GEOCHEMICAL TRAVERSE ACROSS HONDURAS

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ABSTRACT OF THE THESIS

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The distribution of volcanic fields in Honduras allows detailed across the arc geochemical studies. Samples collected in Honduras from three volcanic provinces, Zacate Grande, Tegucigalpa, and Lake Yojoa (30, 120, and 160 Km. away from the front respectively) were analyzed for major and trace elements, and Sr and Nd isotope ratios.

As part of this study a routine procedure was established to use an ICP-MS to determine abundance of trace elements on geological samples.

The geochemistry of the rocks from Honduras show differences among the three volcanic regions. At Zacate Grade, the area closest to the trench, lavas display LILE enrichment and HFSE depletion commonly thought to be the effect of the involvement of subducted material on the magma genesis process. Like most of the basalts from the Central American volcanic arc, these magmas can be the product of mantle modified by subducted material. The effect of subducted material is not seen in samples from Lake Yojoa. The alkali basalts from this region furthest from the trench, appear to derived from a MORB-source based on low Sr isotopic signature. Modest LREE/HREE ratios indicate that

the lavas from this region are the product of low degree melting of depleted mantle. Because the alkali basalts from Honduras indicate a depleted source without involvement of an enriched one, the mantle underneath this volcanic arc seems more heterogeneous than previously thought.

In most of the graphs representing geochemical parameters the samples from Tegucigalpa are intermediate between those of Lake Yojoa and Zacate Grande samples. Tegucigalpa samples are most likely the result of assimilation-fractional crystallization of material similar to the lavas from Lake Yojoa and some granitic crustal component, or material similar to Zacate Grande basalts and continental crust. The LILE and HFSE patterns for lavas from Tegucigalpa imply that subducted material could have been a component of the original melt of these magmas, but in less quantity than for volcanic front samples. The data from this research show that the magmas from the volcanic front might have migrated to back-arc regions, causing some geochemical similarities among the different volcanic fields.

ACKNOWLEDGEMENT

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

At convergent plate margins there are two regions where magma is extruded: the volcanic front and the back arc regions. Back arc volcanism is common in continental arcs but is usually volumetrically of minor importance. In contrast many island arcs have back arc basins, with rift zones and abundant volcanism like that of Mid-Ocean ridges (Saunders and Tarney, 1984; Ikeda and Yuasua, 1989; McCulloch and Gamble, 1991).

Central America volcanism, the result of convergence between the Caribbean and Cocos Plates (Fig. 1), occurs in two provinces: the volcanic front (VF) and behind the volcanic front (BVF) (Stoiber and Carr, 1973). The geochemistry of the aligned stratovolcanoes of the front has previously been determined (Carr and Rose, 1987). Carr et al. (1990) suggest that the sources of these lavas are mixtures in different proportions of depleted mantle, enriched mantle, subducted sediments and continental crust.

BVF volcanism in Central America occurs in scattered shield volcanoes and cinder cones behind breaks of the VF segments (Carr et al., 1979). The distribution of these centers is controlled by structural features that trend north-northeast, oblique to the volcanic front. Geochemical studies of some the BVF areas were carried out by Carr (1974), Walker (1981) and Patino (1990). However, not all of the BVF areas have been studied in detail and the relation between the BVF lavas, subducted material and

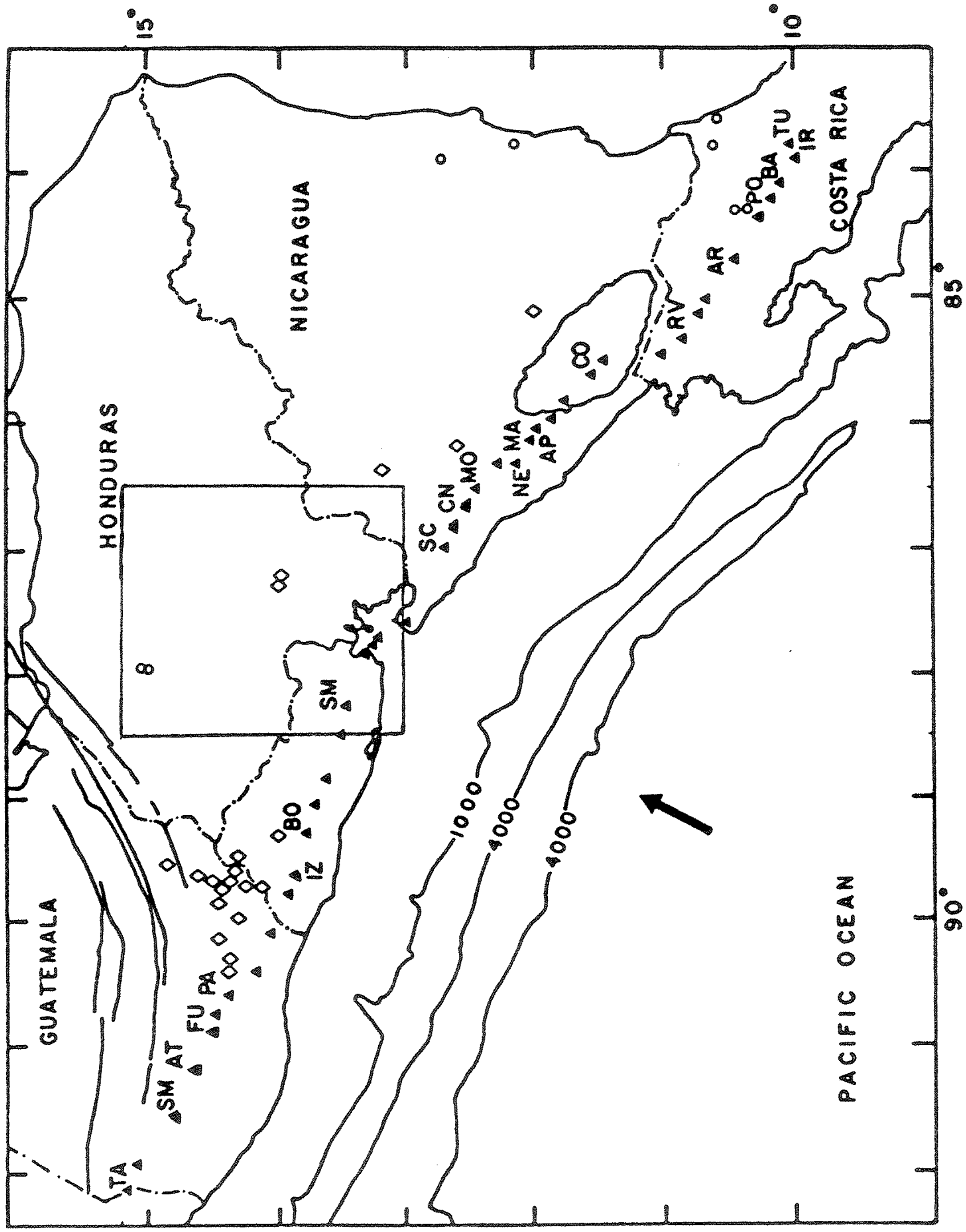


Fig. 1. Central America. Direction of convergence of Cocos-Caribbean plates given by the arrow. Triangles represent Volcanic Front centers. Diamonds mark Behind the Front Volcanic areas. Circles are alkaline volcanic centers. After Carr and Stoiber (1990). Box marks area in figure 2.

continental crust is not yet clear.

Volcanological studies of Honduras are scarce because there are no historically active volcanic centers. Nevertheless, Honduras is a good place to study cross arc volcanism because there is an alignment of volcanic fields that extends from the volcanic front back to the Caribbean. Forty-five samples were collected from the Quaternary volcanic centers behind the volcanic front in Honduras; from the Gulf of Fonseca (30 Km from the front) in the Pacific through Tegucigalpa (120 Km behind the arc), ending in the area of Lake Yojoa (160 Km away from the volcanic front) in the Northwest part of the country. The geographical distribution (Fig. 2) of the collected rocks is as follows: seven samples from Zacate Grande, a dissected basaltic andesitic volcano in the Gulf of Fonseca; twenty-five rocks from different lava fields near Tegucigalpa, and thirteen samples from cones and lava fields close to Lake Yojoa. The objective of this study is to analyze the geochemistry of these three volcanic fields to identify the materials from which the lavas originated and the magnitude of the involvement of depleted mantle, enriched mantle, subducted material and continental crust in the magma genesis process.

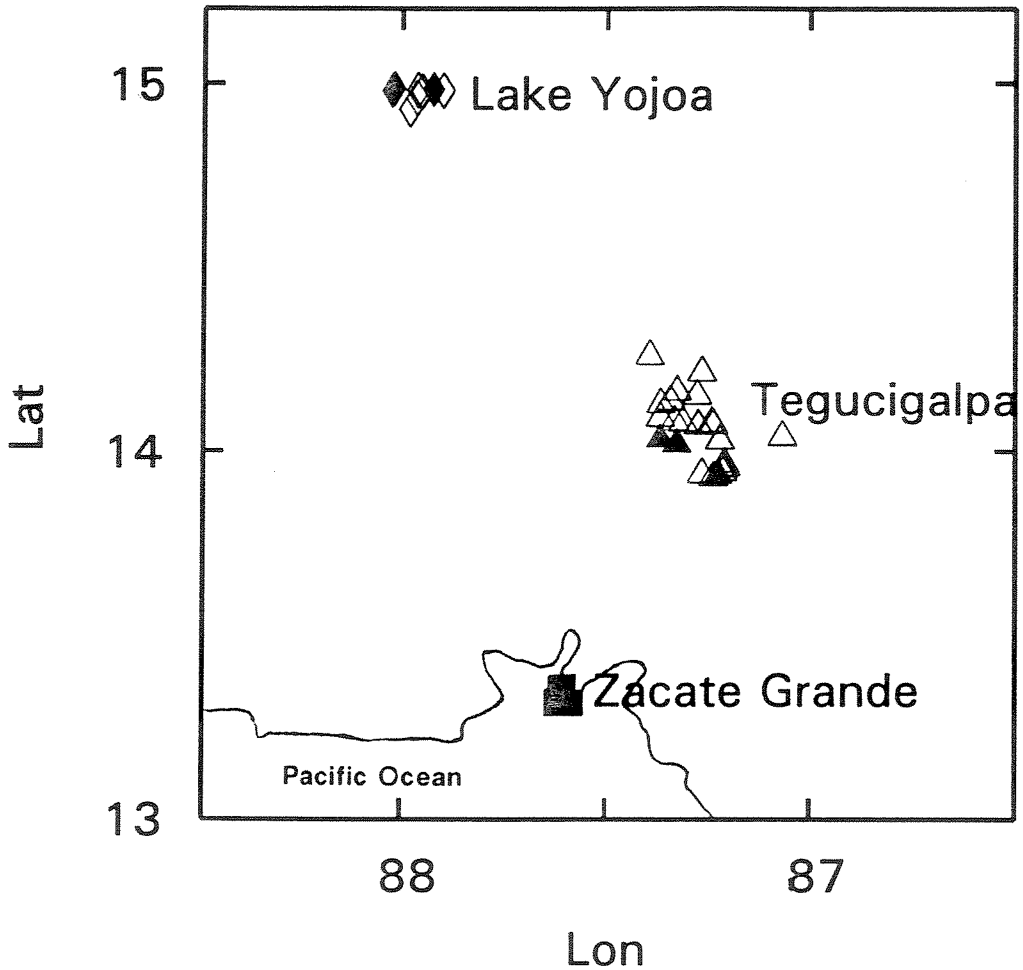


Fig. 2. Geographic distribution of samples.

II. BACKGROUND

A. HONDURAS QUATERNARY VOLCANIC FIELDS

Honduras lacks the large active Quaternary volcanic centers found in other Central America countries. The largest volcanoes in Honduras are in the Gulf of Fonseca, a few kilometers behind the break between the volcanic front of El Salvador and Nicaragua (Williams and McBirney, 1969). Other Quaternary volcanoes in Honduras are distributed in clusters in Tegucigalpa, Lake Yojoa, the Sula Graben and in Utila Island, the Gulf of Honduras in the Caribbean (Williams and McBirney, 1969). The grouping of Quaternary volcanic fields in Honduras is controlled by a system of northeast and northwest trending faults and fractures. Similar tectonic patterns are observed in Guatemala where grabens trending north-south control the distribution of volcanic fields in the area near Ipala. The faults in Honduras are accompanied by parallel fractures that do not have vertical displacements, and are made observable only by river courses and alignments of Quaternary volcanoes (Williams and McBirney, 1969). The faults seem to have formed around the same time or before Quaternary volcanism started due to the regional arching of mainland Honduras (Williams and McBirney, 1969).

B. GEOCHEMISTRY OF BACK-ARC LAVAS

BVF lavas from different arcs are enriched in large ion lithophile elements (LIL) compared to high field strength

(HFS) elements; they have high $^{87}Sr/^{86}Sr$ ratios, and light rare earth element (LREE) enriched patterns (Price et al., 1992; Kienle et al., 1980; Tatsumi et al., 1992). At Egmont Volcano, behind the Taupo Volcanic zone (New Zealand), Price et al. (1992) observed a pattern similar to arc lavas, that is, a strong depletion of Nb and a large peak in Sr. Lavas enriched in LIL relative to HFS elements from BVF are assumed to be the result of involvement of slab-derived material in the genesis of the magmas that erupt in these areas (Price et al., 1992; Davidson, 1987). Nevertheless, not all the BVF samples exhibit LIL enrichment relative to HFS. BVF samples from the Tonga and Cascades arcs and BVF alkali basalts from Izu-Bonin arc lack Nb depletion, and the Sr peak is small or absent (Ewart and Hawkesworth, 1987; Donnelly-Nolan et al., 1991; Leeman et al., 1990; Tatsumi et al., 1992).

Another contrasting feature of back arc lavas from different arcs is the REE patterns. Samples from the behind the front of the Izu-Bonin (Tatsumi et al., 1992), Taupo arcs (Price et al., 1992) and an evolved basalt from Crater Lake (Donnelly-Nolan et al., 1991) show enriched REE patterns, that is La/Yb > 1 (chondrite normalized). However, samples from the back arc of the Tonga arc, Niua fo'ou Island (Ewart and Hawkesworth, 1987), and a primitive sample from Crater Lake (Donnelly-Nolan et al., 1991) have depleted REE patterns. The different authors conclude that the REE patterns are governed by the degrees of melting, the pressure at which melting occurs, and the type of material that melts. Enriched REE patterns can result from small percentage melting of depleted mantle (DM) or any degree of melting of enriched mantle (EM). In the examples cited above, the authors indicate that enriched LREE patterns are caused by low degree melting at high pressures of an enriched source (Price et al., 1992; Tatsumi et al., 1992). Alternatively, crustal assimilation (Donnelly-Nolan et al., 1991) may be the cause in some areas such as in the Cascades.

Isotope ratios of erupted lavas can be used as indicators of source material. $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotope ratios for some back arc areas are reported in the literature (Tatsumi et al., 1992; Price et al., 1992; Ewart and Hawkesworth, 1987; Hawkesworth et al., 1977; and Davidson, 1987). The samples vary from high $^{143}Nd/^{144}Nd$ - low $^{87}Sr/^{86}Sr$ (Izu-Bonin Arc and Lesser Antilles) along the mantle array to low $^{143}Nd/^{144}Nd$ - high $^{87}Sr/^{86}Sr$ (Niua fo'ou Island, Egmont Volcano, and Lesser Antilles) ratios, off the mantle array. Different authors have different interpretations for the increase of strontium isotope ratios. Davidson (1987) argues that in the case of the Lesser Antilles the isotope signal is influenced by crustal contamination. On the other hand, Price et al. (1992) indicate that the isotope values of Egmont Volcano result from the involvement of slab material in the original melt.

In conclusion, the most common view is that most of the back arc lavas are the product of high pressure, low degree melts and that the possible source of the melt is a mixture of some or all the following components: depleted mantle, enriched mantle, slab material, and in the case of continental arcs, continental crust.

III. ANALYSIS

Samples were taken from the cores of large boulders (usually 10 cm. inside the outer surface), crushed and powdered in a tungsten carbide mill. Major and some minor elements (Ba, Sr, V, Cr, Ni, Zr, Sc, and Cu) were done by atomic emission spectrometry in a direct current plasma spectrometer, SMI III DCP-AES, following Feigenson and Carr (1985). Rare earth elements and other trace elements (Rb, Nb, and Y) were analyzed by inductively coupled plasma mass spectrometry, VG Plasma Quad II ICP-MS, in the Chemistry department. I decided to take advantage of the of ICP-MS and analyze for some trace elements because of the low detection limits the instrument has for a wide range of elements. Strontium and neodymium isotopes were analyzed by M. Feigenson in the thermal ionization mass spectrometer, of the Geology department.

A. SAMPLE PREPARATION

Two common techniques to prepare rocks for wet chemical analysis are acid attack and fluxing. The acid attack has the advantage of dissolving the sample quickly by adding and evaporating different ratios of several types of acids. However, most of the time the acids used volatize silica and therefore the SiO_2 percentage can not be determined. Fluxing rocks is an easy and safe method to completely dissolve the sample. This procedure requires the addition of $LiBO_2$ to reduce the melting temperature of the minerals that make up the rock. However, a major disadvantage of this method is that the concentration of solids in the final solution is very high.

Taking into account the advantages and disadvantages described above, two sample preparation techniques were done in the course of this study, one for solutions to be analyzed in the DCP and another for solutions to be used in the mass spectrometers. $LiBO_2$ fluxing was used to prepare the samples for analysis in the DCP by which I determined the percentage of major element oxides and the concentration of some trace elements. The large amounts of solids in this solution prevent the ICP-MS from a good performance because as the cone gets dirtier the intensity of the signal decreases. Table 1 contains the averaged results of 3 runs in the ICP-MS of two solutions of IZ (our in-house rock standard from Irazu Volcano, Costa Rica) prepared by fluxing and acid attack diggestion. It is clear from the percentages of the standard deviations that the acid attack method is more suitable to prepare samples to be analyzed in the ICP-MS. The percentages of standard deviations of most of the twenty-four elements are less than 10%. The

TABLE 1

PRECCISION AND ACCURACY OF ICP-MS USING DIFFERENT PREPARATION TECHNIQUES

	REF*	$LiBO_2$ Flux		Acid Attack	
		Avg of 3	% stdev	Avg of 3	%stdev
Rb	49	41.34	10.83	48.39	2.09
Sr	790	705.16	9.50	816.90	3.31
Y	21.5	18.40	14.08	23.08	3.44
Zr	176	155.35	8.47	170.34	0.80
Nb	20.1	16.58	7.66	20.08	1.73
Cs	0.733	0.90	3.91	0.70	14.25
Ba	782	845.82	2.90	760.66	1.20
La	40.7	50.67	3.82	41.03	0.39
Ce	77.1	80.22	4.73	75.52	0.25
Pr	8.33	8.95	4.20	8.03	2.34
Nd	34.9	40.13	6.10	34.54	6.74
Sm	6.25	7.16	13.32	6.12	7.84
Eu	1.58	1.86	7.68	1.67	15.06
Gd	5.05	6.09	0.68	5.19	2.30
Tb	0.699	0.77	10.47	0.69	2.66
Dy	3.99	4.15	10.08	3.72	8.48
Ho	0.714	1.06	21.25	0.78	5.03
Er	2.2	3.33	18.45	2.13	6.35
Yb	1.8	2.19	10.45	1.45	6.55
Lu	0.188	0.20	11.82	0.15	12.10
Hf	4.8	6.05	10.02	4.22	4.26
Pb	7.75	37.55	10.71	6.49	6.27
Th	10.1	12.56	13.46	9.83	4.85
U	3.57	3.31	5.81	4.01	5.14

* Feigentson and Carr (1985)

exceptions are Cs and Eu for which percentages are up to 15%. In addition, elements that are in low concentrations in solution tend to have higher percentages of the standard deviation because their concentrations in solution are close to the detection limits of the instrument. After comparing the results of fluxing and acid attack digestion, the latter method was used to prepare the samples for the mass spectrometers (ICP-MS and MS).

B. DCP-AES

The samples were run and the results calculated following the procedure that Feigenson and Carr (1985) describe. The sample preparation for the solutions to be measured in the DCP was done as follows: 0.1 g of sample powder was mixed with 0.4 g of $LiBO_2$, and the mixture was fluxed at 1000°C for 10 minutes. The fluxed material was dissolved in 50 ml of 4% nitric acid; minor elements were examined on this stock solution in the DCP-AES. For major elements, 5 ml were taken from the stock solution and diluted with 50 ml of 2% nitric acid; then the solution was analyzed by DCP-AES.

C. ICP-MS

The Chemistry department recently obtained an ICP-MS and as part of this project on Honduras rocks I developed a routine procedure to use the mass spectrometer to analyze geological samples. The basic parts of the procedure have been established (sample preparation, sample intake and instrumental conditions), but there still remain some details that need to be worked out depending on the elements and rock types to be analyzed.

An inductively coupled plasma mass spectrometer has the advantage of being able to analyze very quickly low concentrations of a wide range of elements. It takes approximately 2 hours to determine 24 elements in 25 samples. In addition, the amount of sample required is very small: 0.1 g. of sample in a final volume of 30 ml. The volume needed to run the sample in the instrument usually is about 10 ml. This volume varies depending on the auto sampler conditions: pump rate, uptake time, and number of repeats desired.

Nevertheless, running geological samples on this type of instrument is not problem free. The major difficulties are matrix effects, drift, spectral interferences, and memory (Longerich et al., 1990; and Jarvis, 1990). Matrix effects alter the detection limit of an element and the effects are influenced by the amount of dissolved solids, concentration of acids, and operating conditions. In whole-rock analysis it is almost impossible not to have matrix effects, but I minimized them by: analyzing the same type of rocks, the use of internal standards, low solid levels in the solution, and consistent operating conditions in the sample preparation and runs.

Drift in an element signal with time, usually drift down, is unavoidable because of the deteriorating operating conditions of the instrument as the run proceeds. I ran two samples (low standard and high standard) after four unknowns to monitor how the signal intensity for the different elements drifted from the begging to the end of the procedure. To correct for drift I used internal standards and computer programs.

Spectral interferences among elements and their oxides, hydroxides, chlorides, hydrides and fluorides are common problems when determining some elements in geological samples (Longerich et al., 1990; and Jenner et al., 1990). The intensity of the interference changes with time and is matrix dependent. Selecting isotopes of different masses for different elements is enough to avoid isobaric interferences. However, for the REE the major interferences are not isobaric but oxide interferences. I tried to determine what percentage of the signal in a given mass would be produced by an oxide and how much by an REE isotope. For this experiment I prepared two solutions: one contained known concentrations (similar to what I expect to find in the samples) of the elements that form oxides that interfere with REE isotopes; the second solution contained known amounts of the REEs whose isotopes had interference problems with oxides of other elements. I found that the oxides had little influence on the signal of a given REE isotope. It has been documented that adequate operating conditions, such as gas flow and nebulizer flow, help to reduce oxide interferences on the REE (Ruiz, personal communication). However, it must be taken into account that rocks have a matrix effect that affects the intensity of interferences.

The sample digestion for the mass spectrometers was done following Albrecht et al. (1991) (appendix 1), with the modification that I did not use bomb digestion but rather open beaker. I did not find major differences between the results from both techniques (Table 2), but the open beaker digestion was faster and less expensive. One hundred milligrams (0.1 g) of sample powder was treated with different acids and after several evaporation steps (HF, $HF+HClO_4+HNO_3$, $HClO_4$, $HClO_4$, HNO_3, HNO_3) the sample was taken up in 2.5 ml of 20% nitric acid and then diluted to 5 ml. This solution was split: 2.5 ml for isotope (Sr and Nd) analysis and the remainder for trace element analysis in the ICP-MS. A dilution factor of 5000 was calculated so that the most abundant isotope to be measured (Ba) would not have a concentration greater than 200 ppb in solution and to avoid having large amounts of solids injected into the ICP-MS. Three hundred microliters (0.3 ml) of the solution containing dissolved sample were diluted to 30 ml with a solution of 2% nitric acid that had 50 ppb of Mo, In, and Bi used as internal standards. The addition of internal standards is recommended by reasearchers who work with the ICP-MS (Longerich et al., 1990; Jenner et al., 1990; and Jarvis, 1990). The selected elements should be such that

TABLE 2

BOMB vs. OPEN BEAKER DIGGESTION FOR BCR-1

PPM Int. stds	REF	BOMB In +Bi	OPEN In +Bi
Rb	47.2	47.5	44.2
Sr	330	327.8	324.4
Y	38	37.4	34.3
Nb	14	10.6	14
Cs	0.96	0.7	0.8
Ba	681	664.2	672.3
La	24.9	24.5	25.3
Ce	53.7	50.7	52.1
Pr	6.8	6.3	6.9
Nd	28.8	29.5	30.8
Eu	2	1.8	1.7
Sm	6.6	5.6	6.2
Gd	6.7	5.9	6.3
Tb	1	1.1	1
Dy	6.3	5.8	6
Er	3.6	3.2	3.3
Yb	3.4	3.2	3.2
Lu	0.51	0.4	0.5
Hf	4.9	4.4	4.7
Pb	13.6	13.4	9.7
Th	6	5.3	5.4
U	1.75	1.8	1.7

REF values are from Govindaraju (1989).

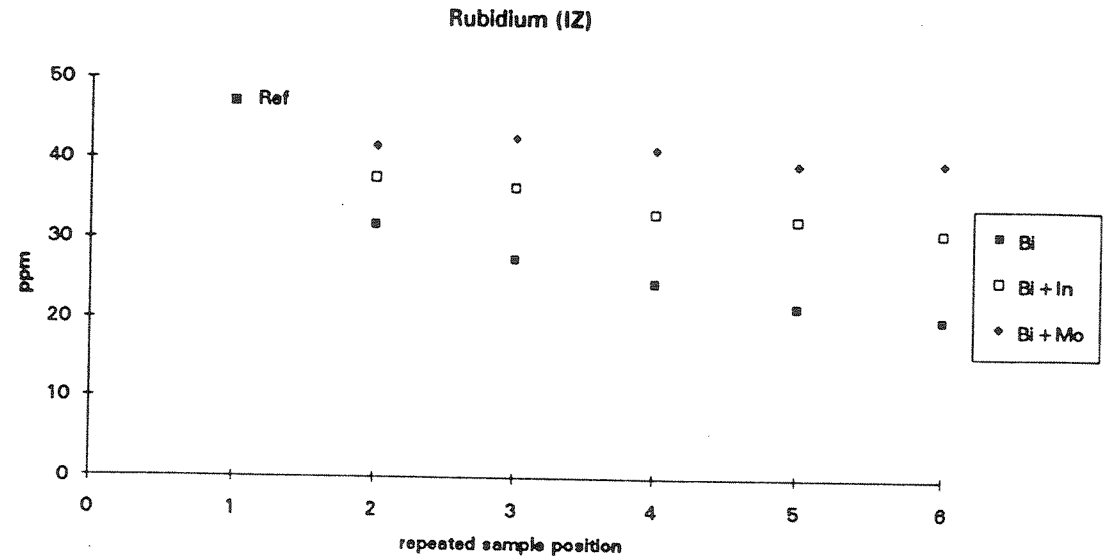
they are not very abundant in the samples and have few isotopes. The sample solutions contained 50 ppb of Mo, In, and Bi that were used as internal standards in the ICP-MS to correct for drift. Three internal standards were used because of the large range of masses (85 to 238 amu) to be scanned, so I selected elements of small (Mo), intermediate (In) and large (Bi) masses. Figure 3 shows the results for Rb, Cs, and U when using one, two and three internal standards. For Rb any run without Mo represented larger deviation from the reference value. Indium helped the Cs value to be closer to the reference value. Finally, Uranium was always the same because Bi was included all the time. After comparing results with one, two and three internal standards, I concluded that to obtain the best results for the set of 24 elements, with a wide range of masses, the solutions to be analyzed must have three internal standards. Thus the drift corrections were based on masses that were distributed throughout the scanned masses.

The ICP-MS operating parameters are listed in table 3. I tested running samples without washing with clean 2% nitric acid in between samples, but the drift of the signals of the internal standards was larger than 70% (Fig. 4 and 5) making the results inaccurate. In figure 4 I also observed that after running the blank (after six samples) the intensity of the signals increased. The samples were run twice to allow the signal to be more stable and to get

TABLE 3

PLASMAQUAD OPERATING PARAMETERS

PLASMA	
Forward rf power	1350 W
Reflected rf power	<2 W
Coolant flow (Ar)	13 L/min.
Nebulizer flow (Ar)	1 L/mime
Spray chamber temperature	controlled at 2 +/- 0.2°C
Nebulizer	Meinhard concentric
Sampling depth	12 mm beyond load coil
MASS SPECTROMETER	
Sampler, Ni	1.0 mm orifice (Nicone)
Skimmer, Ni	0.75 mm orifice (Nicone)
Interface operating pressure	1.9 mbar
Analyzer pressure	2.5 E-6 mbar
DATA ACQUISITION	
Mass range	84.91 to 240.94
Number of channels	2048
Number of sweeps	100
Collector	Pulse
Dwell time (µs)	320
Uptake time (sec.)	60
Acquisition time (sec.)	60
Rinse time (sec.)	40
Skipped mass regions	122.5-132.5 & 133.5-136.5



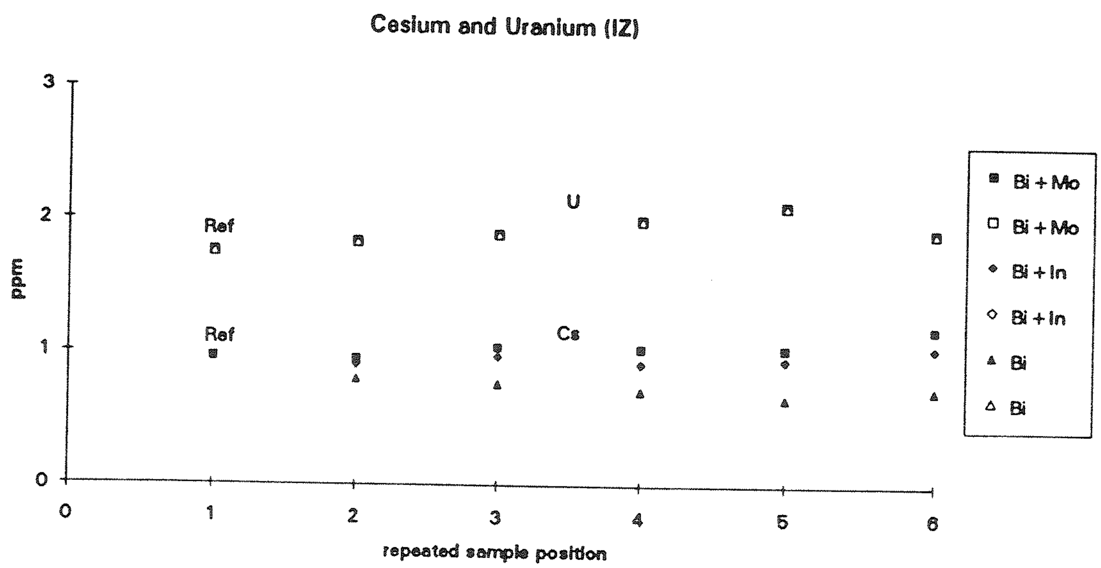


Fig. 3. Variation of the Cs, Rb, and U concentrations in the ICP-MS depending on the use of different internal standards .

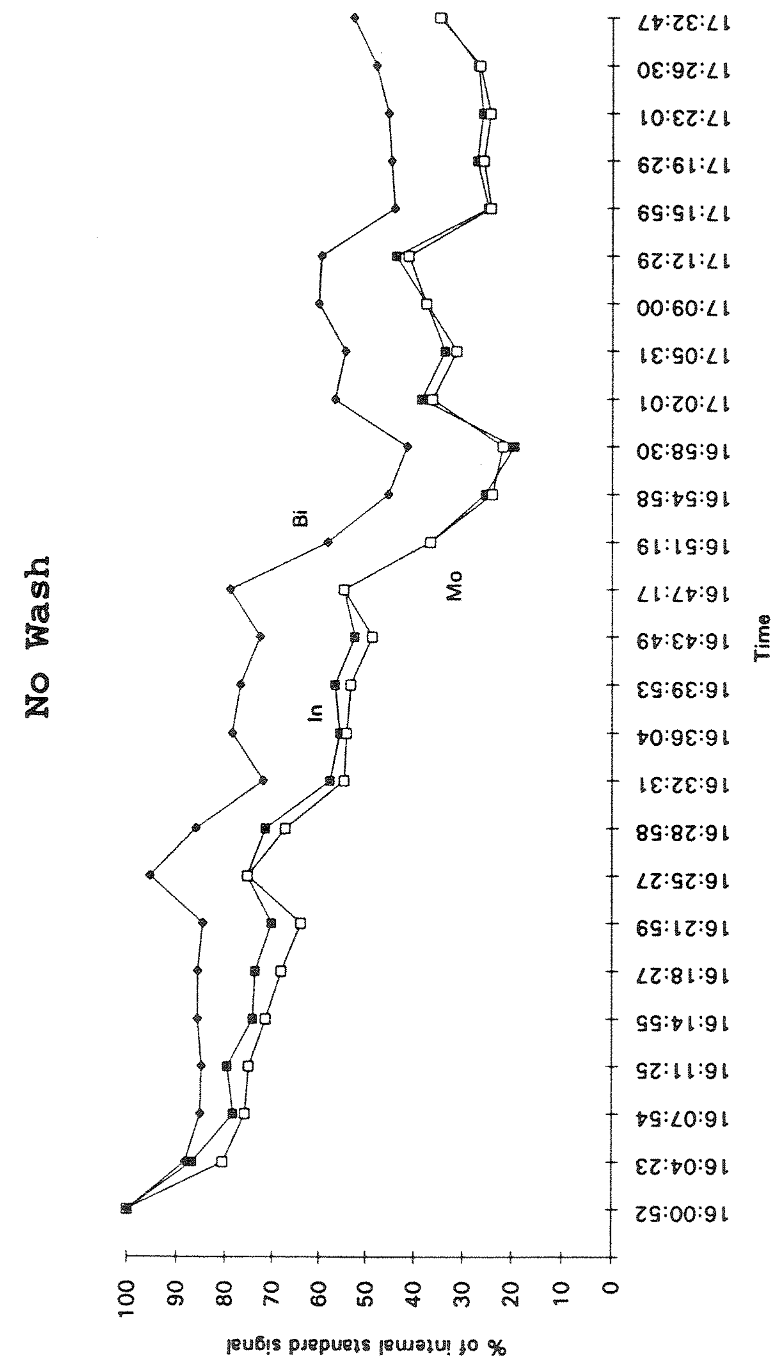


Fig. 4. Drift of the signal of elements used as internal standards (In, Mo, Bi) through the course of a run in the ICP-MS when no rinse was used in between samples

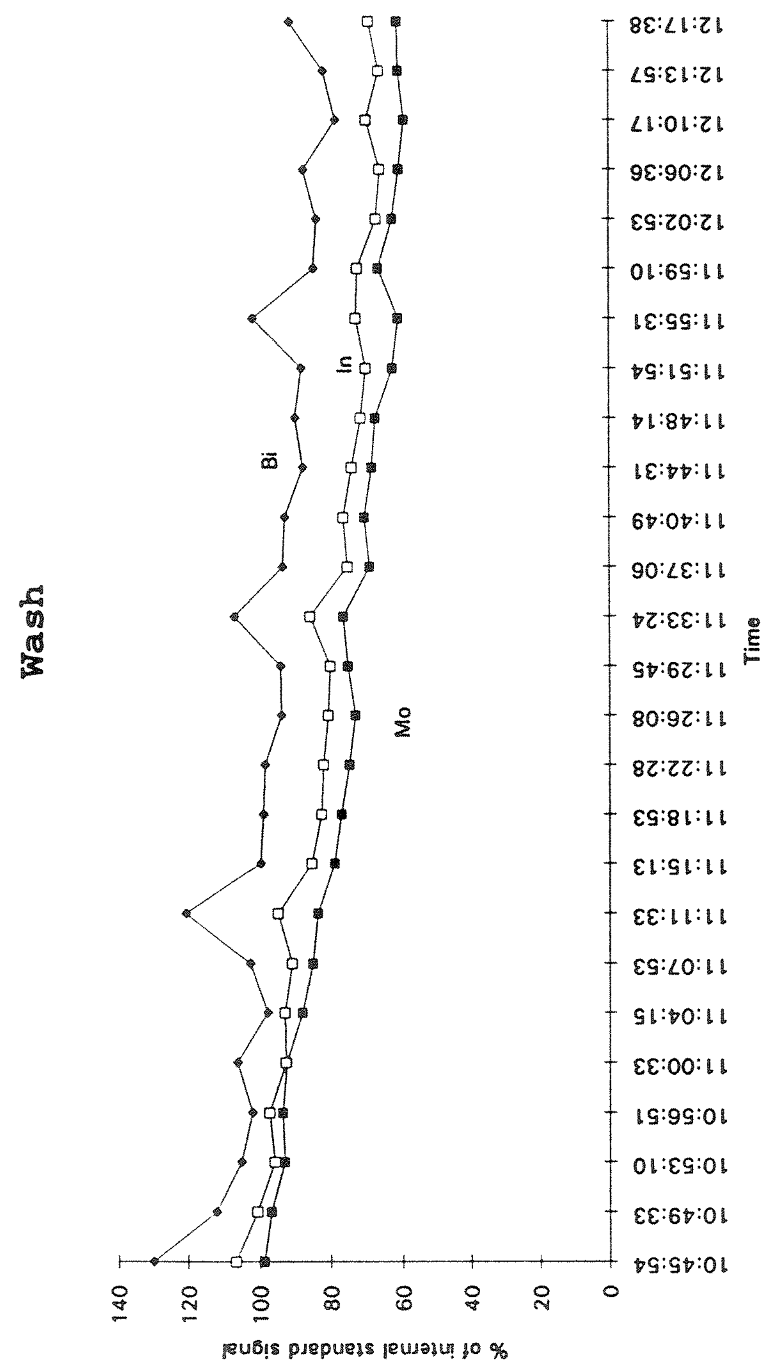


Fig. 5. Drift of the signal of elements used as internal standards (In, Mo, Bi) through the course of a run in the ICP-MS when clean acid was used as rinse in between samples.

better statistics. The concentrations were based on an in-house standard (IZ); USGS standards were run with the samples to check sample preparation, run conditions, and the calculation of concentrations. Appendix 2 gives the reference values and concentrations obtained for USGS standards run in the ICP-MS in the course of this research.

Although the ICP-MS software corrects for drift based on the internal standards, Jarvis (1990) suggests monitoring for signal drift based on running a standard solution frequently. In our study the results from the ICP-MS were run through a drift correction program written by Carr, the objective being to correct for drift based on two solutions (blank and the in-house standard, IZ) that were run after every set of four samples; this is what Longerich et al. (1990) call external calibration.

IV. RESULTS

Appendix 3 contains the chemical results of the samples analyzed in the course of this research. Basalts and andesitic basalts (SiO_2 range from 45 to 55%) from Zacate Grande, Tegucigalpa, and Yojoa are considered in the following descriptions of major and trace elements. Samples with higher silica content were not taken into account because of the effect that fractionation has on the concentration of some elements. However, in the description of isotopes all samples were considered because isotopes are not affected by fractionation but by mixing. In the diagrams of geochemical data the following symbols are used: filled boxes (Zacate Grande with Ba/La > 60), open boxes (Zacate Grande with Ba/La < 50), open triangles (Tegucigalpa with steep REE pattern), filled triangles (Tegucigalpa with flat REE pattern), open diamonds (Lake Yojoa, $TiO_2 > 2.5$) filled diamonds (Lake Yojoa, $TiO_2 < 2.1$).

A. MAJOR ELEMENTS

1. *Zacate Grande*: The SiO_2 and alkali (Na_2O+K_2O) content of the samples categorize them as subalkaline (Fig. 6). A more precise description of the rocks can be made using Miyashiro's (1974) classification based on MgO vs. Fe/Mg. According to this scheme the Zacate Grande samples are considered mostly tholeiites, except for Za2 which is calc-alkaline. In Fenner diagrams (MgO ranges from 2.85% to 5.44) (Fig. 7), the samples from this area display interesting patterns especially regarding SiO_2 and K_2O. The sample with the highest MgO has the highest content of silica and potassium, i.e. the oxides increase with increasing contents of MgO. This is an opposite trend to the one expected to be produced by fractionation. A positive correlation of MgO and SiO_2 and K_2O can be explained if the lavas are not only the product of fractionation but also of mixing among different sources. The extremes of the two processes, fractionation and mixing, are represented by samples Za6 and Za2. Sample Za6 has the lowest MgO, SiO_2, and K_2O, and the highest Al_2O_3 and CaO.

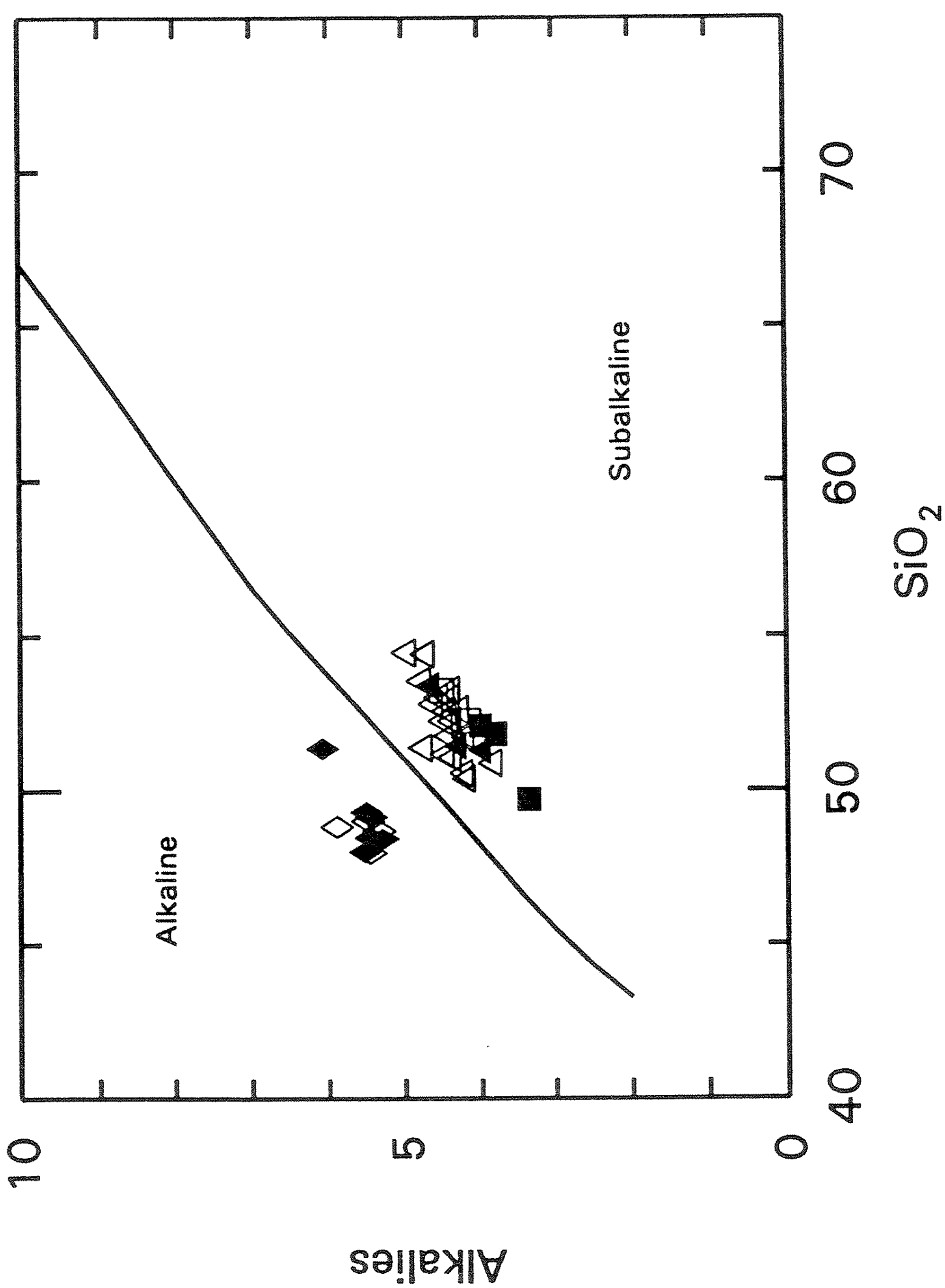


Fig. 6. Classification of basaltic rocks from Honduras. Samples from Zacate Grande (boxes) and Tegucigalpa (triangles) are subalkaline but samples from Lake Yojoa (diamonds) are alkaline. The three areas have distinct alkali content for a given SiO_2 content.

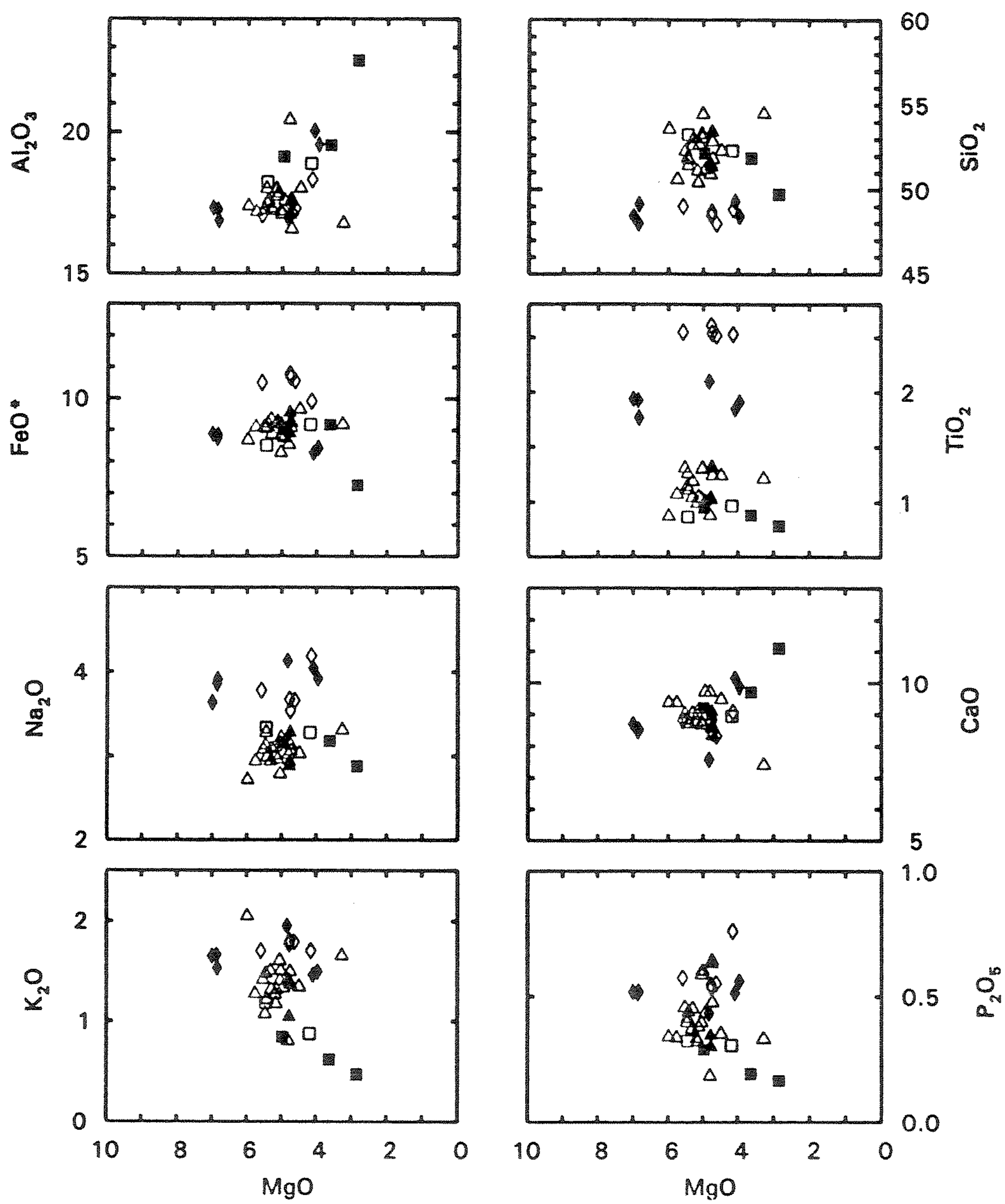


Fig. 7. Fenner variation diagrams of samples with SiO_2 between 45% and 55%. Samples from Zacate Grande (boxes) and Tegucigalpa (triangles) cluster separate from Lake Yojoa (diamonds).

In contrast, Za2 has the highest percentage of MgO, SiO_2, and K_2O, and the lowest amount of Al_2O_3 and CaO, representing a mixing end member; this combination can only be generated by mixing a mafic source with a source rich in silica and potassium.

2. *Tegucigalpa*: The rocks from the Tegucigalpa area are subalkaline based on their sodium, potassium, and silica contents (Fig. 6). However, the lavas from Tegucigalpa have higher concentrations of K_2O than those from Zacate Grande. The MgO content of these tholeiites varies from 3.3 to 6%. The sample with the lowest MgO (Honc114) also has the lowest CaO, and highest SiO_2, indicating clinopyroxene and olivine fractionation. As in rocks from the Zacate Grande area, effects of mixing can be observed. Honc118, a calc-alkali lava, has high contents of MgO, SiO_2, and K_2O, a discrepancy that can be explained if mixing is one of the mechanisms by which the magma was generated.

3. *Lake Yojoa*: By far the most distinctive rocks of the three groups are the lavas of Lake Yojoa. The samples are alkali basalts (Fig. 6); their high sodium, potassium, and low silica contents for a given MgO value (Fig. 7) distinguish them from samples from Zacate Grande and Tegucigalpa. In addition, the TiO_2 concentrations of samples from Lake Yojoa are the highest of the studied regions. Within this set of samples, there are two

subgroups, one with a concentration of TiO_2 less than or equal to 2.1%, and the other with values greater than 2.5%.

B. TRACE ELEMENTS

1. *Zacate Grande*: Zacate Grande samples show a positive correlation of K (ppm) with Rb, Ba, Cr, Zr, Nb, and La (Fig. 8). The Rb and Ba concentrations of lavas from Zacate Grande are similar to those from other Central American volcanic front samples (Carr et al., 1990) and lavas from Egmont Volcano, Taupo Volcanic Zone (Price et al., 1992). The Nb contents of samples from Zacate Grande are similar to other Central American VF rocks, mainly samples from Guatemala, El Salvador, and low Ti lavas from Nicaragua (Bennett, 1990).

2. *Tegucigalpa*: The trace elements for samples from the Tegucigalpa area are very scattered compared to the distribution of major elements. Two samples that illustrate this behavior are Honc114 and Honc118. These two samples have in common their high K, Rb, and Ba concentrations. However, Honc118 has higher Cr, and lower Nb and La than Honc114. The apparently mixed sample, Honc118, is also evident in trace element diagrams.

3. *Lake Yojoa*: Samples from Lake Yojoa are distinguished from Zacate Grande and Tegucigalpa by their lower Rb, Ba, and Cu, and by their higher Zr and Nb. Sample Yo4, the most

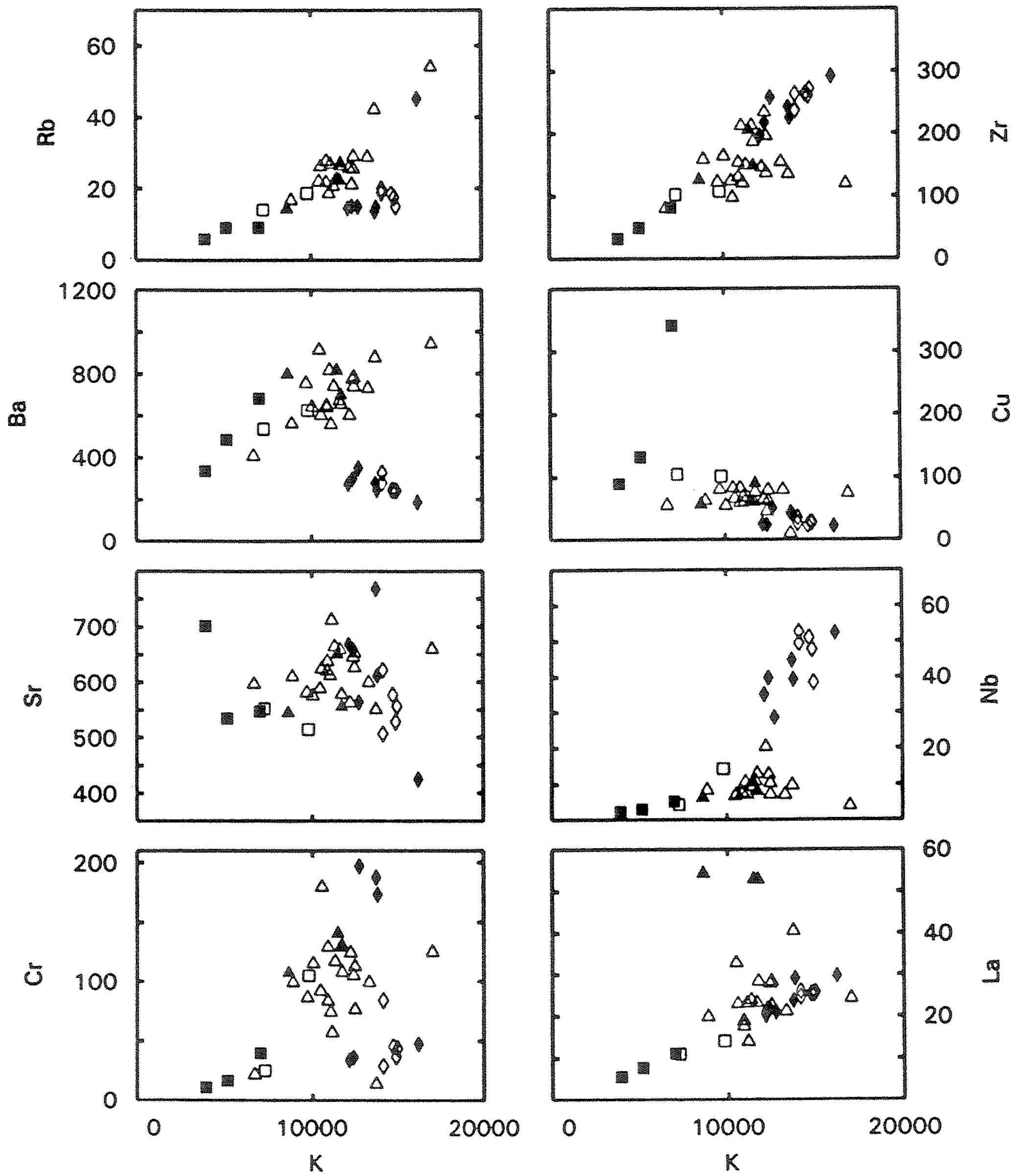


Fig. 8. Variation of trace elements. Potassium (ppm) vs. selected trace elements (simbols as in Fig. 7).

fractionated of the samples from Lake Yojoa, has high concentrations of K, Rb, and Nb, and low concentrations of Ba and Sr. The samples with the highest TiO_2 (open diamonds) have slightly higher K, Rb, and Zr than those with lower titanium, except Yo5.

C. RARE EARTH ELEMENTS

All the samples display enriched rare earth element patterns, La/Yb > 1 (chondrite normalized)(Fig. 9). The La/Yb ratios for Zacate Grande samples are the lowest (4.6-6.6), those for Yojoa the largest (6.7-11.6) and the La/Yb ratios for Tegucigalpa samples are intermediate (6.0-9.5). In addition, cerium anomalies were observed in samples from all three regions.

Three samples from Tegucigalpa (Honc104, Honc121, Honc122) will not be considered in the discussion because their Yb concentrations are greater than 6 ppm, making their REE patterns flatter. The flat REE patterns indicate that the lavas were affected by weathering (Humphris, 1984).

D. ISOTOPES ($^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$)

1. *Zacate Grande*: The $^{87}Sr/^{86}Sr$ ratio varies from 0.703703 to 0.703881, and the $^{143}Nd/^{144}Nd$ ranges from 0.512921 to 0.513023 (Fig. 10). The values are intermediate between the values from Tegucigalpa and Lake Yojoa. The Zacate Grande lavas display a positive correlation between Sr and Nd isotope ratios, like other Central American volcanic front

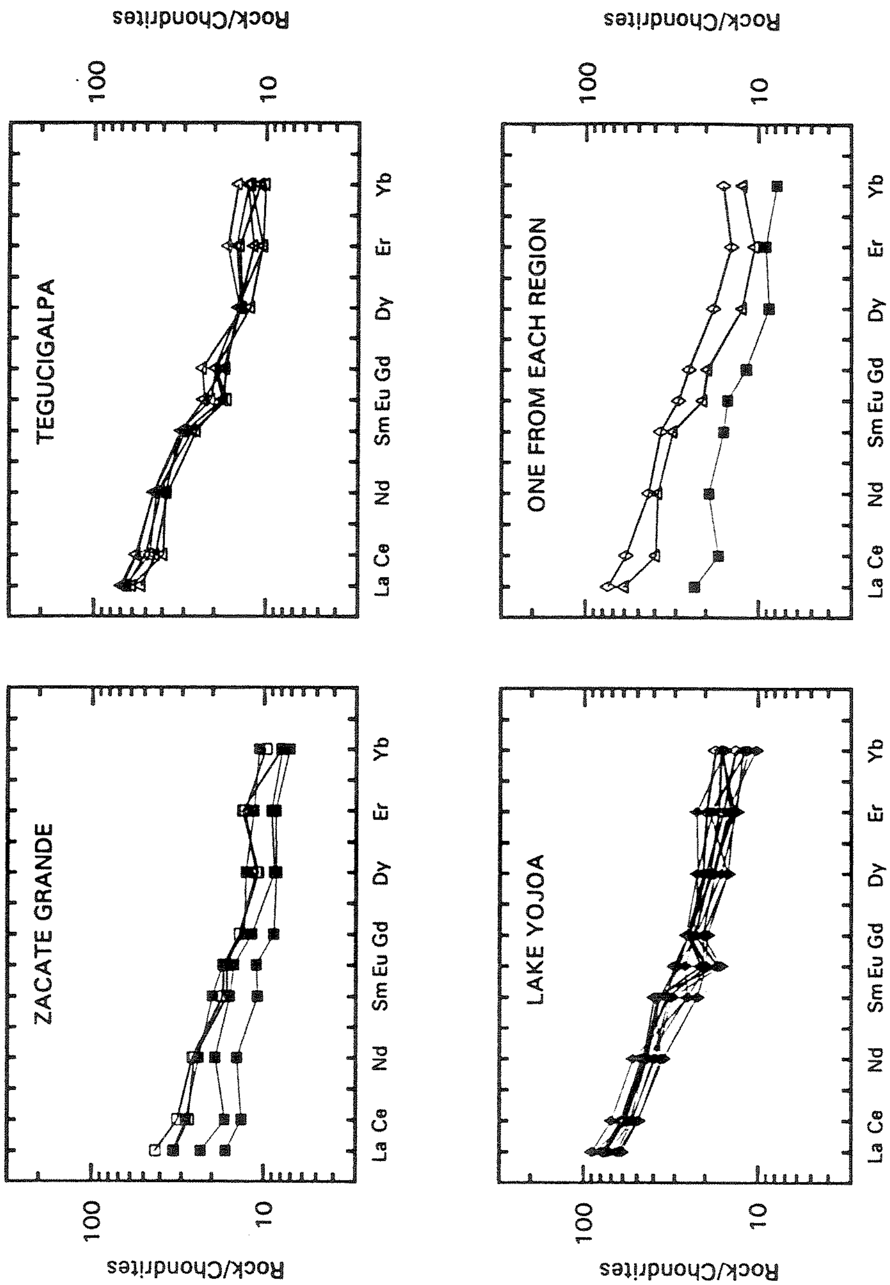


Fig. 9. Chondrite-normalized Rare Earth Element plots for selected samples. All the samples are LREE enriched. The slope of the pattern increases with distance away from the trench.

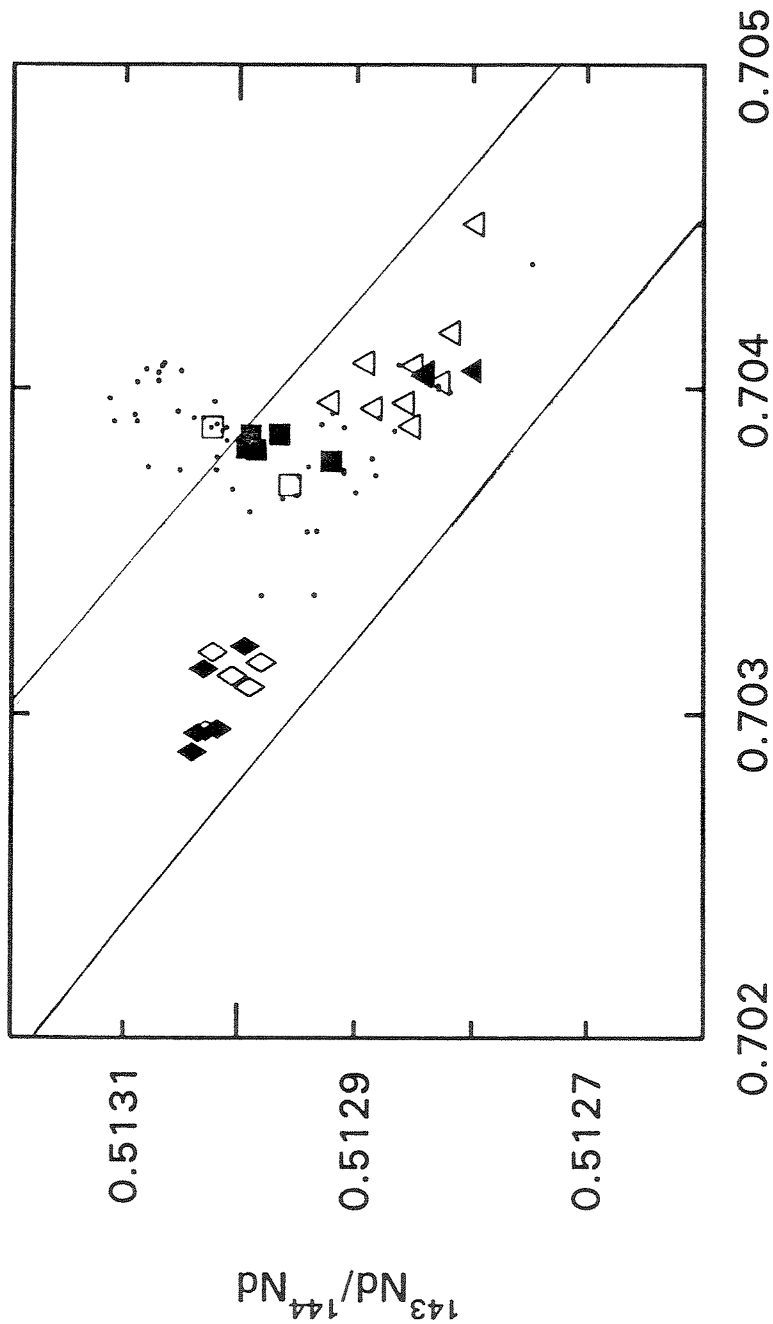


Fig. 10. Sr and Nd isotope variations. The area between the lines represents the mantle array. Dots are samples from other volcanic areas in Central America.

samples.

2. *Tegucigalpa*: The $^{87}Sr/^{86}Sr$ (0.703956 to 0.704509) and the $^{143}Nd/^{144}Nd$ (0.512797 to 0.512891) ratios of these lavas plot on mantle array, with high Sr isotope ratios and low Nd isotope ratios. Lavas from Guatemala VF and BVF, and Egmont Volcano have similar isotope ratios.

3. *Lake Yojoa*: The samples from this region have isotope ratios that trend along the mantle array. Sr isotope values (0.702884 to 0.703207) are the lowest of the studied regions, in fact the ratios are the lowest of the entire Central American arc; and the ratios of the Nd isotopes (0.51298 to 0.51304) are the highest of the three volcanic fields studied.

V. DISCUSSION

In a traverse across the volcanic fields in Honduras there are no abrupt breaks in the concentrations of most elements, but rather a continuum among the three regions which may indicate that magma from one region migrates into the next and mixes with the "local" magma to some extent. There is a gradational change in Ba/La and HFSE with latitude, that is distance away from the front (Fig. 11). Alternatively, there is a gradual change in processes.

Ba/La ratios decrease with distance away from the volcanic front. Samples from Zacate Grande have the highest

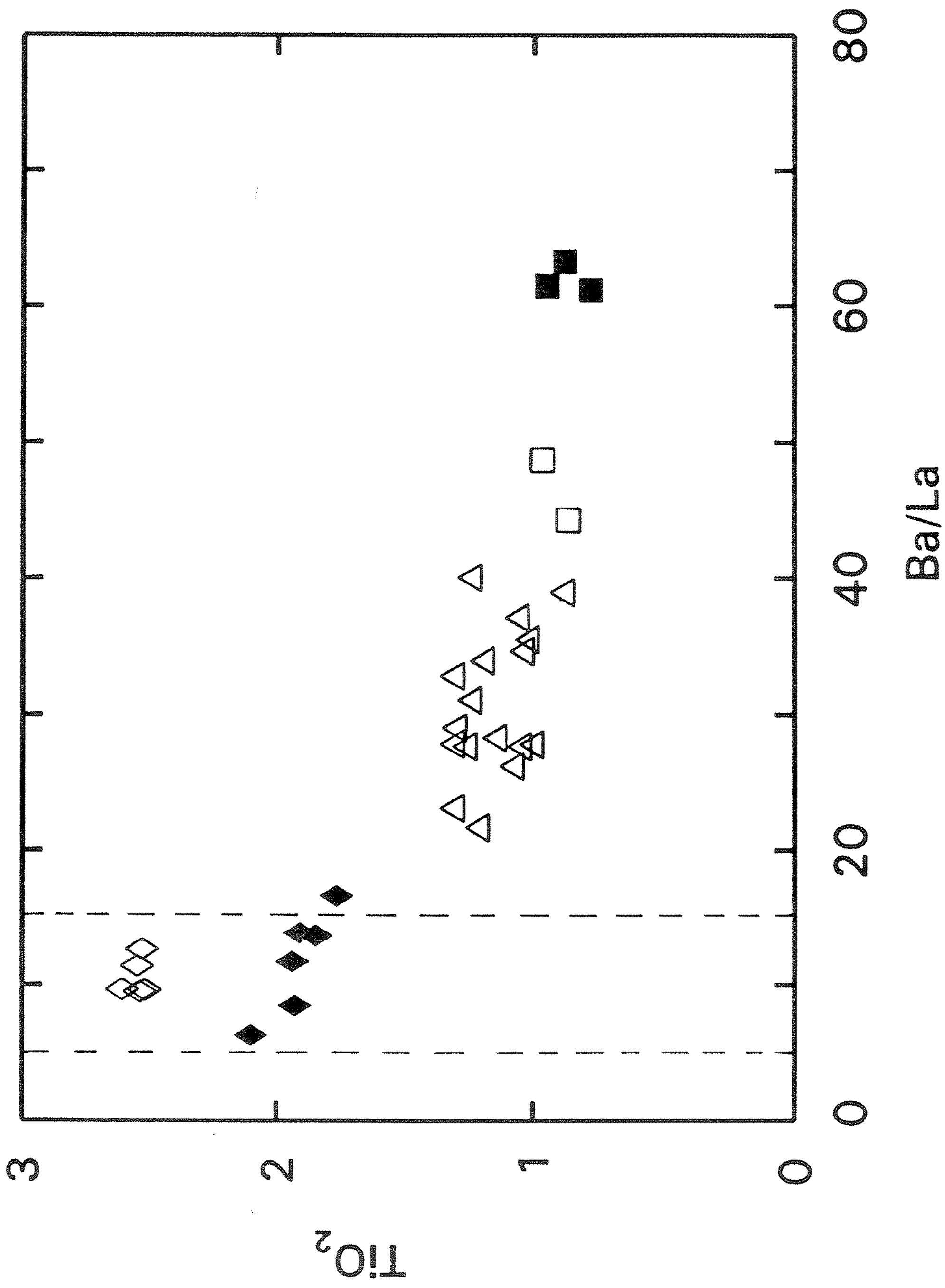


Fig. 11. Ba/La and TiO_2 values vary with distance away from the trench. Ba/La ratios are distinct for each volcanic region (each symbol). The TiO_2 contents of Lake Yojoa samples divides them into two groups. Dashed lines limit OIB and MORB fields.

values, 67.36 to 44.32; Tegucigalpa area samples have intermediate values (40.05 to 15.37), and the Lake Yojoa samples have the lowest values, ranging from 16.60 to 8.46. In comparison, Ba/La for ocean island basalts (OIB) ranges from 5 to 15 (Morris and Hart, 1983). Conversely, HFS elements (Ti, Nb) increase with latitude (distance away from the front), with the samples near the front having the lowest values and the ones from Lake Yojoa having the highest. For example, in Zacate Grande TiO_2 ranges from 0.62% to 1.00%, from 0.83% to 1.32% in Tegucigalpa, and then drastically increases to between 1.76 and 2.61 in Lake Yojoa lavas.

A. Zacate Grande: The geochemical characteristics of the rocks from this region are for the most part congruent with features of VF lavas from other areas in Central America. It can be said with confidence that subducted material plays an important role in the genesis of the magmas from Zacate Grande because these lavas display the LIL element enrichment and HFS element depletion (Fig. 12), commonly associated with slab influence on the magma genesis. In addition, the presence of ^{10}Be (7.03×10^6 atms/gr. in Za7) confirms the involvement of subducted material in the magma genesis.

The unusual positive correlation between the isotope ratios observed by Carr et al. (1990) in samples from Central America VF basalts is present in samples from Zacate

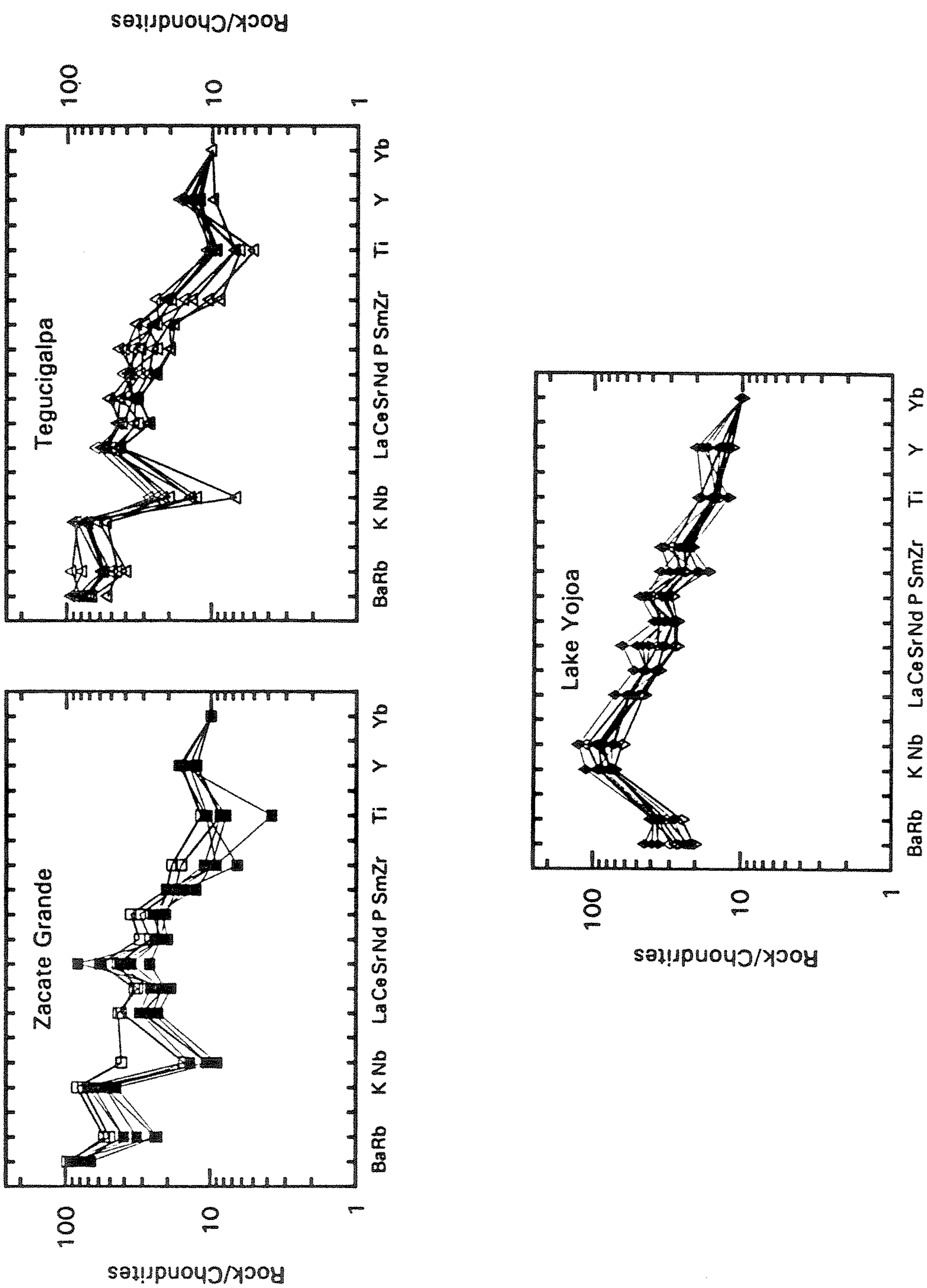


Fig. 12. Spider diagrams after Thompson et al. (1982). Samples from Zacate Grande display the typical arc pattern, that is Nb depletion, and Sr enrichment. Tegucigalpa samples have similar pattern to the previous ones, but the peaks are smaller. Alkali basalts from Lake Yojoa do not show the Nb depletion or the Sr enrichment pattern.

Grande, indicating a similarity of sources to those required for the volcanic front. Carr et al. (1990) indicate that the VF lavas from Central America are the result of melting a mixture of enriched and depleted mantle with mantle modified by metasomatic fluids. The isotopic signature of Zacate Grande samples can be reproduced by mixing a magma with low Nd isotope ratios (a sample that has not been greatly affected by slab material, Za6) with a sample with high Nd isotope ratios (magma with a high slab component, CN1)(Fig. 13). The isotope signature of the first sample is similar to that of enriched mantle, and the isotope signature of the second sample represents mantle that has been greatly modified by subducted material. Thus, the lavas from this region can be modeled as mixtures of mantle material modified to different extents by subducted slab components.

B. Tegucigalpa: the tholeiitic rocks from the area near Tegucigalpa display geochemical characteristics that are similar to those from other BVF areas in Central America, mainly SE Guatemala and El Salvador. For the most part the geochemistry of the lavas from Tegucigalpa is intermediate between that of Zacate Grande and Lake Yojoa basalts. To identify the source material of the lavas from Tegucigalpa all the geochemical parameters described must be considered. Because of the distance from the front (120 Km), subducted material is questionable as a source component for the lavas

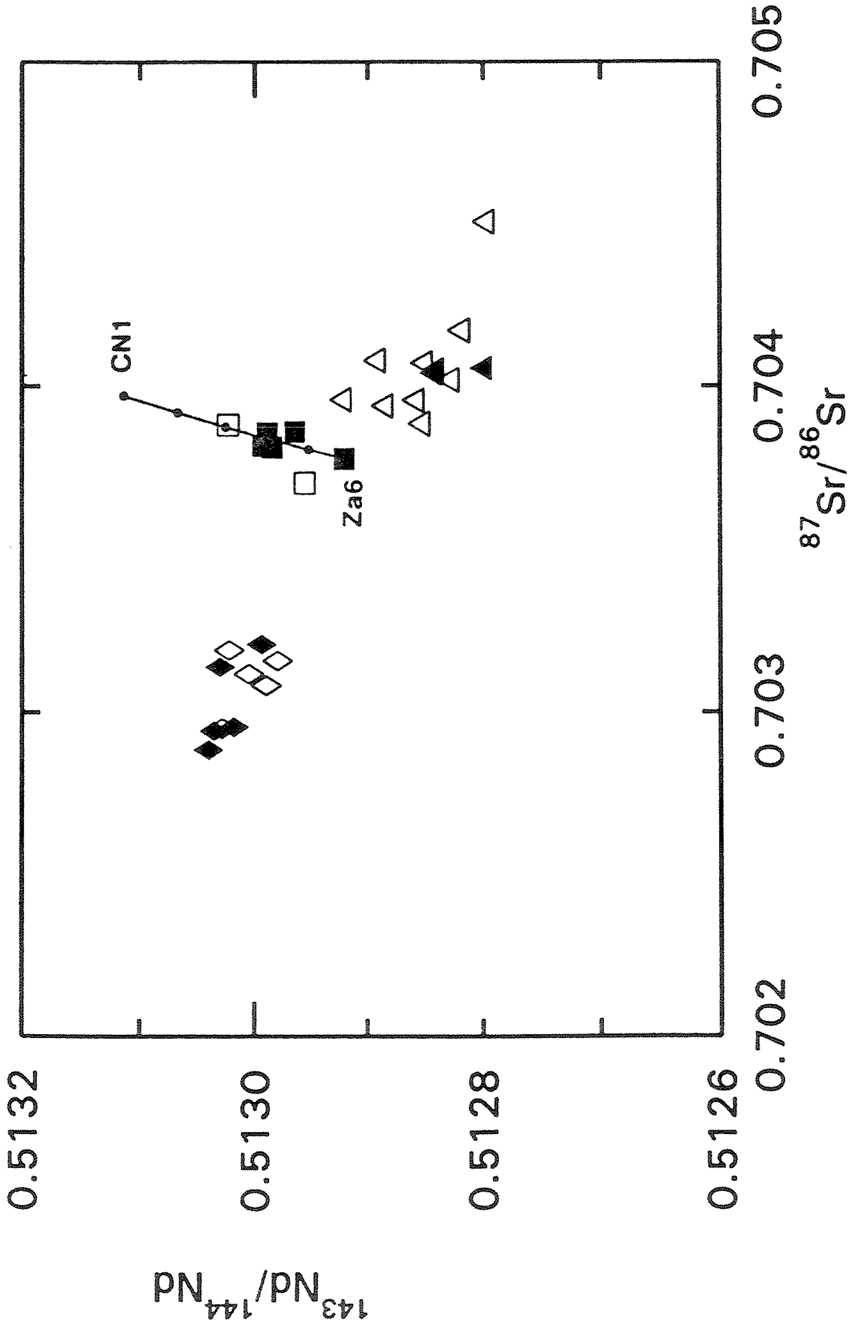


Fig. 13. Zacate Grande isotopic signature can be reproduced by mixing Za6 (low Nd isotope ratios) with CN1 (high $^{143}Nd/^{144}Nd$). The first component has isotope ratios similar the EM values, whereas CN1 is close to MM (mantle modified by slab material).

that erupted in this region. However, the rocks have some common features with rocks from areas closer to the front.

In spider diagrams (Fig. 12) the samples from Tegucigalpa show Nb depletion and Sr enrichment as do the samples from Zacate Grande, but with the difference that the samples from the region further away from the front have smaller peaks than the samples closer to the front. Therefore, one could conclude that the source material for both regions is similar, but that the proportions of the components are different.

Looking at isotope ratios of Sr and Nd (Fig. 10), it is evident that the source materials for Zacate Grande and Tegucigalpa basalts are different. The rocks from Tegucigalpa have higher $^{87}Sr/^{86}Sr$ and lower $^{143}Nd/^{144}Nd$ than samples collected closer the VF. The isotope ratios of the samples from this particular area are similar to those observed by Carr et al. (1990) in some Guatemala VF and BVF areas. The authors concluded that the isotope ratios are the product of contamination of the magmas with crustal material. The isotopic signature of the rocks from Tegucigalpa is also similar to the isotope ratios reported by Price et al. (1992) for Egmont Volcano 140 Km. west of Taupo Volcanic Zone, New Zealand. In this case the high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ ratios are reported to be the result of the involvement of subducted material in the genesis of the lavas. This conclusion was reached because of the similarities in the isotopic signature of lavas from the front and behind it; this is not the case in Central America where samples from the VF have distinct positive correlation between Nd and Sr isotope ratios, and BVF lavas display a negative correlation of the isotope ratios. In Tegucigalpa samples, the high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ signature could be the product of melting a mixture of mantle and crustal material, with the crustal component dominating the isotope signature.

DePaolo (1981) argues that isotope ratios of magmas are not only modified by binary mixing, but also by assimilation of wallrock during their ascent and emplacement. He developed a model of assimilation-fractional crystallization (AFC) in which these two phenomena are taken into account to evaluate sources of magmas. Using the equations of DePaolo (1981), we can evaluate the role that crustal material played in the generation of the magmas from Tegucigalpa area (Fig. 14).

The parental magma (Co) can be represented by an alkali basalt from Lake Yojoa (Yo1) with the lowest Sr isotope ratio and the highest Nd isotopic signature ($^{87}Sr/^{86}Sr$ of 0.70288 and $^{143}Nd/^{144}Nd$ of 0.51304) or by basalts from Zacate Grande. The wallrock is considered to be a diorite or agranite (G2 or G1 respectively) collected in Southeastern Guatemala with isotope ratios of 0.70659-0.51263 and 0.70595-0.51274 for Sr and Nd respectively. The isotopic signature of most of the samples from Tegucigalpa falls along the curve generated by modeling assimilation of

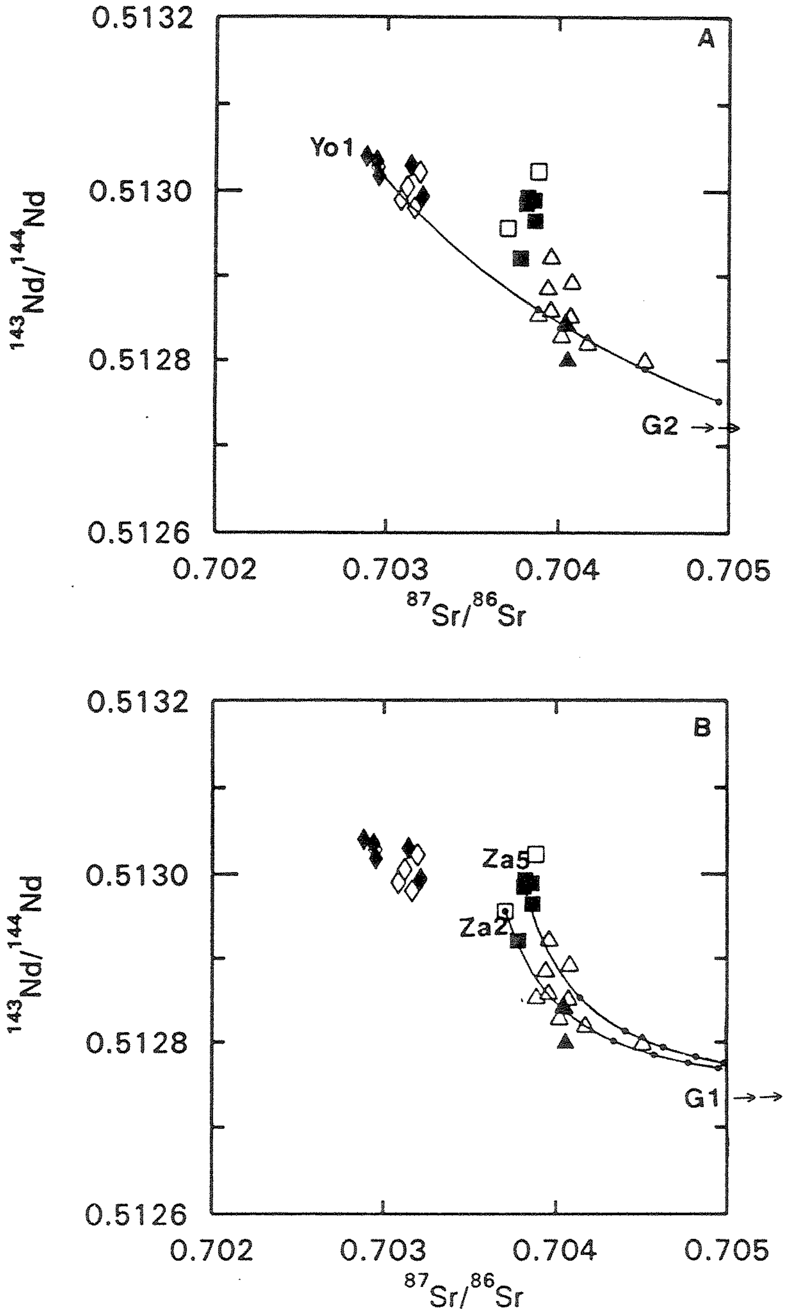


Fig. 14. Assimilation-Fractional Crystallization model for samples from Tegucigalpa. D_{Sr} is 0.1, D_{Nd} is 0.01, R is equal to 0.9, tick marks represent relative mass of magma remaining. Co is Yo1 and Ca is G2 (A). In graph B, Za2 and Za5 are used as Co and G1 is Ca. See text for details. Tick marks inticate 10% melting intervals.

crustal material (G2) and fractionating mantle melt (Yo1)(Fig. 14a). In this model the partition coefficient for Sr is considered to be less than 1 (0.1) and that for Nd << 1 (0.01). R, the ratio of mass which is assimilated to crystallizing mass, is 0.9. Modeling Yo1 shows that some of the magmas from which Tegucigalpa lavas originated from were mostly affected by crustal material but not by subducted slab material. This model does not agree with the trace element (HFS depletion) data that implies that fluid derived from the slab played a role in the generation of magmas from this area. Moreover, some samples from the Tegucigalpa area that have higher Nd isotopic signature do not fall along the curves generated by modeling Lake Yojoa basalts and granites.

Another alternative to reproduce the isotope ratios of samples from Tegucigalpa is to use the AFC model but start with Zacate Grande samples that have high and low $^{143}Nd/^{144}Nd$ ratios (Fig. 14b) and contaminate with crustal material. The assimilation of G1, a granite from SE Guatemala, by magma that has an isotopic signature similar to that of Za2 or Za5, produces basalts with isotopic signatures similar to those observed in rocks from Tegucigalpa area. This second model agrees more with the trace element patterns observed.

In a Ba/La vs. La/Yb graph the Tegucigalpa samples plot between those from Lake Yojoa and Zacate Grande. The trace element ratios of Tegucigalpa samples can be reproduced by mixing a Lake Yojoa basalt with Zacate Grande basalts to different extents (Fig. 15). As in the isotope ratios plot, it is necesary to use two Zacate Grande lavas that have been modified by subducted material to different extents. The influence of crustal material is evident in a diagram of Ba/La vs. $^{143}Nd/^{144}Nd$ (Fig. 16). The increase in the Ba/La ratios is explained by the increase of subducted material in the lavas from Tegucigalpa, but the low Nd isotope ratios can only be explained by crustal contamination of the magmas.

C. Lake Yojoa: All the studied samples from this region 160 Km. away from the VF are alkali basalts with the lowest SiO_2 of the studied samples (Fig 6), except for two trachytes, which were not considered in the course of this discussion. The rocks from this region are unusual compared to the Central American volcanic arc because they display high alkali and TiO_2 content for a given SiO_2 and the lowest Sr isotope ratios of the arc.

In a diagram of $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ isotope ratios (Fig. 10) the samples from Lake Yojoa show a slight negative correlation between the two isotope ratios. Sr isotope data divide the lavas into two distinct groups, indicating that there is not a single source from which the lavas originated. One group has higher $^{143}Nd/^{144}Nd$ and lower $^{87}Sr/^{86}Sr$ ratios, and the other group has higher ratios of Sr isotopes and lower ratios of Nd isotopes. The

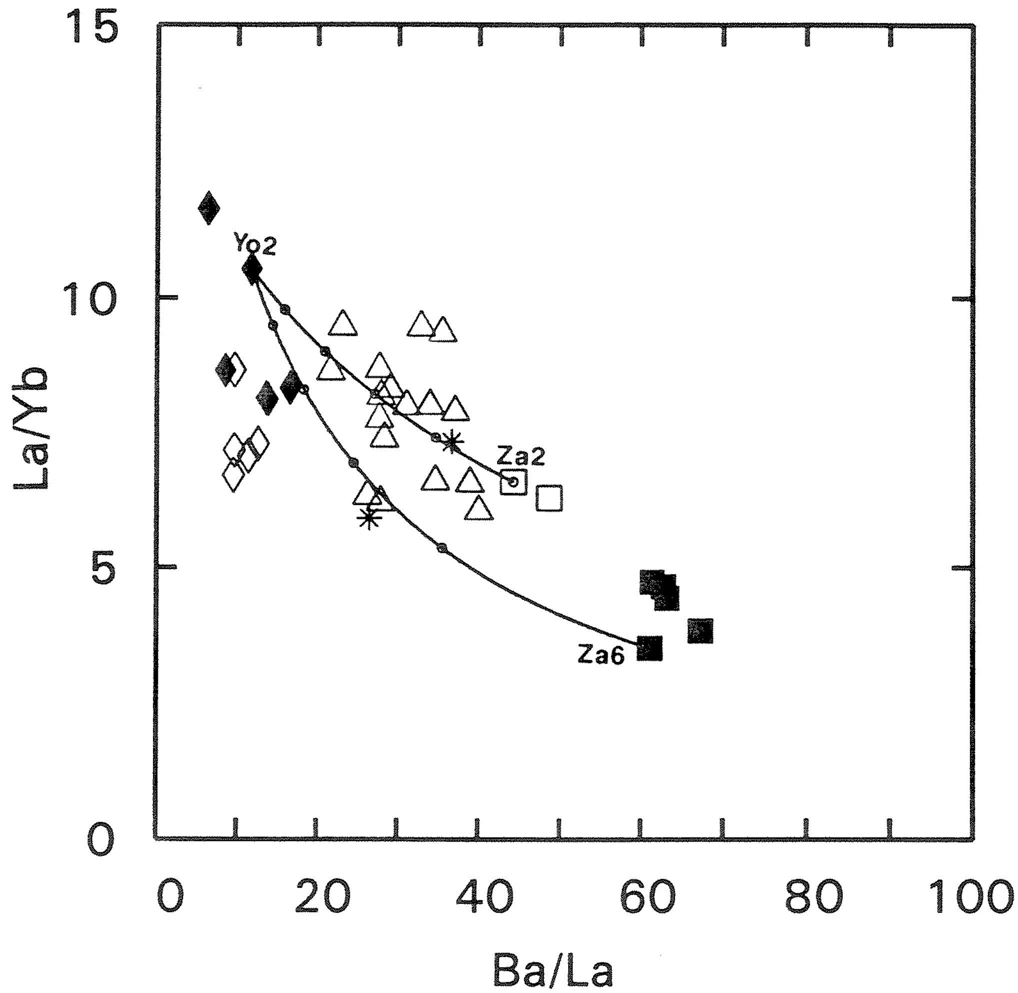


Fig. 15. Trace element ratios of samples from Tegucigalpa are intermediate between those from Lake Yojoa and Zacate Grande. Most of the ratios of Tegucigalpa samples can be reproduced by mixing material from Yo2 and Za2 or Za6. Crustal material represented by G1 and G2 (stars).

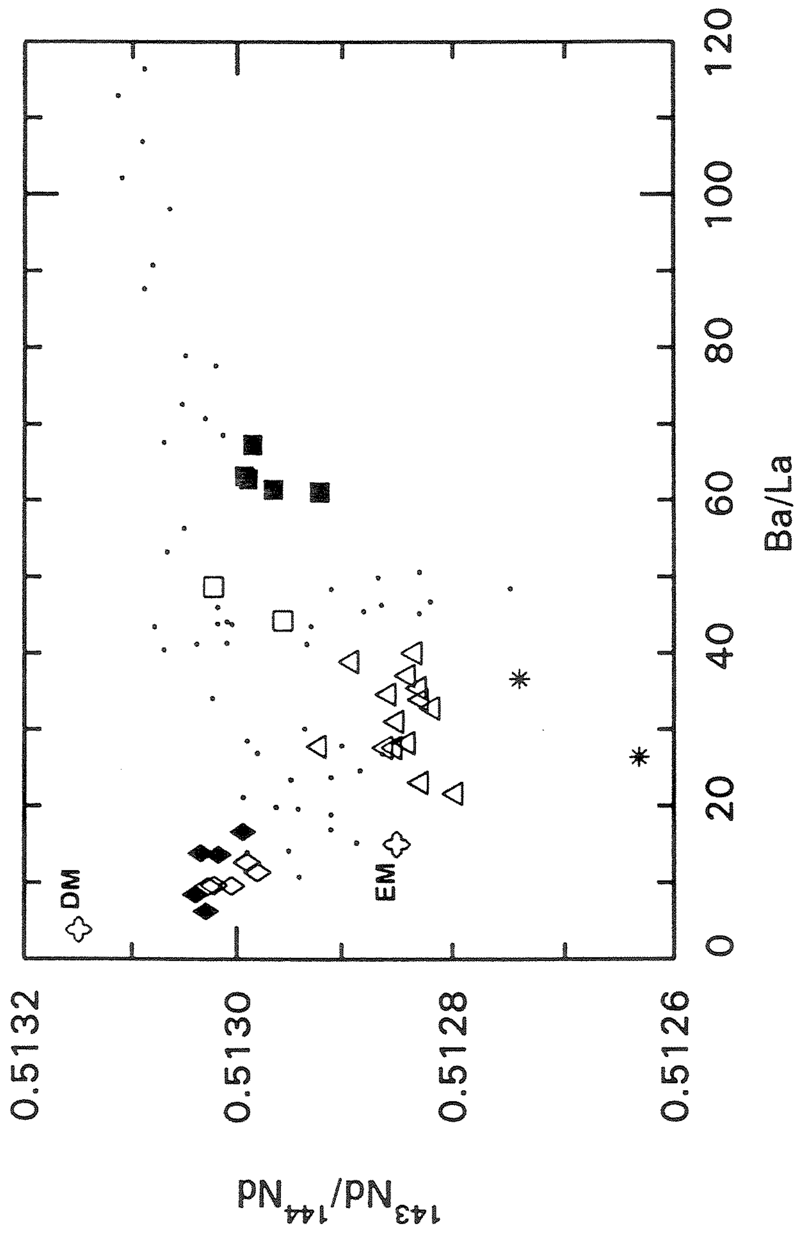


Fig. 16. The Crustal effect on Tegucigalpa samples can be seen using trace element and isotope ratios. Tegucigalpa samples have lower isotope ratios, but the Ba/La values are intermediate between the other two regions. Dots represent lavas from other areas in Central American volcanic arc and stars represent crustal material, G1 and G2.

isotopic signature of these alkali rocks indicates that they most likely originated from a mixture of depleted and enriched mantle or depleted mantle and crustal material.

The La/Yb ratios are lower than the ratios of some samples from Costa Rica which were inferred to be the product of low degree melting of enriched mantle (Carr et al., 1990), but the REE ratios of the alkali basalts from Lake Yojoa are higher than those of other samples closer to the front that are the products of higher degrees of melting. The La/Yb ratios are low, but greater than one, implying that these basalts are the product of low degree melting of a depleted source. The alkali lavas from Lake Yojoa and Costa Rica are not only different in their La/Yb ratios but also in their isotopic signature. The samples from the Honduran region have lower $^{87}Sr/^{86}Sr$ ratios, closer to the DM field, whereas the alkali rocks from Costa Rica plot in the EM area. Feigenson and Carr (1992) explain the trace element ratios and isotopic signature of lavas from the Central American arc by the existence of veins of enriched mantle in a matrix of depleted mantle. However, the lavas from Lake Yojoa area do not support this theory, and depleted mantle seems to be the dominant component that melts to form the magmas from this region. The mantle, from which the magmas that form the Central American volcanoes are derived, is not as homogenous as previously thought. A possible explanation for the heterogeneity is that the mantle underneath most of the Central American arc was depleted by a previous volcanic episode. These volcanic deposits could be the thick ignimbrites that cover large areas from Guatemala to Nicaragua, but are less aboundant in Costa Rica. Taking into account major and trace element abundances, incompatible elements ratios and isotopic signatures of the samples from this region 160 Km. away from the front, it can be concluded that these lavas originated most likely from melting depleted mantle subsequently contaminated by crustal material.

The Lake Yojoa lavas erupted in an extensional environment, the Sula Graben. These melts may be a consequence of adiabatic decompression that was not geochemically related to the subducted Cocos plate. These lavas do not show any signal of having been contaminated by subducted material, as evidenced by constant Ba/La, lack of LIL element enrichment and no HFS elements depletion. The geochemical characteristics of the lavas from Lake Yojoa are affected by depth and degree of melting, whereas contamination plays a minor role.

VI. CONCLUSION

The geochemistry of the three volcanic regions of Honduras studied in the course of this research show some marked differences, reflecting the different nature of original materials from which the lavas originated. Zacate Grade samples are the product of high degree melting of a mantle mixture modified to different extents by subducted material. The samples from this dissected cone are similar to other samples from the Central American VF even though they are located 30 Km. behind the front; the similarities are LILE enrichment, HFSE depletion, and positive correlation of Nd and Sr isotope ratios.

The alkali basalts from Lake Yojoa are probably a sample of the mantle beneath the volcanic arc unmodified by subduction derived fluids. The lavas from Lake Yojoa have a distinct Nd and Sr isotopic signature, displaying the lowest Sr isotope ratios found in the Central America volcanic arc. The isotopic signature and the modest La/Yb ratios imply that these lavas orignated by low degree melting of depleted mantle. The magmas were probably contaminated by crustal material during their ascent and emplacement. In addition, slab material is not considered to be a component of the mixture from which these lavas originated because they do not display HFSE depletion. The great distance between Lake Yojoa area and trench allows the magmas to avoid any contamination with subducted material.

Tegucigalpa area lavas, about 120 Km. behind the front, are the product of crustal assimilation and fractional crystallization. Most of the samples from this region can be explained by AFC modeling of material from Zacate Grande and a granite. The LILE and HFSE patterns for lavas from Tegucigalpa indicate that subducted material was present during the magma generation process.

In summary, a geochemical traverse from the Central

American volcanic front to 160 Km. behind the front shows the different sources and extends of melting. The volcanic front lavas are the result of high degree melting of mantle modified by subducted slab material. As the distance behind the front increases, the chemistry of the magmas changes because of the decrease of the slab component until only small degree melting of depleted mantle occurs. The changes observed among the three studied regions are not unique to this segment of the Central American volcanic arc, similar geochemical characteristics have been observed in other volcanic arcs, for example in the Cascades, Izu-Bonin, and Taupo Volcanic Zone.

APPENDIX 1

SAMPLE PREPARATION FOR ICP-MS

OPEN BEAKER ACID ATTACK

Adaptation from Albrecht et al,1991

1. Weight 100 mg. of sample, record exact weight, into a teflon beaker.
2. Add 5 ml HF, and evaporate to dryness. Be careful with violent reactions of the samples with the acid. Better if done on a hood with a window protector down.
3. Add 5 ml HF, 2 ml $HClO_4$, 2 ml HNO_3 (all concentrated acids). Put on a hot plate overnight at a low temperature (LO).
4. Evaporate the solution that remains on the beakers.

5a. Add 2 ml of $HClO_4$, and evaporate. It is necessary to do this step twice to make sure the fluorides dissolve.

5b. Add 2 ml of $HClO_4$, and evaporate.

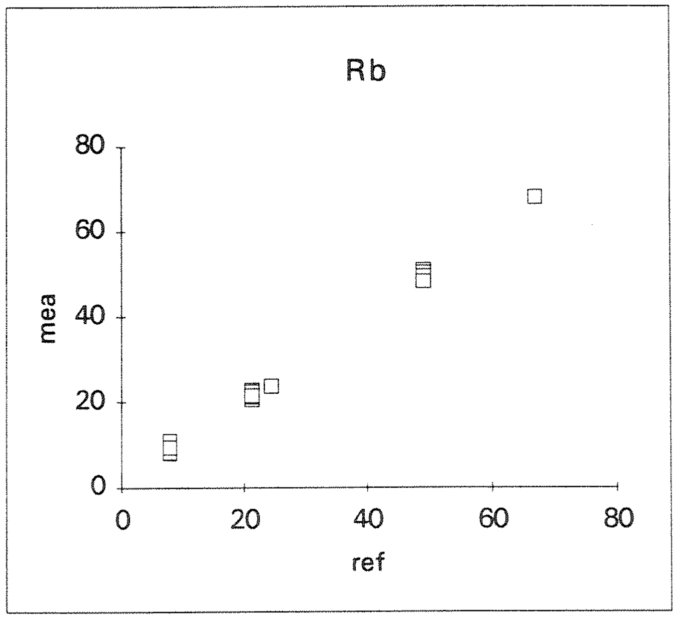
6a. Add 2 ml of 20% HNO_3, and evaporate. Again this step must be done twice to assure complete dissolution of the sample.

6b. Add 2 ml of 20% HNO_3, and evaporate.

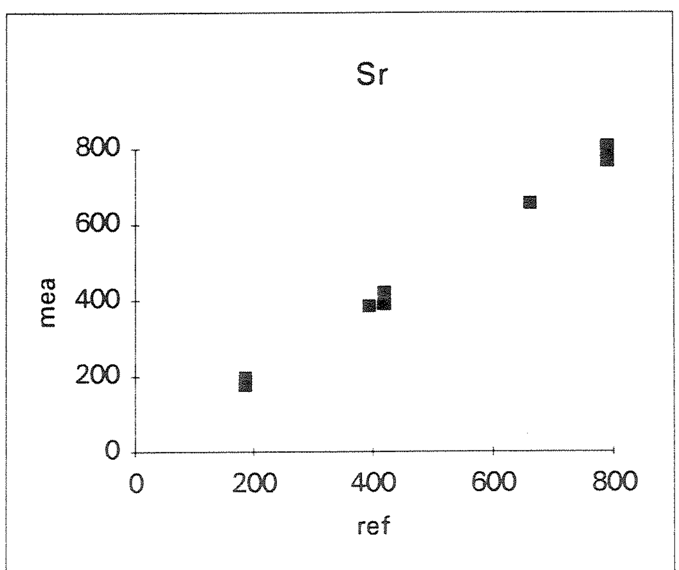
7. The sample is then taken in 2.5 ml of 20% HNO_3, and then diluted with water to 5 ml, to have a final 10% HNO_3.

APPENDIX 2
USGS STANDARDS

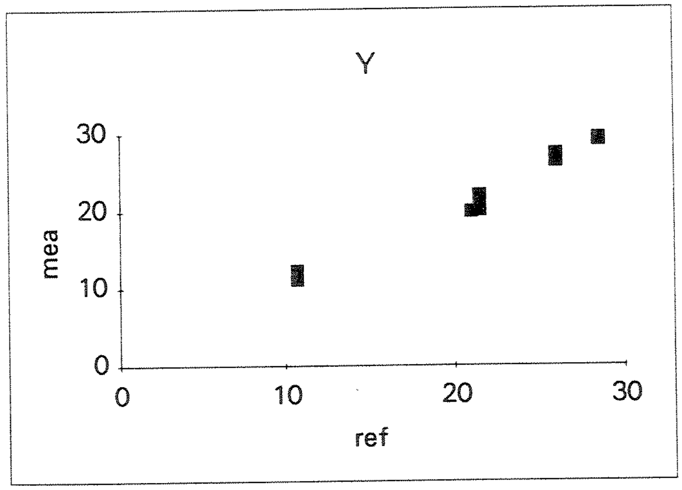
Rb (ppm)	Ref	Mea
BHVO run1	8	8
BHVO 1mk	8	10.8
BHVO 214	8	9.227
BHVO 220	8	8.013
BHVO 220	8	9.27
IZ 124	49	50.72
IZ 130	49	49.3
IZ 220	49	48.96
IZ 220	49	48.93
IZ 225	49	50.08
IZ 225	49	50.09
IZ 47	49	49.15
IZ 414	49	48.16
AGV 124	67	67.91
W1 214	21.4	22.7
W1 130	21.4	20.6
W1 130	21.4	21.1
W1 225	21.4	21.92
W1 47	21.4	22.28
W1 47	21.4	21.18
W1 414	21.4	21.47
205IZ 414	24.5	23.7
IZ5 214	24.5	23.61



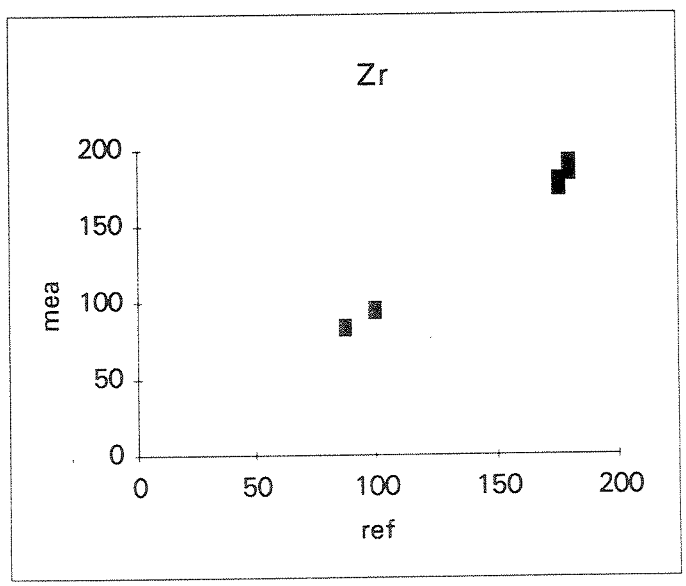
Sr (ppm)	Ref	Mea
BHVO 24	420	421.1
BHVO 220	420	406.9
BHVO 214	420	391.9
BHVO 220	420	392.1
IZ 124	790	770.5
IZ 130	790	766.6
IZ 220	790	802.4
IZ 220	790	789.2
IZ 225	790	776.8
IZ 225	790	797.2
IZ 47	790	787.9
IZ 414	790	808.5
AGV 124	662	655.8
W1 214	187	193.5
W1 130	187	176.6
W1 220	187	195.8
W1 225	187	196.4
W1 47	187	191.9
W1 47	187	185.5
IZ5 214	395	385.7



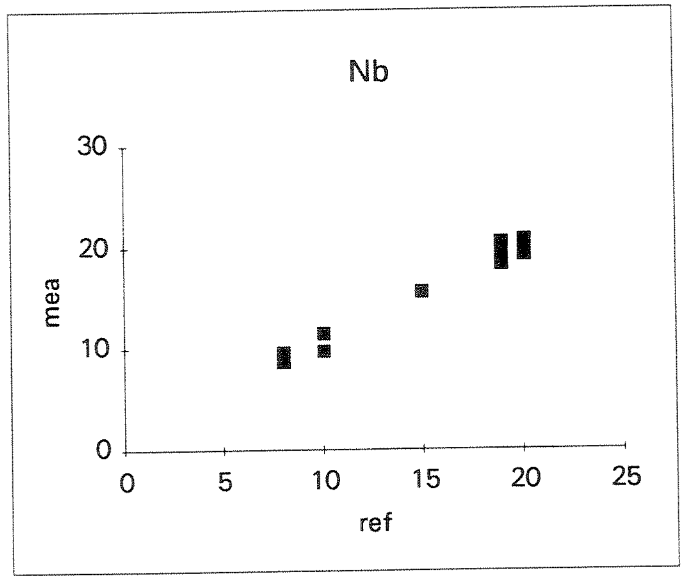
Y (ppm)	Ref	Mea
BHVO 24	28.5	29.05
BHVO 220	28.5	29.32
BHVO 214	28.5	29.22
BHVO 220	28.5	29.09
IZ 124	21.5	20.12
IZ 130	21.5	21
IZ 220	21.5	21.49
IZ 220	21.5	20.57
IZ 225	21.5	20.47
IZ 225	21.5	20.74
IZ 225	21.5	21.63
IZ 47	21.5	21.95
AGV 124	21	19.9
W1 47	26	26.42
W1 414	26	27.31
205IZ 414	10.75	12.23
IZ5 214	10.75	11.04



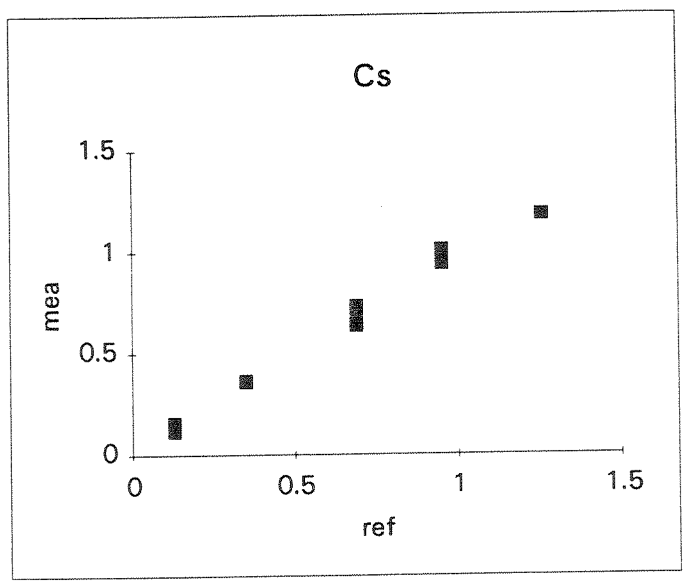
Zr (ppm)	Ref	Mea
BHVO 24	180	189.1
BHVO 220	180	192.2
BHVO 214	180	183.2
BHVO 220	180	190.3
IZ 225	176	178.6
IZ 225	176	175.6
IZ 225	176	173.3
IZ 47	176	181
W1 214	100	94.23
W1 220	100	96.05
W1 225	100	92.57
W1 47	100	93.22
205IZ 414	88	84.96
IZ5 214	88	82.06



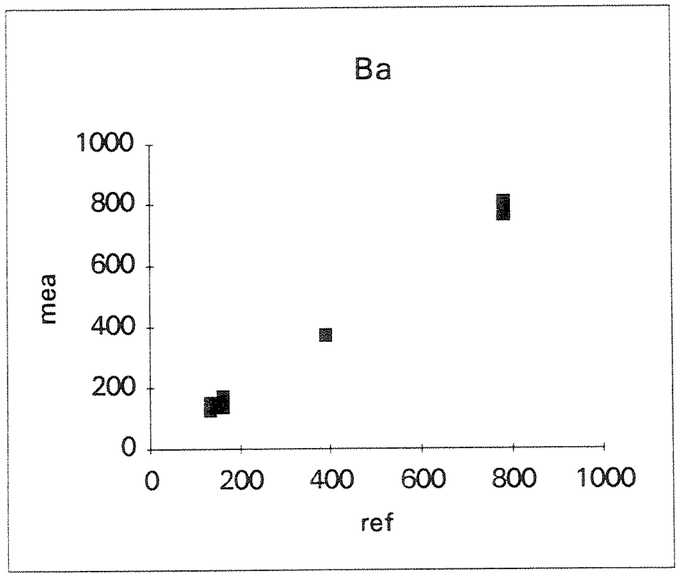
Nb (ppm)	Ref	Mea
BHVO 24	19	18.2
BHVO 220	19	19
BHVO 220	19	20.14
BHVO 220	19	20.46
IZ 124	20.1	20.02
IZ 220	20.1	19.95
IZ 225	20.1	19.48
IZ 225	20.1	19.21
IZ 47	20.1	20.61
IZ 414	20.1	20.62
IZ 414	20.1	20.05
AGV 124	15	15.55
W1 214	8	8.575
W1 130	8	9.18
W1 130	8	9.35
W1 220	8	8.988
W1 47	8	8.659
W1 47	8	9.475
W1 414	8	9.352
205IZ 414	10.05	11.38
IZ5 214	10.05	9.706



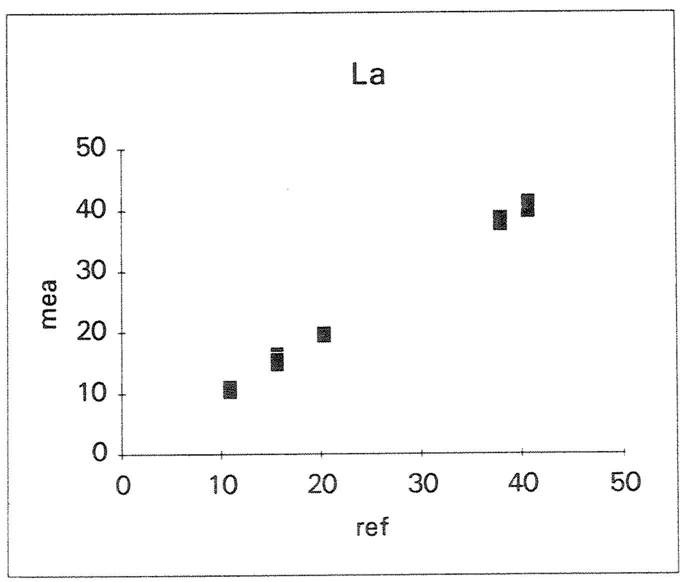
Cs (ppm)	Ref	Mea
BHVO run1	0.13	0.14
BHVO 24	0.13	0.114
BHVO 1mk	0.13	0.133
BHVO 130	0.13	0.119
BHVO 220	0.13	0.155
BHVO 220	0.13	0.144
IZ 1run1 f	0.693	0.71
IZ 1run2 f	0.693	0.73
IZ 124	0.693	0.707
IZ 130	0.693	0.728
IZ 220	0.693	0.664
IZ 220	0.693	0.633
IZ 225	0.693	0.643
IZ 47	0.693	0.717
AGV run2	1.26	1.18
W1 214	0.95	0.951
W1 130	0.95	0.947
W1 220	0.95	1.011
W1 225	0.95	0.941
W1 414	0.95	0.961
205IZ 414	0.35	0.363
IZ5 214	0.35	0.358



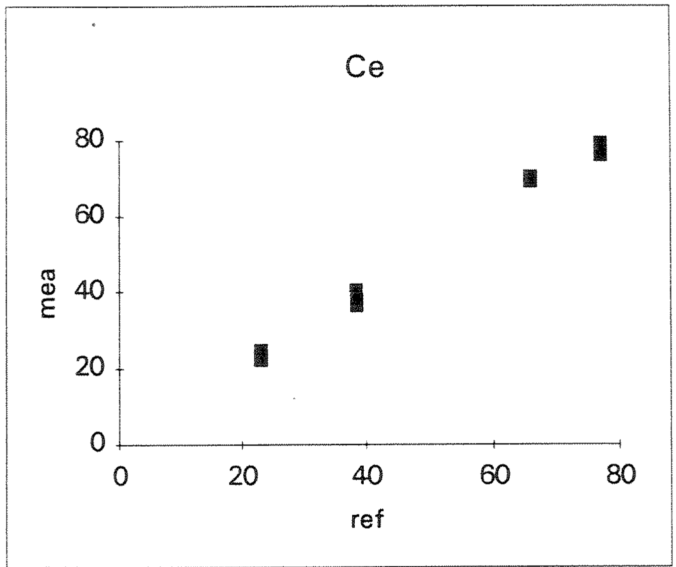
Ba (ppm)	Ref	Mea
BHVO 24	135	135
BHVO 130	135	148.6
BHVO 220	135	127.9
BHVO 214	135	143.1
BHVO 220	135	124.8
BHVO 220	135	131.3
IZ 1run1 f	782	777.4
IZ 1run2 f	782	788
IZ 124	782	761.9
IZ 130	782	805.8
IZ 220	782	784.8
IZ 225	782	796.4
IZ 225	782	794.8
IZ 225	782	767.1
IZ 47	782	789.3
AGV run2	1221	1215
AGV 124	1221	1198
W1 214	162	162.7
W1 130	162	160.1
W1 130	162	153.7
W1 220	162	151.8
W1 225	162	168.4
W1 47	162	163.1
W1 47	162	135.6
W1 414	162	154
205IZ 414	391	370.4
IZ5 214	391	373.3



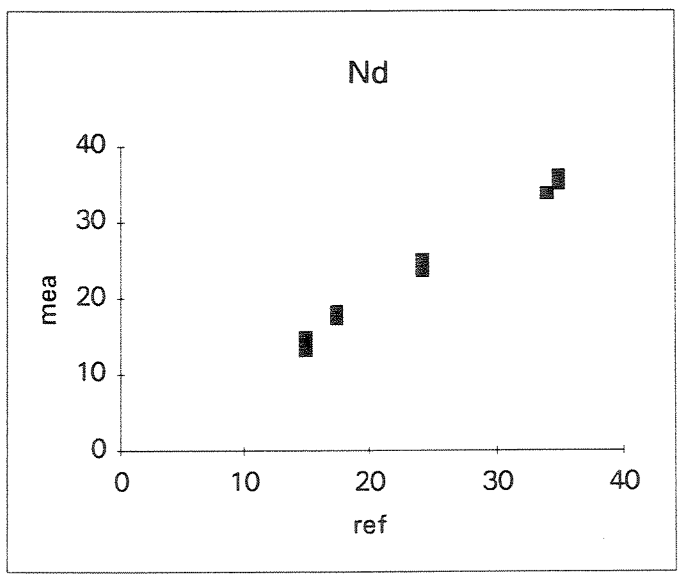
La (ppm)	Ref	Mea
BHVO run1	15.6	16.24
BHVO 24	15.6	16.32
BHVO 1mk	15.6	14.7
BHVO 130	15.6	16.3
BHVO 220	15.6	15.66
BHVO 214	15.6	15.02
BHVO 220	15.6	15.51
BHVO 220	15.6	15.38
IZ 1run1 f	40.7	39.55
IZ 1run2 f	40.7	40.47
IZ 124	40.7	40.83
IZ 130	40.7	41.3
IZ 220	40.7	39.69
IZ 220	40.7	39.66
IZ 225	40.7	40.89
IZ 225	40.7	39.7
IZ 47	40.7	41.3
AGV run2	38	37.59
AGV 124	38	38.68
W1 130	10.9	10.5
W1 130	10.9	10.2
W1 220	10.9	11.2
W1 225	10.9	11.06
W1 47	10.9	11
W1 47	10.9	10.6
205IZ 414	20.35	19.36
IZ5 214	20.35	19.87



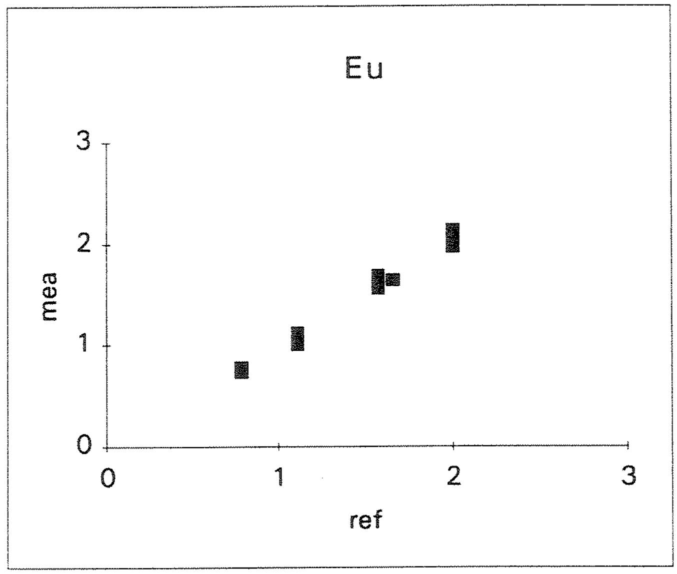
Ce (ppm)	Ref	Mea
BHVO 24	38.5	40.15
BHVO 130	38.5	40.3
BHVO 220	38.5	38.65
BHVO 214	38.5	36.44
BHVO 220	38.5	37.39
IZ 1run1 f	77.1	78.67
IZ 1run2 f	77.1	79.14
IZ 124	77.1	78.21
IZ 130	77.1	78.2
IZ 220	77.1	78.37
IZ 225	77.1	78.37
IZ 225	77.1	79.14
IZ 225	77.1	76.02
IZ 47	77.1	77.17
AGV run2	66	69.04
AGV 124	66	70.24
W1 214	23	24.24
W1 130	23	22.5
W1 130	23	22.3
W1 220	23	24.5
W1 225	23	23.41
W1 47	23	23.63
W1 47	23	22.15
W1 414	23	23.39
205IZ 414	38.55	36.38
IZ5 214	38.55	37.74



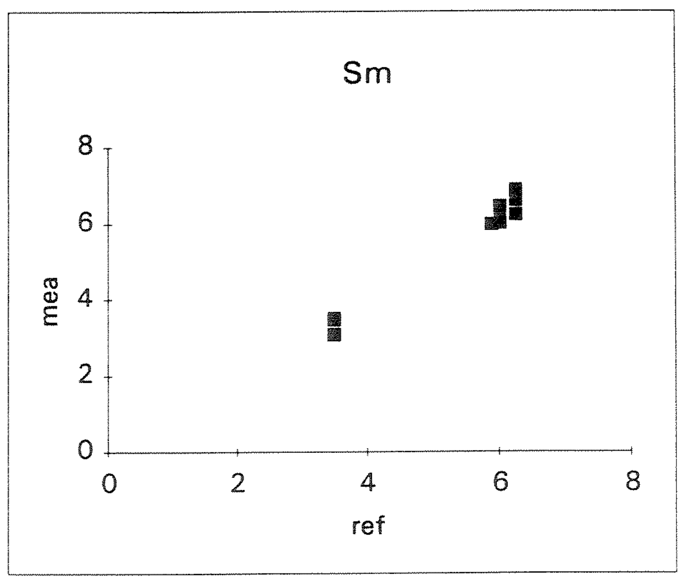
Nd (ppm)	Ref	Mea
BHVO 1mk	24.2	23.6
BHVO 214	24.2	24.87
BHVO 220	24.2	23.83
BHVO 220	24.2	23.81
IZ 1run1 f	34.9	35.27
IZ 1run2 f	34.9	35.42
IZ 124	34.9	35.03
IZ 130	34.9	35.3
IZ 220	34.9	34.92
IZ 225	34.9	36.07
IZ 47	34.9	35.26
AGV 124	34	33.64
W1 214	15	13.36
W1 130	15	13.2
W1 47	15	14.82
W1 47	15	13.07
205IZ 414	17.45	18.22
IZ5 214	17.45	17.31



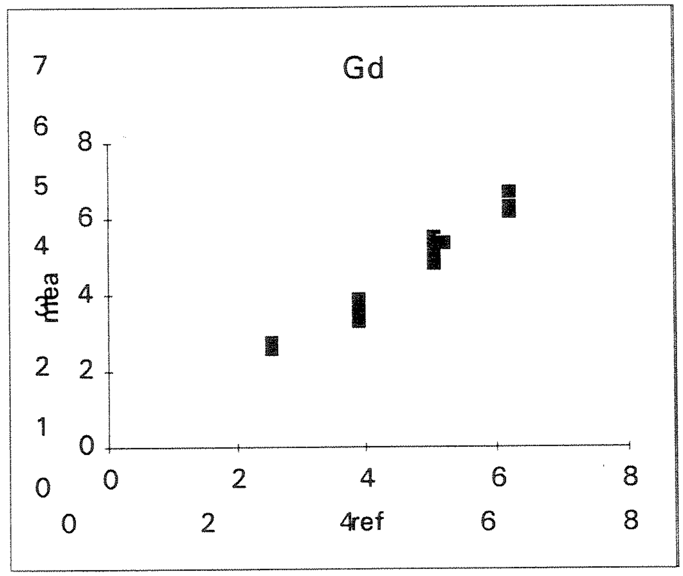
Eu (ppm)	Ref	Mea
BHVO run1	2	2.13
BHVO 1mk	2	1.97
BHVO 130	2	2.1
BHVO 214	2	2.037
BHVO 220	2	2.053
IZ 1run1 f	1.58	1.57
IZ 1run2 f	1.58	1.55
IZ 130	1.58	1.58
IZ 225	1.58	1.557
IZ 225	1.58	1.608
IZ 47	1.58	1.586
IZ 414	1.58	1.681
IZ 414	1.58	1.65
AGV run2	1.66	1.64
W1 214	1.11	1.05
W1 130	1.11	1.11
W1 130	1.11	1
W1 47	1.11	1.037
205IZ 414	0.79	0.731
IZ5 214	0.79	0.774



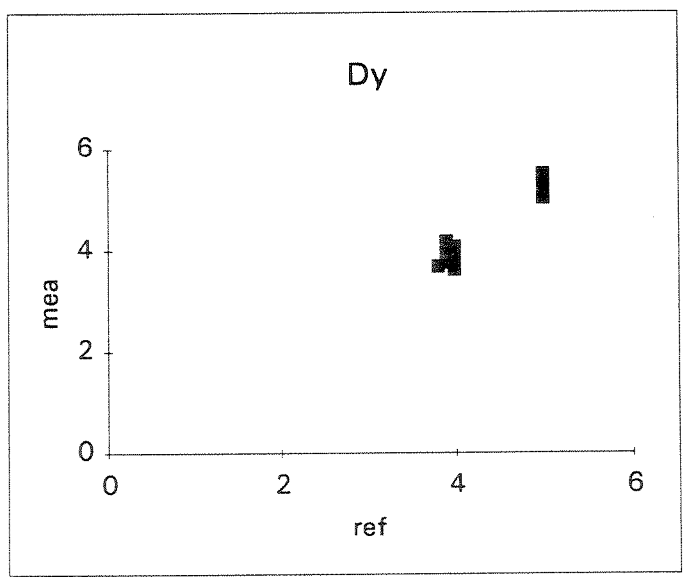
Sm (ppm)	Ref	Mea
BHVO 24	6.02	6.139
BHVO 1mk	6.02	6.33
BHVO 130	6.02	6.01
BHVO 214	6.02	6.438
IZ 1run1 f	6.25	6.34
IZ 1run2 f	6.25	6.55
IZ 124	6.25	6.548
IZ 130	6.25	6.67
IZ 220	6.25	6.224
IZ 225	6.25	6.861
IZ 47	6.25	6.604
IZ 414	6.25	6.827
AGV run2	5.9	5.97
W1 214	3.5	3.449
W1 130	3.5	3.05
W1 130	3.5	3.49
W1 47	3.5	3.447



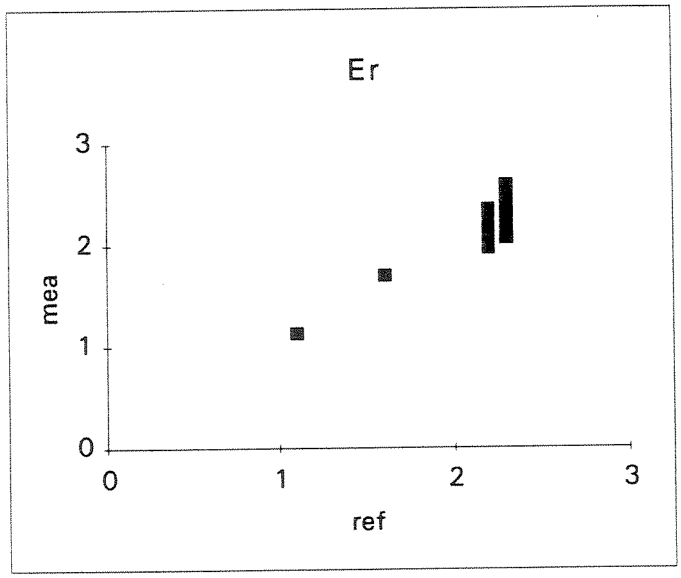
Gd (ppm)	Ref	Mea
BHVO run1	6.2	6.29
BHVO 130	6.2	6.69
BHVO 214	6.2	6.667
BHVO 220	6.2	6.143
IZ 124	5.05	5.488
IZ 130	5.05	4.79
IZ 220	5.05	5.329
IZ 225	5.05	5.195
IZ 225	5.05	5.177
IZ 225	5.05	4.904
IZ 47	5.05	5.371
AGV run2	5.2	5.33
W1 214	3.9	3.452
W1 130	3.9	3.56
W1 220	3.9	3.749
W1 225	3.9	3.87
W1 47	3.9	3.337
W1 47	3.9	3.298
W1 414	3.9	3.548
205IZ 414	2.53	2.751
IZ5 214	2.53	2.566



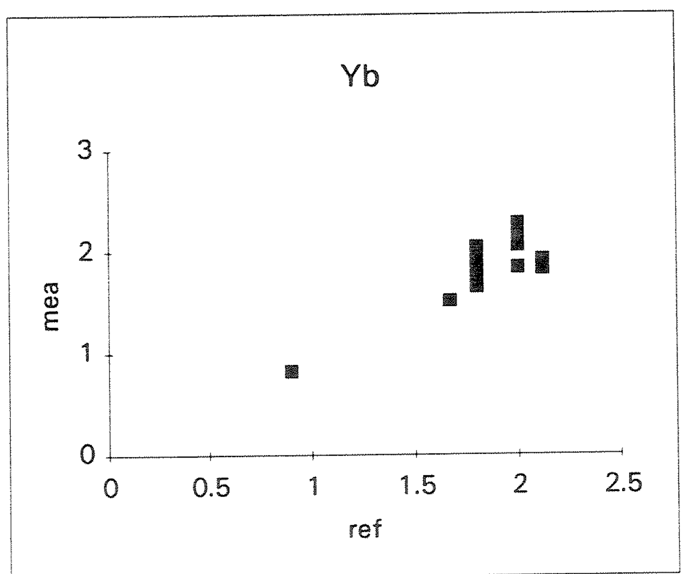
Dy (ppm)	Ref	Mea
BHVO 24	5	5.138
BHVO 1mk	5	5.1
BHVO 130	5	5.49
BHVO 220	5	5.013
BHVO 214	5	5.441
BHVO 220	5	5.327
IZ 1run1 f	3.99	3.66
IZ 1run2 f	3.99	3.71
IZ 130	3.99	3.59
IZ 220	3.99	4.079
IZ 225	3.99	3.637
IZ 225	3.99	3.609
IZ 225	3.99	4.053
IZ 47	3.99	3.997
IZ 414	3.99	3.79
AGV run2	3.8	3.67
W1 214	3.9	3.832
W1 130	3.9	4.17
W1 225	3.9	4.068
W1 47	3.9	3.952
W1 414	3.9	3.751



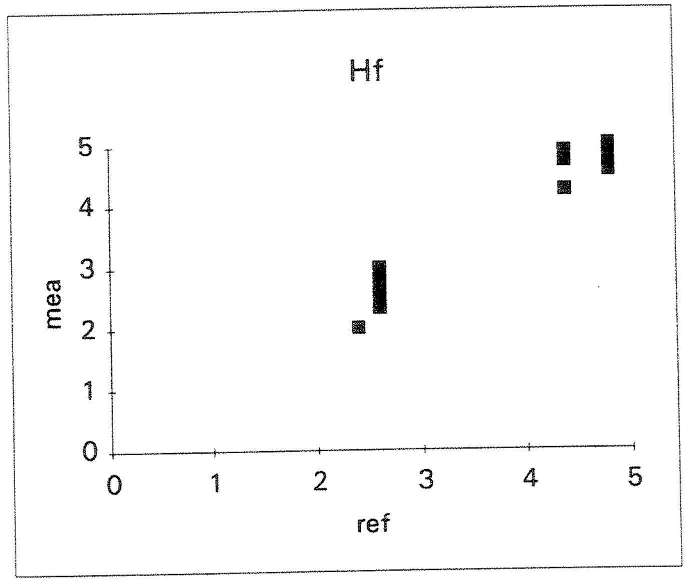
Er (ppm)	Ref	Mea
BHVO 24	2.3	2.197
BHVO 1mk	2.3	2.59
BHVO 214	2.3	2.446
BHVO 220	2.3	2.411
BHVO 220	2.3	2.571
IZ 1run1 f	2.2	1.97
IZ 1run2 f	2.2	2.01
IZ 124	2.2	2.139
IZ 130	2.2	2.34
IZ 220	2.2	2.117
IZ 220	2.2	1.962
IZ 225	2.2	1.979
IZ 225	2.2	2.218
IZ 225	2.2	2.034
IZ 47	2.2	2.068
IZ 414	2.2	2.16
IZ 414	2.2	2.323
AGV 124	1.61	1.697
W1 214	2.3	2.237
W1 130	2.3	2.21
W1 130	2.3	2.14
W1 220	2.3	2.118
W1 225	2.3	2.437
W1 47	2.3	2.322
W1 414	2.3	2.062
IZ5 214	1.1	1.126



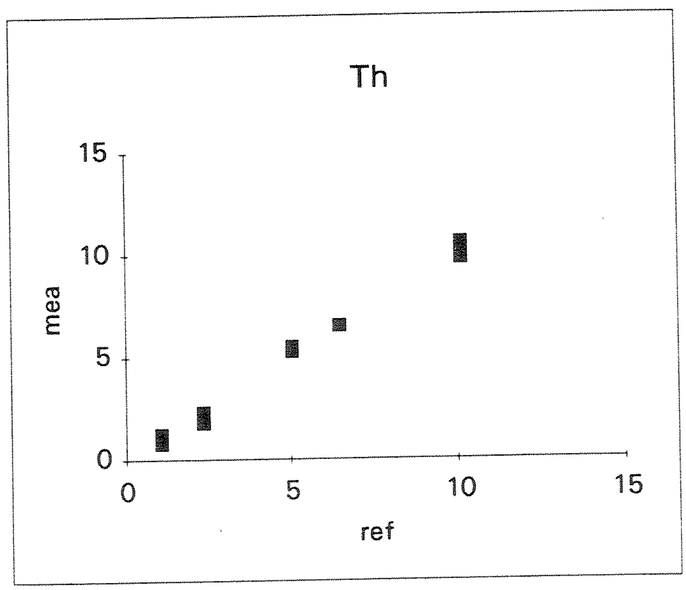
Yb (ppm)	Ref	Mea
BHVO 24	2	2.27
BHVO 1mk	2	2.11
BHVO 130	2	1.84
BHVO 220	2	2.054
BHVO 214	2	2.162
BHVO 220	2	1.849
BHVO 220	2	1.833
IZ 1run1 f	1.8	1.86
IZ 1run2 f	1.8	1.89
IZ 124	1.8	1.819
IZ 130	1.8	2.01
IZ 220	1.8	2.036
IZ 220	1.8	1.699
IZ 225	1.8	1.899
IZ 225	1.8	1.84
IZ 225	1.8	1.746
IZ 47	1.8	1.645
IZ 414	1.8	1.662
AGV run2	1.67	1.51
W1 130	2.12	1.82
W1 47	2.12	1.921
IZ5 214	0.9	0.818



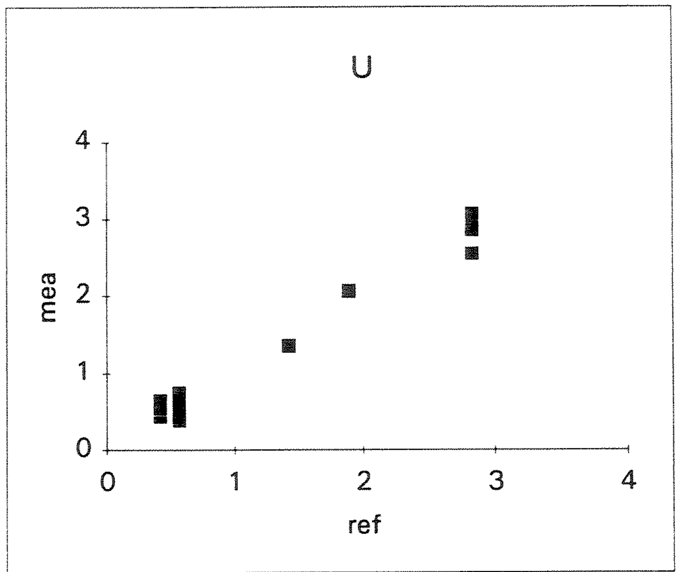
Hf (ppm)	Ref	Mea
BHVO 24	4.38	4.89
BHVO 130	4.38	4.71
BHVO 214	4.38	4.234
IZ 124	4.8	4.661
IZ 130	4.8	4.68
IZ 220	4.8	4.639
IZ 220	4.8	4.557
IZ 225	4.8	4.999
IZ 225	4.8	4.887
IZ 225	4.8	4.676
IZ 47	4.8	5
IZ 414	4.8	4.927
W1 214	2.6	2.991
W1 130	2.6	2.34
W1 130	2.6	2.7
W1 225	2.6	2.556
W1 47	2.6	2.806
W1 47	2.6	2.536
W1 414	2.6	2.59
IZ5 214	2.4	2.002



Th (ppm)	Ref	Mea
BHVO 24	1.08	0.759
BHVO 130	1.08	1.18
BHVO 220	1.08	1.279
BHVO 214	1.08	1.006
BHVO 220	1.08	1.245
BHVO 220	1.08	1.003
IZ 1run1 f	10.1	9.86
IZ 1run2 f	10.1	10.5
IZ 130	10.1	9.94
IZ 220	10.1	9.976
IZ 220	10.1	10.54
IZ 225	10.1	10.44
IZ 225	10.1	10.28
IZ 225	10.1	9.841
IZ 414	10.1	10.02
AGV run2	6.5	6.52
W1 130	2.4	2.17
W1 225	2.4	2.099
W1 47	2.4	2.289
W1 414	2.4	1.768
205IZ 414	5.05	5.515
IZ5 214	5.05	5.267



U (ppm)	Ref	Mea
BHVO 1mk	0.42	0.636
BHVO 130	0.42	0.439
BHVO 220	0.42	0.43
BHVO 214	0.42	0.532
BHVO 220	0.42	0.542
IZ 130	2.83	3.01
IZ 225	2.83	2.939
IZ 225	2.83	2.539
IZ 47	2.83	2.843
IZ 414	2.83	3.054
AGV run2	1.89	2.05
W1 214	0.57	0.582
W1 130	0.57	0.455
W1 130	0.57	0.46
W1 220	0.57	0.384
W1 225	0.57	0.747
W1 414	0.57	0.417
IZ5 214	1.42	1.36



APPENDIX 3

GEOCHEMICAL DATA FOR HONDURAS SAMPLES

Sample	HON101	HON102	HON103	HON104	HON105	HON106
SiO2	59.22	59.12	54.42	53.38	53.00	52.98
TiO2	0.86	0.83	1.31	1.32	1.30	1.19
Al2O3	17.70	17.56	17.10	17.64	17.08	17.21
FeO	6.44	6.19	9.19	9.29	8.28	8.88
MnO	0.13	0.12	0.17	0.16	0.15	0.16
MgO	2.11	2.07	5.01	4.75	5.03	5.29
CaO	6.79	6.98	8.68	9.09	8.77	9.04
Na2O	3.09	3.00	3.22	3.28	3.15	3.09
K2O	2.43	2.21	1.50	1.38	1.40	1.31
P2O5	0.25	0.25	0.60	0.63	0.59	0.45
Rb	nd	nd	25	23	22	22
Ba	600	599	738	815	671	638
Sr	412	436	653	651	659	638
V	140	129	216	229	219	220
Cr	7	9	113	141	129	129
Ni	4	2	45	69	38	65
Zr	150	150	195	205	213	153
Sc	17	17	24	26	25	24
Cu	27	27	62	62	61	59
Nb	nd	nd	10.3	10.6	10.8	7.2
La	nd	nd	22.5	53.0	23.1	18.8
Ce	nd	nd	48.4	99.7	49.7	41.3
Nd	nd	nd	28.5	63.7	28.2	25.5
Sm	nd	nd	6.35	19.20	6.15	7.37
Eu	nd	nd	1.74	4.67	1.78	1.28
Gd	nd	nd	6.44	18.50	4.83	4.76
Dy	nd	nd	4.69	24.60	4.78	4.30
Er	nd	nd	3.18	17.70	3.33	2.57
Yb	nd	nd	2.38	18.10	2.78	2.35
Y	nd	nd	30.10	211.50	30.20	26.30
Ba/La	nd	nd	32.81	15.37	29.04	33.95
La/Yb	nd	nd	9.45	2.93	8.31	8.00
87Sr/86Sr	nd	nd	0.70417	0.70404	0.70414	0.70407
143Nd/144Nd	nd	nd	0.51282	0.51284	0.00000	0.51283
Lat	nd	nd	13.928	13.935	13.943	13.956
Lon	nd	nd	-87.236	-87.224	-87.214	-87.206

Sample	HON107	HON108	HON109	HON110	HON111	HON112
SiO2	53.25	52.62	50.89	52.25	50.39	51.07
TiO2	1.03	1.05	0.88	1.24	0.99	0.99
Al2O3	17.20	17.83	20.42	18.01	17.72	17.98
FeO	8.82	9.27	8.54	9.66	9.22	9.18
MnO	0.16	0.16	0.15	0.16	0.18	0.19
MgO	5.04	5.12	4.80	4.48	5.15	5.17
CaO	8.67	9.17	9.71	9.48	8.97	8.76
Na2O	2.79	2.96	3.02	3.03	3.01	3.11
K2O	1.60	1.31	0.80	1.34	1.17	1.26
P2O5	0.40	0.38	0.18	0.35	0.32	0.33
Rb	29	28	nd	27	nd	22
Ba	731	649	406	557	752	912
Sr	599	620	596	712	581	588
V	220	228	236	235	251	250
Cr	99	83	22	57	86	92
Ni	64	78	36	46	47	45
Zr	154	130	80	120	122	124
Sc	25	26	24	25	29	29
Cu	79	82	55	60	81	83
Nb	7.1	7.6	nd	7.2	nd	6.7
La	21.1	17.5	nd	13.9	nd	32.8
Ce	43.5	37.9	nd	30.7	nd	69.7
Nd	25.6	23.4	nd	20.6	nd	42.0
Sm	5.94	5.13	nd	6.20	nd	10.70
Eu	1.37	1.35	nd	1.04	nd	2.41
Gd	5.44	4.69	nd	4.80	nd	11.10
Dy	4.88	4.99	nd	4.30	nd	8.86
Er	3.75	2.33	nd	2.60	nd	5.47
Yb	3.20	2.22	nd	2.30	nd	5.29
Y	28.10	29.20	nd	28.90	nd	54.20
Ba/La	34.64	37.09	nd	40.05	nd	27.82
La/Yb	6.59	7.88	nd	6.04	nd	6.20
87Sr/86Sr	0.70396	0.70405	nd	0.70399	0.70394	0.70396
143Nd/144Nd	0.51286	0.51284	nd	0.51283	0.51288	0.51292
Lat	13.954	13.965	14.029	14.069	14.071	14.076
Lon	-87.212	-87.209	-87.220	-87.273	-87.237	-87.240

Sample	HON113	HON114	HON115	HON116	HON117	HON118
SiO2	51.73	54.46	51.83	51.39	50.57	53.54
TiO2	1.11	1.21	1.14	1.26	1.07	0.87
Al2O3	17.58	16.77	17.99	17.47	17.17	17.38
FeO	9.21	9.18	9.04	9.08	9.09	8.68
MnO	0.17	0.17	0.15	0.14	0.16	0.20
MgO	5.41	3.27	5.46	5.44	5.75	5.98
CaO	8.72	7.40	8.85	8.71	9.38	9.38
Na2O	2.99	3.31	3.13	3.28	2.94	2.72
K2O	1.21	1.65	1.07	1.47	1.27	2.05
P2O5	0.44	0.33	0.40	0.41	0.34	0.34
Rb	nd	42	17	26	26	54
Ba	639	878	560	601	600	942
Sr	575	550	610	563	624	660
V	226	255	239	222	215	252
Cr	115	14	99	124	180	125
Ni	50	17	42	75	67	58
Zr	163	135	158	145	97	119
Sc	28	28	26	25	27	29
Cu	55	10	63	65	66	74
Nb	nd	9.7	8.4	20.4	7.2	3.9
La	nd	40.5	19.8	21.7	22.9	24.2
Ce	nd	72.7	34.0	40.8	39.5	38.9
Nd	nd	49.3	24.1	27.2	26.0	25.3
Sm	nd	11.50	6.31	5.38	6.69	6.18
Eu	nd	2.82	1.60	1.29	1.85	1.44
Gd	nd	12.00	5.39	5.42	7.35	7.07
Dy	nd	11.50	4.21	4.91	6.65	6.13
Er	nd	7.21	2.35	2.65	3.26	3.59
Yb	nd	4.69	2.68	2.80	3.62	3.69
Y	nd	71.90	31.20	30.70	55.80	53.90
Ba/La	nd	21.67	28.29	27.67	26.21	38.94
La/Yb	nd	8.64	7.39	7.75	6.33	6.56
87Sr/86Sr	0.70402	0.70451	0.70401	0.70388	0.70409	0.70408
143Nd/144Nd	0.51283	0.51280	0.51284	0.51285	0.00000	0.51289
Lat	14.152	14.163	14.260	14.136	14.128	14.077
Lon	-87.276	-87.325	-87.392	-87.341	-87.365	-87.311

Sample	HON119	HON120	HON121	HON122	HON123	HON124
SiO2	52.25	52.57	51.45	51.30	51.77	52.80
TiO2	1.31	1.04	1.04	1.02	1.24	1.31
Al2O3	17.24	17.31	17.08	17.53	17.19	16.57
FeO	9.10	9.34	8.91	9.56	9.24	9.09
MnO	0.16	0.17	0.12	0.14	0.16	0.17
MgO	5.52	5.31	4.78	4.77	4.73	4.74
CaO	9.03	9.05	8.57	8.94	8.59	8.35
Na2O	3.08	2.94	2.88	2.93	3.06	3.13
K2O	1.41	1.50	1.41	1.04	1.36	1.49
P2O5	0.46	0.37	0.34	0.30	0.48	0.64
Rb	26	29	27	14	21	21
Ba	654	783	698	796	739	774
Sr	578	626	556	544	664	645
V	224	231	235	246	235	207
Cr	108	76	131	107	117	105
Ni	50	60	71	50	54	34
Zr	186	136	148	126	149	234
Sc	26	26	28	29	27	25
Cu	76	79	90	56	67	45
Nb	12.9	7.2	8.1	6.2	9.4	12.7
La	28.3	28.3	52.8	54.3	23.8	27.8
Ce	48.5	53.4	54.7	64.6	44.8	58.1
Nd	35.5	35.7	55.8	68.0	29.4	38.2
Sm	9.19	8.72	12.30	17.00	8.42	10.60
Eu	2.18	1.42	1.92	2.56	1.58	1.45
Gd	7.58	6.73	13.50	16.00	6.93	7.59
Dy	6.21	7.78	13.40	16.10	5.46	6.11
Er	2.97	5.65	10.40	12.10	4.96	4.11
Yb	2.99	3.26	6.15	6.86	2.98	3.40
Y	37.40	43.20	98.10	98.80	51.50	44.60
Ba/La	23.10	27.67	13.22	14.66	31.06	27.86
La/Yb	9.46	8.68	8.59	7.92	7.99	8.18
87Sr/86Sr	0.70394	0.70398	0.70406	0.00000	0.70407	0.70415
143Nd/144Nd	0.51283	0.51286	0.51280	0.00000	0.51285	0.00000
Lat	14.091	14.081	14.020	14.033	14.039	13.936
Lon	-87.366	-87.331	-87.326	-87.366	-87.067	-87.264

Sample	HON125	ZA1	ZA2	ZA3	ZA4B	ZA5
SiO2	51.18	63.03	53.23	52.26	52.10	58.43
TiO2	1.01	0.62	0.87	0.97	0.95	1.00
Al2O3	17.58	16.50	18.23	18.88	19.12	17.08
FeO	8.75	5.51	8.51	9.18	9.02	7.60
MnO	0.15	0.14	0.17	0.17	0.17	0.20
MgO	4.94	1.13	5.44	4.18	4.97	2.37
CaO	9.72	4.20	8.88	8.95	9.22	6.32
Na2O	3.14	5.13	3.34	3.28	3.16	4.16
K2O	1.33	1.48	1.18	0.88	0.84	1.27
P2O5	0.43	0.34	0.32	0.31	0.29	0.33
Rb	19	22	19	14	9	17
Ba	816	1011	625	536	682	701
Sr	612	502	515	552	547	528
V	229	22	214	225	258	109
Cr	74	6	105	25	40	8
Ni	35	4	79	23	55	6
Zr	212	100	107	102	81	83
Sc	27	10	26	26	25	22
Cu	69	11	101	104	341	49
Nb	10.5	5.7	14.3	4.3	5.2	4.5
La	23.0	16.1	14.1	11.0	11.1	10.4
Ce	46.4	28.6	27.5	23.7	24.6	23.6
Nd	28.2	22.5	16.4	15.9	15.0	17.6
Sm	6.61	5.60	3.52	3.32	4.05	3.17
Eu	1.58	1.81	1.32	1.26	1.34	1.56
Gd	5.45	5.97	3.81	3.83	3.57	4.38
Dy	4.53	6.74	3.80	3.70	4.38	4.65
Er	3.45	5.35	2.90	3.00	2.57	3.89
Yb	2.46	3.47	2.14	1.75	2.35	2.72
Y	31.50	50.70	24.50	25.70	26.80	34.80
Ba/La	35.48	62.80	44.32	48.70	61.44	67.36
La/Yb	9.35	4.64	6.59	6.29	4.72	3.82
87Sr/86Sr	0.70403	0.70386	0.70370	0.70388	0.70386	0.70381
143Nd/144Nd	0.51283	0.51299	0.51296	0.51302	0.51297	0.51298
Lat	14.215	13.358	13.352	13.314	13.313	13.321
Lon	-87.264	-87.603	-87.606	-87.586	-87.586	-87.615

Sample	ZA6	ZA7	YO1	YO2	YO3	YO4
SiO2	49.71	51.83	47.99	48.41	49.13	51.37
TiO2	0.78	0.88	1.93	1.94	1.77	2.10
Al2O3	22.54	19.53	17.26	17.32	16.88	16.92
FeO	7.26	9.17	8.74	8.87	8.84	9.04
MnO	0.14	0.18	0.15	0.15	0.16	0.16
MgO	2.85	3.63	6.86	7.00	6.84	4.83
CaO	11.10	9.71	8.48	8.70	8.53	7.58
Na2O	2.88	3.18	3.86	3.64	3.91	4.13
K2O	0.47	0.62	1.66	1.65	1.53	1.95
P2O5	0.17	0.19	0.51	0.52	0.52	0.43
Rb	6	9	15	14	15	45
Ba	336	484	246	278	349	187
Sr	702	534	612	768	563	425
V	193	291	198	205	205	221
Cr	11	17	173	188	197	47
Ni	6	59	89	121	121	30
Zr	32	49	226	242	258	292
Sc	22	31	25	25	26	24
Cu	89	132	42	43	51	22
Nb	2.2	2.9	39.3	44.7	28.6	52.5
La	5.5	7.7	29.1	23.7	21.0	29.7
Ce	11.7	14.6	47.5	46.6	43.1	60.5
Nd	9.1	12.1	27.5	24.7	22.1	33.2
Sm	2.21	3.20	5.14	6.30	4.52	5.13
Eu	0.85	1.15	2.01	1.25	1.52	1.52
Gd	2.42	3.23	6.37	5.70	5.36	7.10
Dy	2.91	2.99	7.54	6.00	5.07	7.65
Er	1.93	2.04	5.04	3.35	4.22	4.07
Yb	1.57	1.73	3.36	2.25	2.52	2.55
Y	20.30	26.50	55.90	40.70	38.50	50.00
Ba/La	61.15	63.21	8.46	11.71	16.60	6.29
La/Yb	3.50	4.43	8.66	10.53	8.33	11.65
87Sr/86Sr	0.70378	0.70382	0.70288	0.00000	0.70321	0.00000
143Nd/144Nd	0.51292	0.51299	0.51304	0.00000	0.51299	0.51303
Lat	13.313	13.316	nd	nd	nd	14.983
Lon	-87.618	-87.617	nd	nd	nd	-87.924

Sample	YO5	YO6	YO7	YO8	YO9	YO10
SiO2	48.68	48.81	47.96	58.77	48.45	48.99
TiO2	2.54	2.53	2.52	0.46	2.61	2.55
Al2O3	17.57	18.31	17.29	18.86	17.39	17.06
FeO	10.67	9.92	10.56	4.43	10.78	10.51
MnO	0.18	0.18	0.18	0.15	0.18	0.18
MgO	4.75	4.15	4.62	0.52	4.77	5.58
CaO	8.44	9.07	8.33	2.36	8.77	8.81
Na2O	3.54	4.19	3.66	7.04	3.67	3.78
K2O	1.80	1.70	1.79	6.05	1.77	1.70
P2O5	0.54	0.76	0.55	0.10	0.55	0.57
Rb	15	20	18	66	19	19
Ba	244	327	244	6	245	280
Sr	556	622	528	9	576	507
V	279	225	272	4	274	260
Cr	44	29	37	5	45	84
Ni	22	17	24	2	39	87
Zr	272	237	261	473	264	264
Sc	27	25	26	4	28	28
Cu	28	27	27	8	24	36
Nb	38.4	52.7	47.7	75.3	51.0	49.5
La	25.7	25.9	25.4	44.6	25.4	24.6
Ce	53.8	51.8	50.1	82.7	52.0	50.8
Nd	29.4	28.9	28.1	34.0	29.9	27.4
Sm	6.83	8.07	7.70	3.15	6.71	7.51
Eu	2.33	1.30	1.62	2.13	1.51	2.23
Gd	6.88	6.30	6.97	8.42	6.75	6.93
Dy	7.04	6.42	6.21	7.20	6.78	6.19
Er	4.41	3.75	3.05	6.13	3.52	3.20
Yb	3.83	3.55	3.54	5.62	2.93	3.48
Y	45.10	41.00	37.80	57.40	37.30	37.40
Ba/La	9.50	12.63	9.61	0.13	9.65	11.38
La/Yb	6.71	7.30	7.18	7.94	8.67	7.07
87Sr/86Sr	0.70295	0.70308	0.70312	nd	0.70319	0.70316
143Nd/144Nd	0.51303	0.51299	0.51301	0.51306	0.51302	0.51298
Lat	14.980	14.977	14.981	14.995	14.960	14.930
Lon	-87.900	-87.951	-87.962	-87.949	-87.964	-87.981

Sample	YO11	YO12	YO13
SiO2	48.42	59.87	49.29
TiO2	1.91	0.64	1.85
Al2O3	19.56	18.26	20.04
FeO	8.43	4.11	8.28
MnO	0.16	0.12	0.15
MgO	3.96	0.57	4.09
CaO	9.87	1.94	10.14
Na2O	3.92	6.51	4.04
K2O	1.49	5.62	1.46
P2O5	0.56	0.16	0.51
Rb	15	nd	15
Ba	298	417	275
Sr	659	88	668
V	157	12	167
Cr	36	6	34
Ni	20	2	8
Zr	218	399	196
Sc	21	4	21
Cu	24	9	25
Nb	39.7	nd	35.0
La	21.6	nd	20.2
Ce	45.9	nd	42.6
Nd	25.4	nd	23.0
Sm	6.60	nd	7.97
Eu	2.22	nd	1.57
Gd	6.21	nd	5.66
Dy	5.54	nd	5.05
Er	2.96	nd	3.05
Yb	2.66	nd	2.48
Y	33.60	nd	28.90
Ba/La	13.81	nd	13.62
La/Yb	8.12	nd	8.15
87Sr/86Sr	0.70294	nd	0.70295
143Nd/144Nd	0.51303	nd	0.51302
Lat	14.981	14.992	14.986
Lon	-88.026	-88.012	-88.019

Sample	CN1	G1	G2
SiO2	50.80	70.84	59.65
TiO2	0.77	0.26	0.96
Al2O3	19.50	13.37	15.74
FeO	9.70	1.75	6.84
MnO	0.18	0.01	0.14
MgO	4.73	0.14	3.33
CaO	11.50	0.49	6.04
Na2O	2.20	4.66	2.93
K2O	0.46	3.94	1.60
P2O5	0.12	0.04	0.19
Rb	8	nd	nd
Ba	407	863	512
Sr	481	102	237
V	332	2	173
Cr	21	6	52
Ni	18	4	21
Zr	48	275	268
Sc	32	6	23
Cu	163	15	42
Nb	2.4	nd	nd
La	3.6	23.5	19.3
Ce	9.1	48.9	49.1
Nd	7.1	22.8	24.2
Sm	1.95	5.20	6.14
Eu	0.77	0.91	1.31
Gd	2.53	4.61	6.23
Dy	2.95	4.81	6.10
Er	1.73	3.78	4.04
Yb	1.62	3.21	3.27
Y	16.63	32.87	38.82
Ba/La	112.91	36.67	26.45
La/Yb	2.23	7.33	5.91
87Sr/86Sr	0.70397	0.70596	0.70660
143Nd/144Nd	0.51311	0.51274	0.51263
Lat	nd	nd	nd
Lon	nd	nd	nd

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