, 'H' for the Houhora collection, and 'G' for Great Barrier Island. 'X' identifies samples or XRF results supplied by Peter Sheppard and Marianne Turner. Individual samples from each of these areas were assigned integer identifiers. Where more than one Tahanga sample was taken from a location, additional lower-case alphabetic suffixes were assigned. (Table 1). Waitakere and Great Barrier sample locations were recorded on 1:50 000 Topographic maps and sample locations were transferred to Figures 1 and 3. More accurate spatial recording was required for Tahanga subsource samples, so a portion of the Lands and Survey 1986 black and white vertical air photograph of the Kuaotunu Peninsula was enlarged. Sample locations were recorded in the field on this enlargement (Figure 2).

Thin sections of all samples were prepared and photographed. Standard optical petrographic techniques were used to identify minerals and describe rock fabric of the samples.

XRF methods

The ten elements usually present in silicate rocks in major or minor quantities rather than as trace elements, are silicon, titanium, aluminium, iron, manganese, magnesium, calcium, sodium, potassium and phosphorous. These elements were analyzed using powdered rock samples fused with Norrish flux. Fusion disk preparation followed the methods given in Norrish and Hutton (1969) and Parker (1983). Percent loss of weight on ignition was calculated for each sample (LOI). This figure is a guide to the degree of oxidation or weathering the rock sample has been subject to. Trace elements measured include niobium, zirconium, yttrium, strontium, rubidium, thorium, lead, zinc, copper, nickel, chromium, vanadium, barium and lanthanum. Preparation of pressed powder briquettes for trace element analysis followed methods given in Parker (1983).

XRF analysis was completed using an automated PHILLIPS PW 1410/00 XRF spectrometer modified to suit a SIERAY 103 controller interfaced to a Hewlett Packard computer (Parker 1991a). For major/minor element fusion disks a Cr X-ray tube was used. Multi-standard calibration lines constructed using methods described in Parker (1978) were used. International rock standards used in calibration include: BR, JB-1, JG-1, GH, MRG, and NIM-S, with NIM-L and NAF used for calibrating for manganese and sodium measurement. Samples were not prepared in duplicate. Element concentrations were calculated from XRF counts, calibration factors, H_2O- and LOI, and sample concentration in the fusion disc (Parker 1991a). XRF analysis of trace element briquettes was completed using a Rh X-ray tube. Counts were corrected for machine drift, background, line interference, tube line interferences, and for mass absorption effects (Parker 1991b). Calibration factors are calculated from silicate rock standards BR, AGV, W-1, MRG, GH, GA, DR-N, SY-2, G-2, NIM-S, NIM-N and BHVO-1 (see Parker and Sheppard 1997).

Using The XRF results:Methods for developing source discrimination models

The problem here is to find the ways in which the Tahanga complex is chemically distinct from other sources of fine-grained basalt, and to find ways of distinguishing sub-areas of the Tahanga complex on the basis of shared chemical characteristics. This allows the sourcing of artefacts from archaeological sites and museum collections not only to the Tahanga complex, but also to specific sub-areas of that complex.
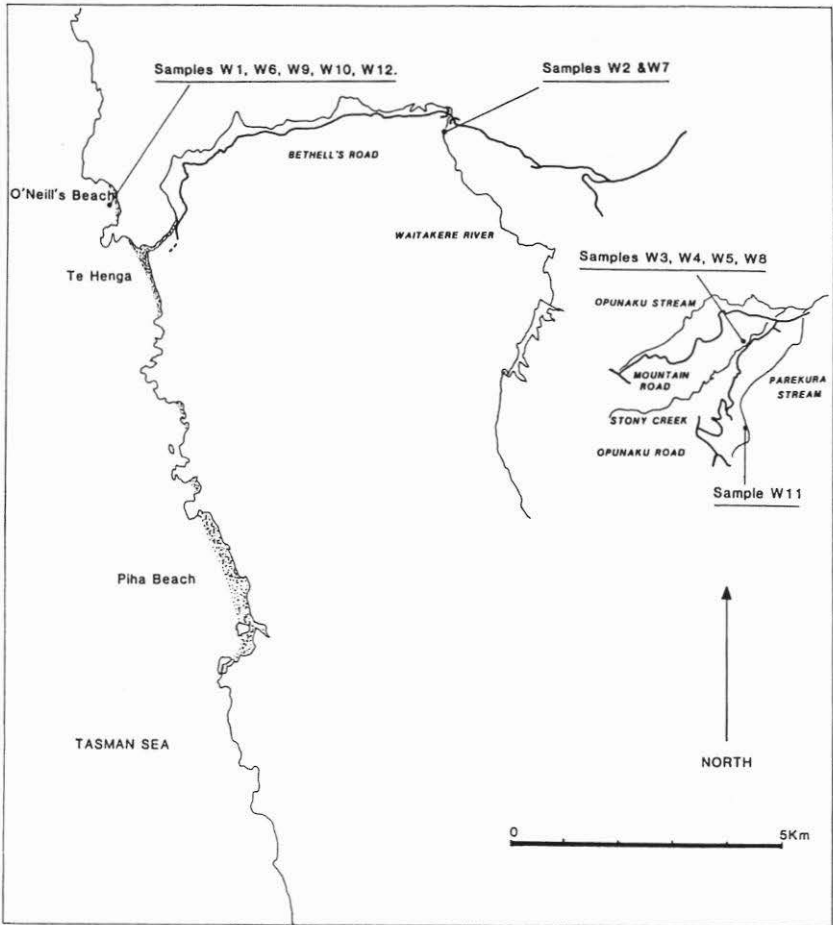
Figure 3. Map showing locations in the Waitakere Ranges from which basalt samples were taken.

The XRF results used for discrimination include ten major/minor elements and fourteen trace element concentrations. Finding which of these element concentrations varied by source and subsource required some idea of what separate geological events were represented in the samples analyzed. Skinner (1976) suggested there were three intrusive centres at Tahanga, and initially it was expected that the samples would be separable into three groups corresponding to these centres. Moore showed three extra areas of Tahanga basalt (Moore 1976: Figure 3) but did not identify these as separate intrusions.

Turner (1992: 88) lists Opito Point as another 'extrusive centre', but found no evidence for adze manufacture from this clastic source. One area of Tahanga basalt mapped by Moore but not called an intrusive centre is a small conical hill near the beach. This was expected to be geochemically distinct from the other areas, which brought the expected number of groups to four, as Opito Point was not sampled. Through the course of the research this number was enlarged to six (Figure2), as distinctive geochemical groups were defined for an intertidal subsource and for some of the areas shown by Moore (1976: Figure 3).

The first technique used for identifying elements that would group the samples according to geologic origin was to sort the XRF results into an order reflecting these six geologic centres. Element concentrations that varied by subsource were then more easily seen. The same thing was done with a set of XRF results that included other areas besides Tahanga. Grouping Tahanga XRF data together, and contrasting these with Waitakere data and Great Barrier data was the first step in deciding which of the twenty-four element concentrations were useful for identifying these broader geological source areas.

Plots of element concentrations, or in some cases functions or ratios of element concentrations, were drawn using the SAS G3D procedure. The SAS G3D procedure creates an isometric view of a cube of space, where the three-dimensional position of each plotted point within the cube represents the values of three variables for one observation. Visual interpretation of G3D plots is aided by being able to adjust tilt and rotation of the angle of view through ninety degrees by altering the SAS program. Considerable experimentation was usually required to be able to see all groups well. This suggests that when using 3 dimensional plots in publications, the figure caption should include the tilt and rotate values used in the SAS program. This practice was followed here.

Using a 3D plot therefore simplifies a sourcing problem down to the question "Does this artefact fall in that (visible) group or not?" while expressing more of the raw data than either a two-dimensional conventional plot or a ternary plot does.

The SAS STEPDISC discriminant analysis procedure was used regularly in conjunction with more intuitive methods of discriminant analysis. STEPDISC used with the stepwise option outputs a ranking of variables in order of their usefulness for producing a specified discrimination model. With a large number of variables and small sample sizes for each class, variables with poor discriminatory power may be included in the selection, so results were treated

as a rough guide only. In general, the SAS manual recommendation was followed concerning stepdisc, that,

> "used carefully, in combination with your knowledge of the data and careful cross-validation, it can be a valuable aid in selecting a discrimination model (Yuan and Sarle 1987: 911)."

As it turned out, there were occasions when STEPDISC suggested a variable that was poor in some respect, but good in others. In general though it proved to be a useful way to isolate the core variables that would produce a plot that grouped the samples in non-overlapping clusters corresponding to subsources.

RESULTS

Thin section analysis:

The thin section characteristics considered diagnostic of Tahanga basalt by Best (1975: 15) were present in all Tahanga samples and in all five Houhora flakes selected from the Museum collection. A sub-trachytic matrix of fine plagioclase feldspar laths, olivines with an opaque rim, and a groundmass including numerous small pyroxenes and opaques was present in all of these samples. In addition, augite crystals with an opaque rim were common in all Tahanga and Houhora samples and in one Great Barrier sample. This suggested the Houhora material was comparable with the Houhora artefacts sampled by Best (1975). Best pointed out that these general similarities combined with some variability in grainsize and mineralogy within subsources meant that distinguishing between subsources on the basis of thin-section characteristics would not be easy, and this was found to be the case in this instance.

The Waitakere samples that were similar to Tahanga basalt in macroscopic appearance and in flaking properties (Bonica pers. comm. 1993) were similar to the Tahanga material in thin section. The sub-trachytic matrix of fine feldspar lathes noted for Tahanga was present. In thin-section the Waitakere materials lacked the altered olivines characteristic of the Tahanga material.

The Mulberry Grove quarry samples from Great Barrier Island were visibly coarser-grained in hand examination and lacked the flaking properties associated with adze manufacture at the Tahanga complex (Turner 1992: 58). In thin section these samples exhibit a higher degree of porphyry than the adze-quality Tahanga or Waitakere samples, having frequent large phenocrysts of plagioclase feldspar that give the coarse-grained appearance. Smaller

phenocrysts with an opaque rim, similar to those present in Tahanga and Houhora materials, were present. Some of these may be olivines but most are probably altered augite.

The sample taken from a beach boulder at New Chums Beach (Figure 1) was similar in thin section to Tahanga basalt, having the same sub-trachytic matrix of plagioclase feldspar lathes, but with unidentified brown unaltered phenocrysts rather than altered olivines.

Tahanga thin-sections showed substantial variation in grain-size for all areas of the quarry complex, but systematic variation between areas of the quarry complex, either in grain-size or mineralogy, were not identified. A more formal quantitative petrographic analysis might be more successful at identifying petrographic characteristics at the subsource level of precision.

XRF analysis
Major/minor element concentrations (percent weight of the total sample) of samples analyzed by XRF are presented in Table 2. The major/minor element concentrations for sample number T30b are missing. One sample, T21b, yielded a loss on ignition greater than one percent. The element concentrations of this sample do not appear to be affected by weathering. The sample also plotted in with others from the same location on the discriminant scheme discussed below, so the high loss on ignition does not seem to be a problem.

Trace element concentrations, in parts per million, are presented in Table 3. The trace element concentrations of sample number W5 are missing. Concentrations were rounded to whole numbers, and values below the limits of machine detection for that element were converted to zero.

Discrimination models from the XRF source data
Major elements: identifying the Tahanga basalt:
A 3-d plot of the major elements aluminium, potassium and phosphorous clustered the three Waitakere samples and both Great Barrier samples in separate groups away from a group containing both the Tahanga and Houhora samples (Figure 4).

Major elements: discriminating between Tahanga subsources:
Through trial and error it was established that a plot using the ratio of magnesium to potassium, phosphorous concentration, and titanium to

Figure 4. (Above) Major/minor element discrimination of source area.
Figure 5. (Below) Major/minor element discrimination of Tahanga sub-areas.
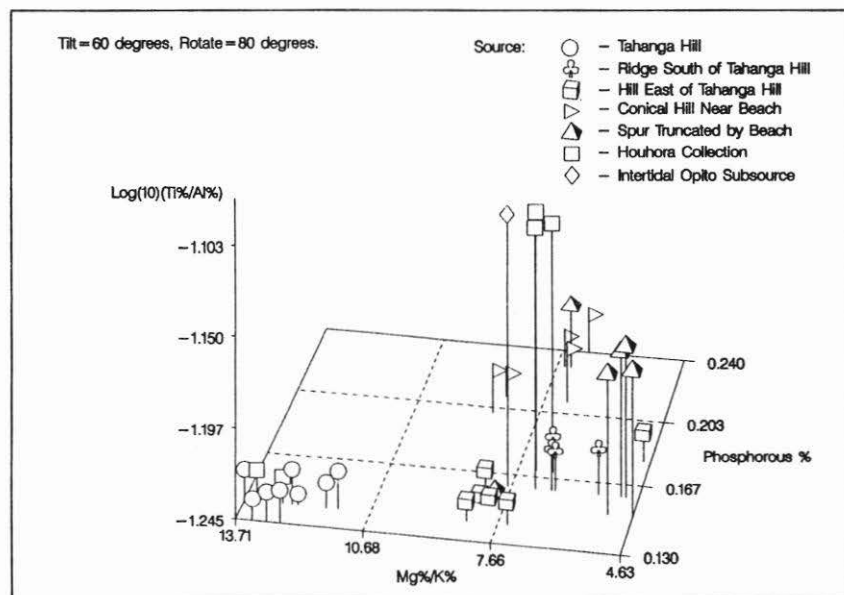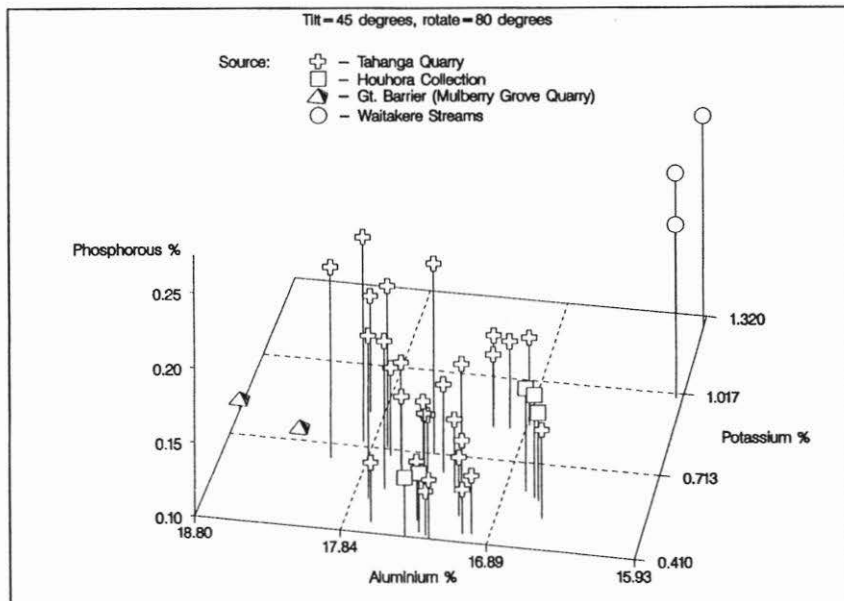
aluminium ratio (a log 10 transform of titanium to aluminium ratio reduced the effect of an outlying group) produced discrete groups corresponding to geologic subsources at Tahanga (Figure 5). The Houhora samples plot in well with two of the Tahanga subsources. Three match the intertidal sample collected by Marianne Turner, while two plot in with the main Tahanga hill group. Two of the samples, picked up on the spur truncated by the beach, plot in with the sample groups of other subsources: one matches the geochemistry of the hill east of Tahanga; the other plots in with samples from the adjacent small conical hill. Both of these are artefacts, and were probably moved to their found locations in the past (Table 1: samples T25a and T27d, Figure 5). One of the samples from the hill east of Tahanga does not fall neatly into any source group. The magnesium to potassium ratio and phosphorous concentration are not what one would expect of the found location of this sample (Table 1: sample X3, Figure 5).

Trace elements: identifying the Tahanga basalt:
Various combinations of trace elements that separated Tahanga from other quarry areas were tried (Figures 6, 7, 8). The discrimination model suggested by Weisler (1993a, 1993b) as generally useful for Pacific basalts, where zirconium to strontium ratio is plotted against niobium to strontium ratio, worked well (Figure 6), although the Tahanga samples formed a fairly loose group in this plot. The Tahanga samples clustered more tightly away from Waitakere sources on a plot of rubidium against copper and zirconium (Figure 7). These were the variables ranked highest by stepwise discriminant analysis run on the trace element data with a three-location classifying variable. The two Waitakere samples for which trace element data was available varied markedly in copper content. This may be variation between Waitakere subsource, or it may reflect variability within the rock matrix. Nodules of native copper were visible in some of the samples prior to crushing, so this material may have a highly variable Copper content for any subsource. Further sampling of the Waitakeres in the future may give a better idea of how useful copper will be as a diagnostic element in North Island basalt sourcing studies.

Trace elements: discriminating between Tahanga subsources:
Trace element discrimination of Tahanga subsources was clearest using zirconium to strontium ratio plotted against zirconium and vanadium (Figure 8). Although stepwise discriminant analysis of the Tahanga trace element data
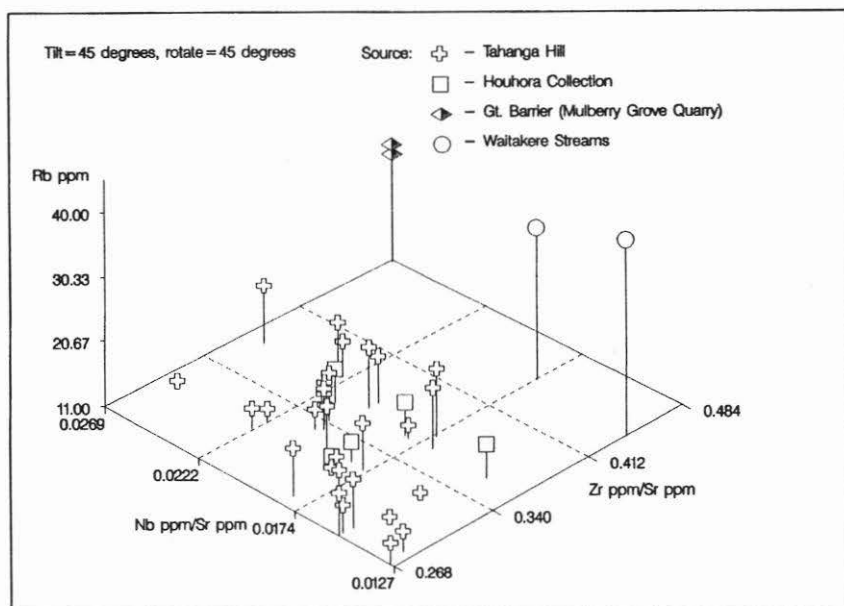
Figure 6. Trace element discrimination of all areas.

ranked strontium higher than vanadium, it was found in practice that vanadium offered better discrimination between the two beach subsources. Niobium to strontium ratio was not a useful variable for discriminating between subsources in the Tahanga case. Samples from the Waitakere ranges and Great Barrier Island were included in this plot, and formed discrete clusters (albeit with a membership of two: larger samples would be preferable) well separated from the Tahanga subsources. The Houhora pieces plotted into the same groups as in the major\minor element plot (Figure 5), as did the two samples thought to have been moved in the past. The anomalous sample from the hill east of Tahanga still tended towards membership of the group from the ridge south of Tahanga hill, as it's zirconium content was what would be expected of this group. In zirconium to strontium ratio it was more similar to other samples from site T10/857 on the hill east of Tahanga.

CONCLUSIONS
Six identifiable sub areas of the Tahanga quarry complex were found. These were: the main Tahanga hill; the ridge south of Tahanga; the hill east of Tahanga; the conical hill near Opito Bay beach, at the Opito Point end; the adjacent spur truncated by the beach; and some large blocks of basalt in the

Figure 7. (Above) Trace element discrimination of all areas.
Figure 8. (Below) Trace element discrimination of Tahanga sub-areas.
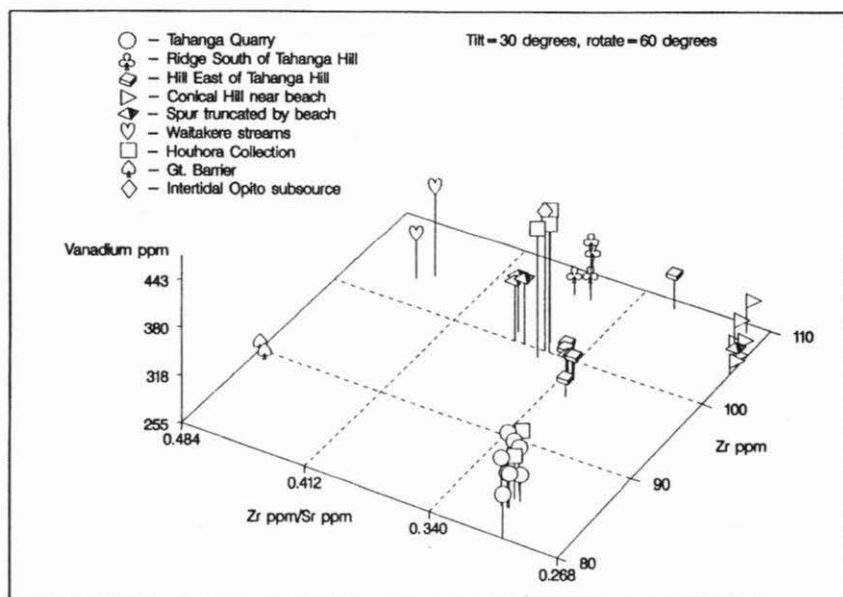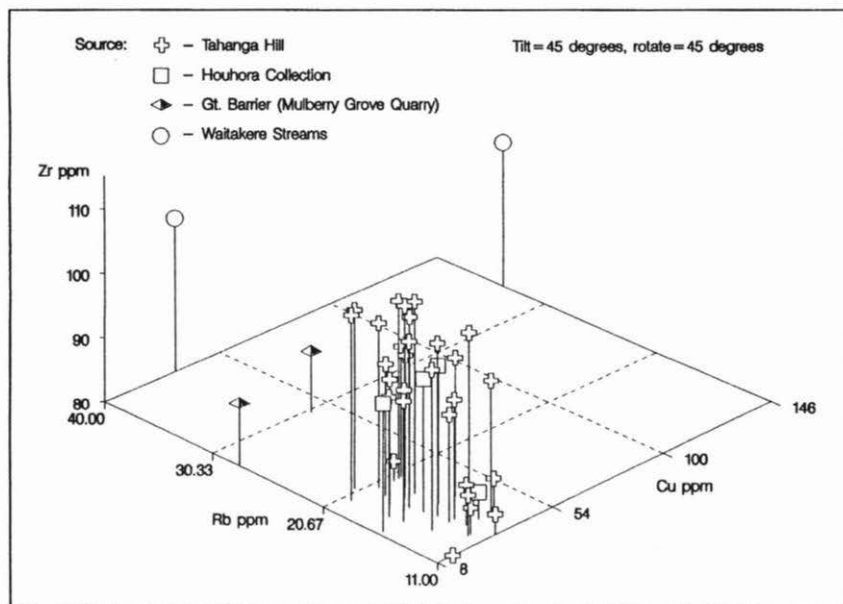
intertidal zone of Opito Bay (Figure 2). Using data of sufficient accuracy on the concentration of selected major/minor or trace elements, it should be possible to source artefacts of Tahanga basalt to one of these areas.

The intertidal subsource has not been as well documented as the other five areas. More samples should be collected from here in future. One sample from the hill east of Tahanga did not fit well into any of the six groups, so it would be prudent to sample this area more fully at some future date to get a better idea of what variation there is in geochemistry. A few more samples from the beach spur and the ridge to the south of Tahanga hill would increase the level of confidence that we can have that these areas can be reliably discriminated.

The basalt from Opito Point and the islet to the north of the point were not sampled; neither were the other Mercury basalts offshore on the Mercury islands. Any future work on characterizing Tahanga basalt could usefully include these areas, even if only to corroborate Moore's assertion that these sources were not used (Turner 1992: 88).

The Tahanga quarry complex in relation to other possible sources
The main focus of this research has been on the Tahanga quarry. Limitations on the number of XRF samples that could be prepared and processed prevented fuller investigation of other basalts and their petrographic and geochemical relationships to the Tahanga sources. A preliminary conclusion is that the Tahanga samples could be distinguished chemically from the five other XRF samples analyzed. Three of these others were from the Waitakere Ranges and two were from the Mulberry Grove Quarry on Great Barrier Island. The Mulberry Grove basalt is less likely to be wrongly sourced to Tahanga than are some of the Waitakere basalts, which are much more similar to Tahanga in that they are fine-grained and are generally physically similar, although a more thorough sampling of this area may turn up basalt more similar to Tahanga. A priority in future North Island sourcing studies of basalt artefacts would be to become more familiar with the sources of basalt along the west coast ranges and with the geochemistry of these sources.

The Houhora collection: relationship to Tahanga
The Houhora collection at the Auckland Institute and Museum contains a large number of basalt artefacts, most of which are fine-grained and lacking visible phenocrysts. Five flakes sampled from this collection all turned out to be very similar to either the main Tahanga hill or to the intertidal beach source. Best (1975) has examined this collection extensively using thin-section petrographic

analysis, and concluded most of the fine basalt was probably from Tahanga. The flakes analyzed using XRF satisfied Best's thin-section petrographic criteria for a Tahanga origin. The agreement between the XRF sourcing results and Best's thin-section results strengthens Best's finding that the Houhora material is from Tahanga. The prospects for assigning these materials to subsources of the Tahanga complex using less destructive techniques in the future are good.

Sources of Error
Quarry sampling at Tahanga included a mixture of outcrop samples, samples from unworked cobbles and quarrying debris samples. Although the outcrop sampling was done with the intent of capturing the full range of variation present at Tahanga, the selection of samples for XRF analysis was done after thin-sections of all samples had been prepared and photographed. Laying out the photographs and rock samples together with Bonica and Turner's comments on the working properties of the samples, made when they were taken, enabled selection of a subset of the rock samples for XRF analysis that seemed to be the grade of material being used in adze manufacture. It is hoped that this sampling strategy has built the effects of selection in the past into the source characterization.

Forty-one samples were submitted for XRF analysis. To adequately characterize the Tahanga complex in relation to other sources using this number of samples is a tall order. Ideally, fifty or so samples from each source should be subjected to petrological analysis to adequately characterise these. Thirty-one of the XRF samples were from the Tahanga complex, so this is probably adequate until shown to be otherwise. The Tahanga subsource groups formed seem fairly robust, since they occur to some extent in a variety of element or element ratio plots. This suggests they are not simply the result of selecting elements that coincidentally vary with subsource, but have some petrogenic significance. The XRF results became available in two batches, and the major-element discriminant model for Tahanga subsources was developed for the first batch. It is encouraging that the second set of results, which included the Houhora artefacts, did plot in neatly with the six separate groups of the first batch. Although sample sizes are small for the Tahanga subsources, we can be reasonably confident that new observations added to the existing set will for the most part reinforce the Tahanga sub-area discriminant scheme rather than throw it into disarray.

What is lacking for characterizing Tahanga with confidence in relation to other sources using geochemical methods is an adequate set of XRF results from

other possible source areas like the Waitakere Ranges. Having a reasonably large set of analytical results from the Tahanga complex should not be considered grounds for complacency that the source characterization process is complete.

Future Prospects

The distribution of Tahanga basalt is in need of refinement. The groundbreaking sourcing work of Moore and Best is almost three decades in the past now. Both Moore and Best suggested that other similar sources were possible, and some of these have now been found. This calls the presently understood distribution of the material into question. This question will not be resolved until a more complete characterization of relevant lithic resources is made by archaeologists. Continuing to make archaeological inferences from a questionable distribution of Tahanga basalt is building on sand.

Looking beyond refinement of the distribution of Tahanga basalt, the ability to identify which Tahanga subsource an artefact is from opens new archaeological prospects. Patterns of use of the quarry can be reconstructed in terms of the flow of materials into archaeological sites at Tahanga and beyond. The sort of changes over time that might be expected are that coastal subsources are likely to have been exploited first, with more inland areas also being used as beach and coastal subsources became depleted. One prospect if such a pattern could be demonstrated from a series of well-dated excavation sites is that this may provide a relative chronology for the 'Archaic' period, where radiocarbon has failed in the past through poor time resolution.

interpreting the XRF results. Sue Courtney and Nan Howett assisted with XRF sample preparation.

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Table 1: Sample descriptions

Sample	Description
GB1	Platy Cobble, Mulberry Grove Quarry, Great Barrier Island, fine grained
GB2	Platy Cobble, Mulberry Grove Quarry, Great Barrier Island, fine grained
H1	Flake, Houhora collection, Auckland Institute and Museum, fine grained basalt, altered olivines
H2	Flake, Houhora collection, Auckland Institute and Museum, fine grained basalt, altered olivines
H3	Flake, Houhora collection, Auckland Institute and Museum, fine grained basalt, altered olivines
H4	Flake, Houhora collection, Auckland Institute and Museum, fine grained basalt, altered olivines
H5	Flake, Houhora collection, Auckland Institute and Museum, fine grained basalt, altered olivines
T01a	Large boulder, top of Tahanga hill, medium-grained
T01b	Large boulder, top of Tahanga hill, coarse-grained, weathered
T02a	Flaked cobble, T10/166 working-floor 3. Fine-grained
T02b	Unworked cobble,T10/166 working floor 3. Medium-grained
T03	Flake, T10/166 working-floor 5. Fine-grained
T04	Small cobble, T10/166 working floor 5. Fine-grained
T05a	Flaked cobble, T10/166 working floor 5. Fine-grained
T05b	Flaked cobble, T10/166 working-floor 5. Fine-grained
T06	Boulder, above T10/400. Coarse-grained
T07a	Flake, T10/400 upper working-floor. Fine-grained
T07b	Cobble. T10/400 upper working-floor. Fine-grained
T08	Fractured (flaked?) cobble from "unworked" area, north slope of Tahanga peak. Medium-grained
T09a	Outcrop, east face of Tahanga, medium-grained
T09b	Outcrop, east face, Tahanga, with flake scars. Medium/fine
T10a	Outcrop, east face, Tahanga T10/401, medium/fine grain
T10b	Same as T10a
T10c	Archaeological spall, T10/401, medium-grained
T11a	Cobble, where road south of Tahanga bisects working-floor. T10/459, fine-grained with white fleck
T11b	Spall. T10/459, road bisects flaking-floor. Fine-grained (platy?) Scoring visible on cortex
T12a	Cobble, road cutting South of Tahanga. Fine-grained
T12b	Same as T12a
T13a	Flake/spall, north-facing gully, T10/858. Fine-grained

Sample	Description
T13b	Typical platy cobble, T10/858, medium-grained
T13c	Cobble, T10/858, medium-grained
T14a	Flake, top working floor, T10/857. Medium/fine
T14b	Cobble, top working floor, T10/457. Medium/fine, flawed
T14c	Flake? Possible fire-cracked, ripply fracture. T10/457 top working floor. Medium/fine
T15	Cobble, stream above Red Bay. Medium Grain. Slightly green colour
T16	Cobble, T10/457 lower. Fine-grained
T16b	Same as T16 except medium-grained
T17	Cobble, T10/857, 2 pieces, 1 is platy, other thin-sectioned. Fine-grained with white fleck
T18	Cobble, T10/856, from triangular scatter. Fine grained
T19	Cobble, T10/855, medium/fine, platy
T20a	Cobble, from exposed linear cobble feature on the north face of the small conical hill near the beach
T20b	Cobble, location as for T20a, medium-grained
T21a	Outcrop, peak of small conical hill, fine-grained
T21b	Cobble, location as for T21a, medium-grained
T21c	Cobble, location as for T21a, medium/coarse
T22a	Broken cobble, stone alignment running down west face of small conical hill near beach,
T22b	Cobble,location as for T22a. Coarse-grained
T23a	Outcrop, beach below spur and T10/200/201, fine-grained, flawed
T23b	Cobble or outcrop? Location as for T23a, fine-grained
T23c	Cobble, location as for T23a, adjacent to outcrop, fine-grained.
T24a	Spall, T10/400 lower edge, now destroyed by subdivision, fine-grained
T24b	Cobble, same location as T24a, med/fine
T24c	Cobble, same location, medium-grained
T25a	Primary flake, below dyke on T10/200, fine-grained
T25b	Small cobble, fragmented surface piles below dyke, T10/200. med/fine
T25c	Small pillowed cobble, T10/200 below dyke, medium/fine grain, weathering
T26	2 small fractured cobbles, from T10/200, outcrop above working floor. medium/fine-grained
T27a	Porous cobble, from T10/200/201, upper dyke on east slope. Medium-grained
T27b	Porous cobble, same location as T27a, medium/coarse-grained
T27c	Porous cobble, same location as T27a, medium-grained
T27d	Spall, surface collected from T10/201 upper dyke. Medium/fine grained e
T28a	Angular cobble from rock heap below outcrop (the more southerly of the eastern dykes on the T10/200/201
T28b	Small cobble, same location as T28a, fine-grained, flawed
T29a	Angular cobble, lower eastern side outcrop, T10/200/201 spur. Medium-grained but porous
T29b	Angular cobble, location same as T29a, medium/fine grain, flawed
T29c	Small flawed cobble, same location, finer grained

T29d   Small cobble, from rock pile below lower outcrop, east side of T10/200/201 Fine-grained Bulldozed?

T30a   Boulder, from east slope of T10/620 conical hill, medium-grained

T30b   Boulder, location same as T30a, sample has old flake scars on reverse Fine-grained

W01   Beach rock, Far end of Te Henga (O'Neill's Beach) Fine grained adze quality stone similar to Tahanga

W02   Stream cobble, Waitakere River, fine grained

W03   River rock, Opunaku Stream, medium/fine with faint red banding and green phenocrysts

W04   Stream cobble, Opunaku Stream, medium grained with native copper. Tough.

W05   Stream cobble, Opunaku Stream, very fine grained and brittle

W06   Beach cobble, Te Henga beach, fine-grained

W07   Stream cobble, Waitakere River, Fine-grained

W08   Stream rock, Opunaku Stream, coarser grained

W09   Beach rock, Te Henga Beach, fine grained but flakes in plates

W10   Beach cobble, Te Henga Beach, fine-grained and tough

W11   Stream Cobble, Parekura stream below Te Mata, Medium grain "dacite"

W12   Beach cobble, Te Henga Beach. Fine grained and slightly brittle Strong ring

X2   Cobble, Tahanga T10/166 from Marianne Turner/Peter Sheppard

X3   Cobble, Tahanga T10/857 from Marianne Turner/ Peter Sheppard

X4   Unknown, Tahanga, Opito Bay beach, Spur truncated by beach, from Turner/Sheppard

X5   Unknown, From buried intertidal Opito Bay subsource, from Turner/Sheppard

Table 2: Major element concentrations (percent weight)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O-	LOI	Total.
G1	55.09	0.91	18.80	8.54	0.17	4.16	8.22	2.95	0.80	0.11	0.30	0.50	100.55
G2	55.14	0.91	18.37	8.71	0.17	4.16	8.21	2.84	0.77	0.10	0.32	0.61	100.31
H1	53.00	1.29	16.75	12.70	0.24	4.17	8.63	2.95	0.61	0.17	0.20	-0.03	100.70
H2	52.72	1.30	16.65	12.56	0.24	4.11	8.43	2.92	0.58	0.16	0.15	-0.11	99.70
H3	52.38	1.03	17.42	10.47	0.23	5.50	9.84	2.60	0.41	0.14	0.18	-0.23	99.98
H4	52.71	1.02	17.34	10.89	0.19	5.50	9.85	2.58	0.43	0.14	0.15	-0.06	100.74
H5	52.33	1.30	16.68	12.20	0.23	4.26	8.48	3.02	0.59	0.17	0.15	0.11	99.51
T02a	52.24	1.02	17.38	10.85	0.22	5.52	9.52	2.45	0.47	0.14	0.17	0.32	100.27
T05b	51.93	1.02	17.12	10.77	0.22	5.73	9.76	2.62	0.50	0.14	0.16	0.08	100.04
T07a	52.24	1.02	17.26	9.87	0.22	5.62	9.71	2.60	0.41	0.14	0.23	-0.03	99.27
T10b	52.41	1.02	17.67	10.60	0.20	5.59	9.53	2.74	0.45	0.14	0.19	0.02	100.56
T10c	51.79	1.01	17.06	10.64	0.22	5.57	9.50	2.74	0.44	0.13	0.12	0.16	99.39
T11a	54.56	1.04	17.25	9.93	0.20	4.07	7.99	3.01	0.73	0.16	0.24	0.50	99.68
T11b	53.83	1.04	17.32	9.98	0.18	4.35	8.16	3.13	0.65	0.16	0.43	0.27	99.51
T12a	54.77	1.06	17.70	9.64	0.20	4.56	8.55	3.03	0.69	0.16	0.18	0.24	100.77
T12b	53.88	1.05	17.61	10.24	0.22	4.50	8.40	3.17	0.66	0.17	0.22	0.43	100.54
T13a	53.68	1.02	17.42	10.45	0.19	4.75	8.80	3.12	0.64	0.14	0.16	0.36	100.74
T14a	53.84	1.00	17.41	10.09	0.23	4.73	8.78	2.96	0.59	0.15	0.25	0.10	100.12
T16	53.21	0.99	17.20	10.03	0.22	4.78	8.53	2.92	0.58	0.15	0.35	0.34	99.30

Sample	SiO$_2$	TiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$T	MnO	MgO	CaO	Na$_2$O	K$_2$O	P$_2$O$_5$	H$_2$O-	LOI	Total
T16b	53.49	1.00	17.14	10.01	0.19	4.70	8.54	3.16	0.56	0.14	0.31	0.36	99.62
T17	53.87	1.01	17.41	10.21	0.20	4.80	8.67	3.08	0.58	0.16	0.19	0.34	100.54
T18	52.12	1.01	17.00	10.60	0.19	5.53	9.68	2.61	0.44	0.14	0.31	0.00	99.65
T20a	52.09	1.07	17.91	9.66	0.20	5.12	9.61	3.01	0.73	0.24	0.33	0.38	100.34
T20b	52.65	1.07	18.08	8.79	0.23	4.93	9.58	3.17	0.66	0.23	0.35	0.53	100.26
T21a	52.55	1.08	17.74	9.78	0.21	5.11	9.49	3.17	0.72	0.21	0.20	0.20	100.46
T21b	51.07	1.04	17.74	9.96	0.22	4.56	8.97	2.68	0.53	0.21	1.28	1.26	99.31
T23b	52.96	1.16	17.10	10.90	0.22	4.33	8.53	2.91	0.83	0.15	0.28	0.26	99.62
T23c	53.45	1.16	16.99	10.28	0.20	4.19	8.41	2.85	0.83	0.16	0.34	0.54	99.41
T24a	51.98	1.01	17.29	10.60	0.21	5.59	9.74	2.55	0.42	0.13	0.20	-0.11	99.60
T25a	51.61	1.08	17.42	9.84	0.26	5.18	9.51	3.12	0.71	0.23	0.29	0.34	99.58
T25b	53.58	1.17	17.14	10.20	0.20	4.17	8.52	2.79	0.90	0.15	0.40	0.73	99.95
T27d	53.21	1.00	17.56	10.34	0.18	4.75	8.74	3.03	0.59	0.16	0.23	0.19	99.97
T30a	52.02	1.06	17.66	9.66	0.18	5.00	8.99	2.77	0.57	0.20	0.94	0.91	99.95
W1	51.67	1.10	15.97	11.59	0.22	4.64	9.27	3.01	1.00	0.22	0.49	0.29	99.48
W3	53.45	1.18	16.14	12.62	0.25	3.36	7.95	3.37	1.32	0.20	0.34	0.08	100.26
W5	54.10	1.21	15.93	11.90	0.28	3.58	7.65	3.48	1.28	0.25	0.92	0.11	100.68
X2	51.97	1.02	17.29	10.84	0.18	5.45	9.63	2.62	0.42	0.13	0.08	0.08	99.70
X3	54.49	1.06	17.94	9.19	0.18	4.03	8.59	3.17	0.84	0.18	0.13	0.30	100.10
X4	53.29	1.16	16.87	11.10	0.17	4.19	8.47	2.71	0.85	0.16	0.21	0.52	99.70
X5	53.05	1.31	16.59	12.40	0.19	4.03	8.38	2.94	0.52	0.16	0.12	-0.19	99.51

Table 3: Trace elements (parts per million)

Sample	Nb	Zr	Y	Sr	Rb	Th	Pb	Zn	Cu	Ni	Cr	V	Ba	La
GB1a	5	90	33	187	30	4	11	79	46	7	21	255	190	7
GB2a	5	90	24	186	28	6	10	104	8	8	21	265	192	10
HRA1	6	100	25	281	16	0	10	102	26	0	8	428	232	10
HRA2	4	101	25	281	16	0	9	124	32	0	11	434	223	13
HRA3	5	84	22	272	13	0	7	96	34	9	7	311	169	7
HRA4	5	88	24	274	14	5	10	97	29	8	21	295	175	11
HRA5	5	99	28	276	16	4	11	114	10	0	13	429	223	10
T02a	5	83	29	269	20	4	9	83	33	10	18	299	199	16
T05b	5	84	28	275	12	0	5	87	26	8	19	289	171	8
T07a	7	83	22	266	11	0	8	86	31	7	23	316	180	10
T10b	4	86	23	268	12	4	9	85	25	12	17	312	176	7
T10c	4	80	29	268	11	0	8	85	14	11	21	310	179	16
T11a	5	107	34	289	21	0	7	103	22	8	10	282	267	17
T11b	6	108	38	296	20	0	8	87	16	7	7	277	259	25
T12a	5	107	25	297	20	6	13	91	35	4	5	336	268	13
T12b	6	110	28	296	18	0	8	91	28	6	9	284	244	14
T13a	6	98	44	290	17	0	7	98	17	5	7	294	236	23
T14a	6	98	26	294	17	0	11	86	23	11	8	287	237	12
T16a	6	99	82	290	18	5	13	95	22	8	6	289	221	57
T16b	6	96	43	291	14	0	8	91	27	9	7	280	227	32

Sample	Nb	Zr	Y	Sr	Rb	Th	Pb	Zn	Cu	Ni	Cr	V	Ba	La
T17a	6	98	50	293	16	0	10	97	18	0	7	287	236	36
T18a	6	83	22	270	14	0	8	91	29	13	19	299	157	6
T20a	6	105	23	389	20	7	11	80	27	8	14	270	341	18
T20b	6	109	26	392	18	4	10	86	28	11	15	298	356	19
T21a	7	107	23	386	18	5	10	88	30	13	15	291	346	19
T21b	5	104	25	388	14	5	12	90	20	9	13	273	419	21
T23b	7	100	26	270	20	0	7	98	36	10	10	347	211	9
T23c	6	100	25	266	19	6	8	97	33	8	5	351	206	12
T24a	6	86	22	271	13	6	12	92	29	15	22	304	170	6
T25a	6	105	24	391	17	5	14	89	25	15	14	284	353	18
T25b	6	100	26	266	19	0	8	97	25	9	5	340	218	10
T27d	6	98	33	291	14	0	10	94	29	7	10	291	231	18
T30a	5	107	28	382	14	6	12	88	35	10	15	260	364	25
T30b	6	106	24	391	15	0	10	86	27	13	12	278	334	18
W1	4	103	29	230	34	5	12	101	146	19	12	318	269	9
W3	3	104	32	236	40	0	12	109	36	11	10	377	318	13
X2	5	85	25	274	13	0	0	91	40	9	18	311	195	12
X3	6	109	27	341	18	5	0	100	32	0	5	303	302	19
X4	6	101	27	267	16	0	0	101	39	0	0	336	224	11
X5	5	100	26	279	13	0	6	104	39	0	4	443	223	10