NIOBIUM CONTENTS OF CENTRAL AMERICAN LAVAS

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A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Science

Graduate Program in Geological Sciences

Written under the direction of Michael J. Carr

and approved by

New Brunswick, New Jersey

October, 1990

ABSTRACT OF THE THESIS

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125 samples of basalts and andesites from the volcanic front in Central America were analyzed for niobium and beryllium. Tungsten content was also determined because the tungsten-carbide mixer/mill is a source of niobium contamination. Regional variation in Nb may be looked at as consisting of two components: a variable degree of Nb depletion relative to Ba and La as shown on spidergrams in most but not all samples, and substantial differences in Nb behavior during differentiation from basalt to andesite. Nb increases in central Costa Rica and in the high Ti lavas from Nicaragua. Niobium appears to decrease with fractionation in western Costa Rica. In most samples from Guatemala, El Salvador and in the normal lavas from Nicaragua niobium remains low in the basalt-basaltic andesite range. However, analysis of a suite from San Miguel, El Salvador, suggests that Nb increases with fractionation.

The size and scope of our data set allow us to evaluate the various models for the origin of the Nb depletion: initial Nb depletion, source retention of Nb, or addition of slab/sediment derived fluids to a depleted mantle source. A slab component is present everywhere there is a Nb depletion except in the alkalic samples from

Costa Rica; however, the slab component correlates with the Nb depletion only in Nicaragua. In Nicaragua there is no initial Nb depletion. The depletions result from a Nb retaining phase in a depleted mantle that has been fluxed by sed/slab fluids. The positive correlation of Nb/La versus TiO_2/Y in Nicaragua suggests a Nb-Ti retaining phase. In Costa Rica there appears to be an initial Nb depletion. The high Ti, high Nb lavas from Nicaragua may result from melting a source with a Nb phase that has undergone a previous melt extraction.

Beryllium was measured because of the importance of ^{10}Be as a sediment tracer. Beryllium in Central America was found to act most like gadolinium, whereas in other volcanic rocks it has been found to act like Nd.

ACKNOWLEDGMENTS

Primary thanks go to Michael J. Carr for giving me the opportunity to do this project, and for the suggestions he made throughout the course of this work. Special thanks are also extended to Mark Feigenson and Jerry Delaney for their discussions and insights on many aspects of the research.

This research was funded by grants from the National Science Foundation, including EAR86-06986 and EAR88-03546.

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I. INTRODUCTION

Niobium depletion is a characteristic of volcanic arcs, both oceanic and continental. With rare exceptions, niobium is depleted in arcs but not in mid-ocean ridge basalts (MORB) or ocean island basalts (OIB) (Gill, 1981). Several models have been proposed to explain the Nb depletion: an initial source depletion (Salters, 1989), retention in a Ti-Nb-Ta (TNT) bearing phase (Reagan and Gill, 1988), or the addition of slab fluids that raise other incompatible elements but leave Nb at a low level (Davidson, 1989). Most models have been evaluated on limited data sets, sometimes on samples from a single volcano. Here in Central America we have a large number of samples from an entire arc. Because the arc is relatively short (1100 Km) and geochemical and geophysical parameters vary along the volcanic front, it is an ideal location to evaluate the various models for Nb depletion.

Beryllium was measured because of the importance of ^{10}Be as a sediment tracer (Brown et al., 1982: Tera et al., 1986; Ryan and Langmuir, 1988; Morris et al., 1990). For the discussion of beryllium see Appendix I.

II. BACKGROUND

A. Geologic Setting and Geochemical Characteristics

The Central American volcanic chain is the result of the subduction of the Cocos plate beneath the Caribbean plate (Fig. 1) (Molnar and Sykes, 1969). The basement

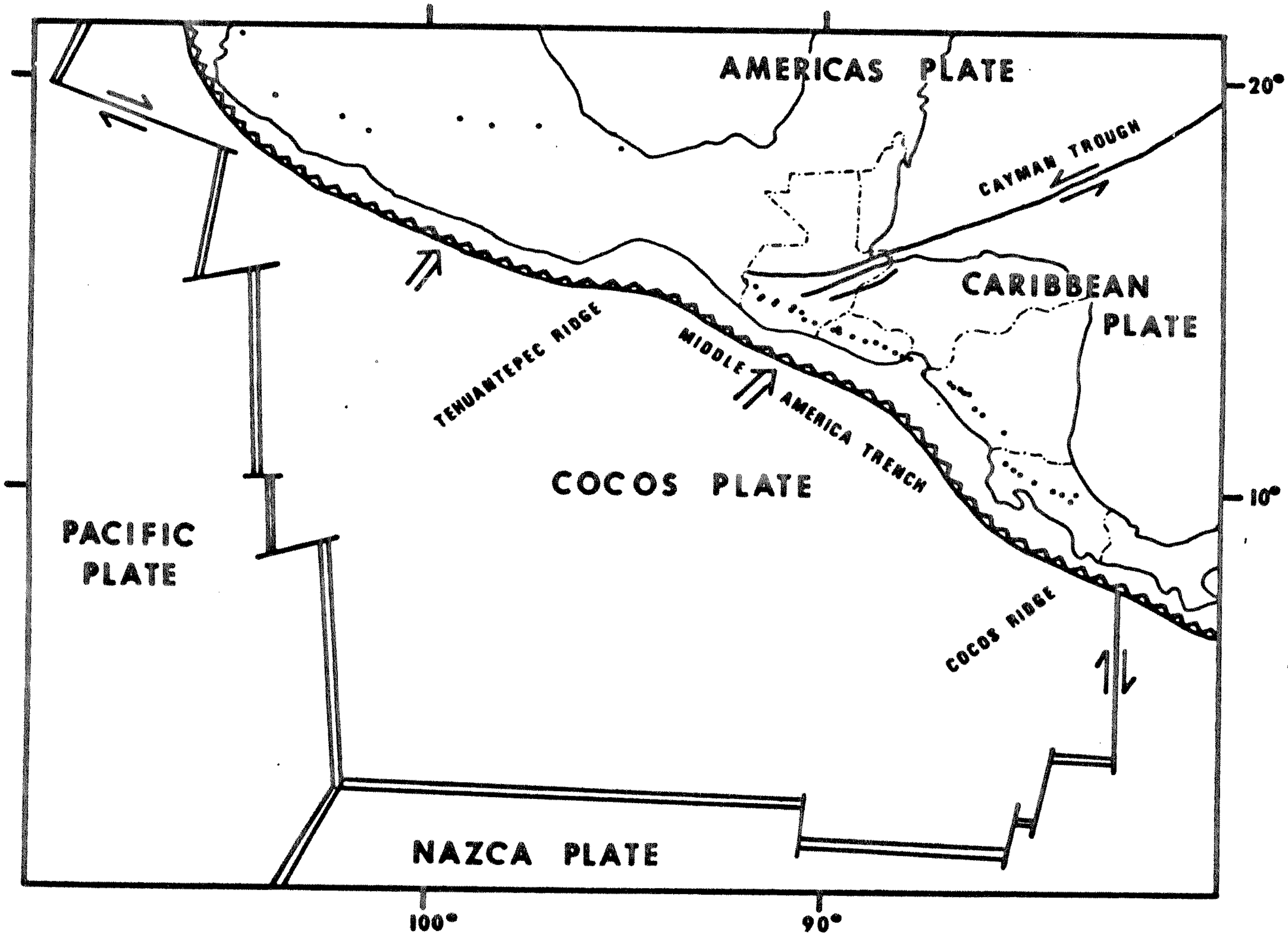


Fig. 1. Tectonic setting of Central American Arc.

beneath Guatemala, El Salvador and Nicaragua consists of Paleozoic metamorphic rocks, while the basement beneath Costa Rica is Mezozoic oceanic crust (Pilcher and Weyl, 1973). The volcanic front consists of eight segments separated by zones of transverse faulting (Stoiber and Carr, 1973).

Along the Central American volcanic front (CAVF) there are approximately forty Quaternary volcanic centers with basalt-andesite-dacite cones (Fig. 2). There are subalkaline cones behind the volcanic front (BVF) in Guatemala (Walker, 1981), unusual Ti-rich basalts in Nicaragua (Walker, 1984), and alkaline basalts in Costa Rica. There are also several large rhyolitic centers in Guatemala and El Salvador (Carr et al., 1979). The basalts are predominately calcalkaline, although there are several tholeiitic centers in Nicaragua and high Al basalts in Guatemala (Grant et al.,1984) and Costa Rica (Prosser and Carr, 1987). The andesites, with the exception of some high Ti lavas in Nicaragua (Walker, 1984) appear to be derived from the basalts by fractional crystallization of olivine, plagioclase, clinopyroxene, and/or magnetite (Walker, 1984; Carr and Pontier, 1981; Fairbrothers et al., 1978; Rose et al., 1977). The silicic lavas may have been produced by melting of the lower crust (Grant et al., 1984) and are not a focus of this project.

While there are many pertinent geochemical studies of the magmatic evolution of individual volcanoes or volcanic

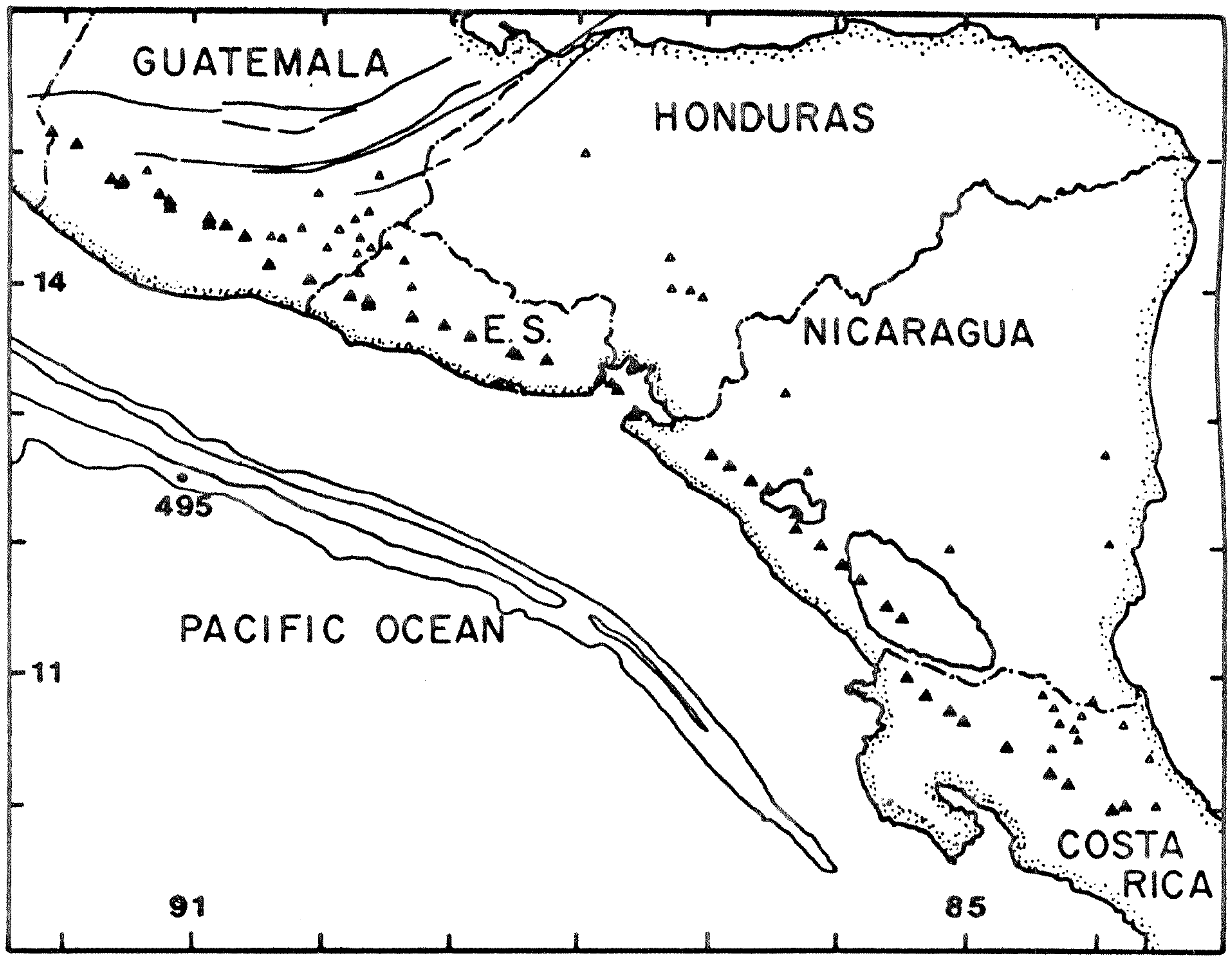


Fig. 2. Locations of Central American volcanoes. Solid triangles represent volcanoes on the volcanic front. Open triangles represent behind the front volcanoes. Site of DSDP Hole 495 is marked. E.S. is El Salvador. Contours mark position of Middle American Trench.

centers, e.g. Arenal (Cigolini and Kudo, 1987), Santa Maria (Rose et al., 1977), Cerro Negro (Walker and Carr, 1986); Fuego (Chesner and Rose, 1984); Poas (Prosser and Carr, 1987); Nejapa and Granada (Walker, 1984), there are few regional studies relating geochemical and geophysical parameters along the entire arc.

In his 1984 study, Carr shows two distinct patterns of regional variation. On a large scale, approximately 1000 km, shifts in apparent cotectics, silica contents, edifice height, magma density, and compatible element concentrations correlate with crustal thickness. On a smaller scale, approximately 150 km, arc segments correlate with volcano size and LIL contents. K_2O was found to be unrelated to depth to seismic zone (Carr et al., 1979). These findings suggest that magma is generated near the upper surface of the subducted slab and ponds near the base of the crust. Fractional crystallization decreases the density of the magma and allows it to rise to the surface. The variation in REE's is also consistent with magma ponding and fractional crystallization near the base of the crust; however, the LREE-enriched lavas in Costa Rica may reflect a different source region (Milionis, 1987).

Regional isotopic studies show the relation between crustal thickness and $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios (Carr, 1984) and more importantly show the existence of several source components (Grant et al., 1984; Feigenson and Carr, 1986; Carr et al., 1990). According to Carr et al. (1990)

there appear to be four potential sources beneath Central America, DM (depleted mantle or N-MORB), EM (enriched mantle or E-MORB), MM (depleted mantle modified by sediment derived fluid) and crust.

Ba/La ratios vary along the arc (Fig. 3). Ba/La ratios are thought to reflect a slab-derived component (Kay, 1980). In general, Ba/La values are: arc>15>MORB or OIB (Perfit et al., 1980). The excess Ba is presumed to come from altered crust or marine sediment. However, Morris and Hart (1983) have shown that much of the variation in Ba/La in arcs reflect a greater variation in La than in Ba. Low ratios, approaching those of MORB and OIB and indicating a small slab component, occur in cental Costa Rica, the high Ti lavas from Nicaragua and the BVF lavas from Guatemala. The highest ratios occur in the low Ti lavas from Nicaragua. The wide range of Ba/La ratios in Nicaragua suggest mixing between a slab-rich and a slab-poor component.

La/Yb ratios are thought to reflect degree of melting although variations in La/Yb ratios may also reflect source differences (Fig.4). In general high La/Yb ratios reflect small degrees of melting, and lower ratios reflect higher degrees of melting. Small degrees of melting occur in central Costa Rica where there are the highest La/Yb ratios. High degrees of melting occur in Nicaragua.

Ba/La and La/Yb ratios covary (Fig 5). Regions with a small degree of melting have a small slab component and

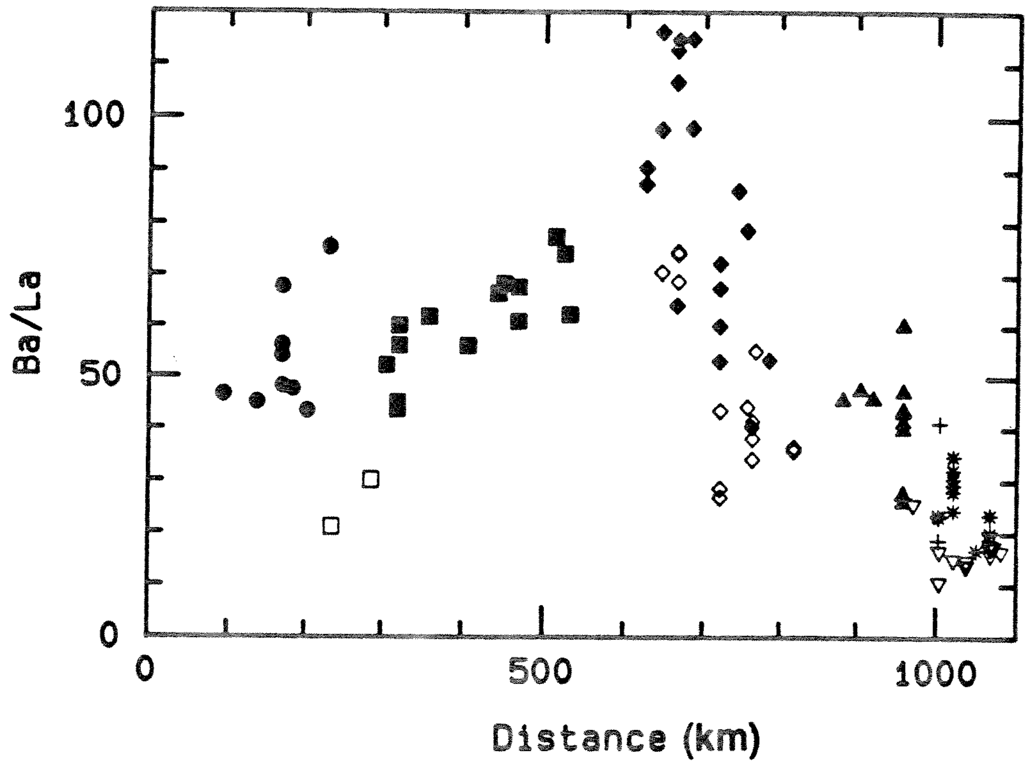


Fig. 3. Ba/La versus distance along the arc. SiO2 < 55 wt%.

SYMBOLS

● CAVF of Guatemala
■ CAVF of El Salvador
◆ CAVF of Nicaragua
▲ CAVF of western Costa Rica
✳ CAVF of central Costa Rica
○ Silicic volcanics of Guatemala
□ BVF lavas of Guatemala
◇ High-ti lavas of Nicaragua
▽ Alkaline lavas of Costa Rica

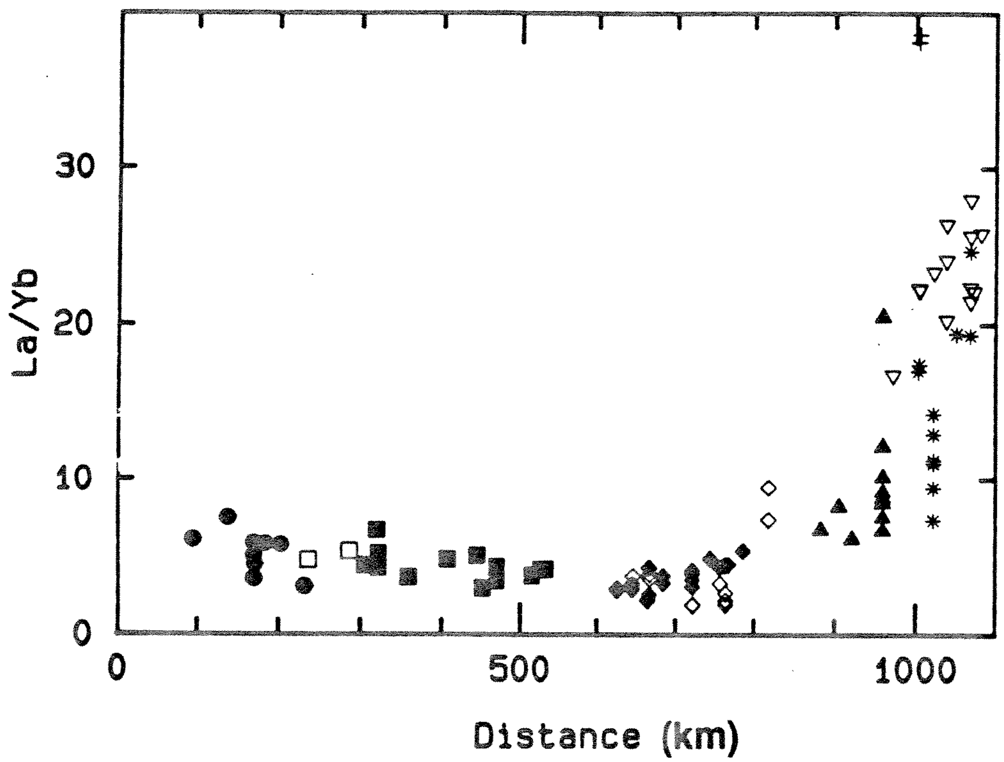


Fig. 4. La/Yb versus distance along the arc. SiO2 <55wt%.
Symbols as in Fig. 3.

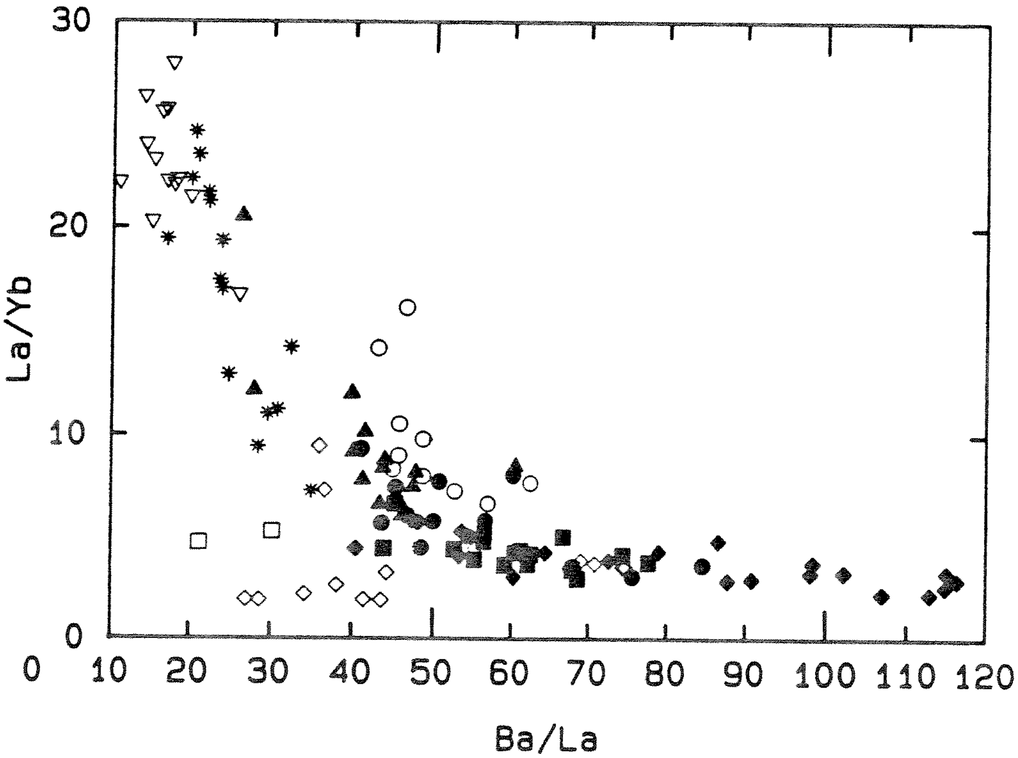


Fig. 5. Ba/La versus La/Yb. Symbols as in Fig. 3.

areas with a high degree of melting have a large slab component.

Based on isotope ratios, Ba/La and La/Yb ratios, and dip of slab, Carr et al. (1990) propose a model relating tectonic and geochemical parameters for magma generation beneath Central America. In western Nicaragua where the dip is steep there is a high degree of melting of a small volume resulting in a low total flux of magma. The Ba/La ratios show a significant slab signature. In central Costa Rica where the dip is shallower there is a lower percent melt through a larger volume resulting in a higher flux of magma. Here the slab component is very small. The most likely mantle structure is a mixture of depleted mantle (DM), enriched mantle (EM) and slab modified mantle (MM).

B. Niobium

A common characteristic of island arc basalts is their depletion of niobium compared with MORB and OIB (Perfit et al., 1981). Niobium is also depleted in the continental crust (Hofmann et al., 1986). Niobium is a high charge, small radius cation which can occur as Nb^{3+}, Nb^{4+} or Nb^{5+} (McCallum, 1978). Because of its size and charge Nb forms complexes more readily than the other elements in the extended rare earth element diagram (Briqueu, 1984). It substitutes readily for Ti in such phases as rutile, sphene, ilmenite and perovskite. It may substitute for Ti in amphibole, clinopyroxene or magnetite. Niobium acts imcompatibly in the common basalt and peridotite minerals.

It typically increases with fractionation in both volcanic arcs and within-plate volcanoes (Pearce and Norry, 1979). Niobium cannot be mobilized by H_2O in dehydration reactions even under high pressure (Tatsumi et al., 1986). Absolute abundance in various tectonic settings are shown in Table 1.

Niobium depletion is often shown on various extended rare earth element diagrams ("spidergrams") (Briqueu et al., 1984; Wood, 1979; Thompson et al., 1984) where the rare earth elements (REE), large ion lithophile elements (LILE) and high field strength elements (HFSE, e.g. Ta, Nb, Ti, Y, Zr, Hf) are arranged in order of increasing compatibility and are normalized to a convenient reference such as MORB or chondrites. These spidergrams show that niobium is depleted relative to Ba and La in most volcanic arcs but is not depleted in MORB or OIB.

A word needs to be said about the construction of spidergrams. The placement of Nb on the spidergram depends on the bulk distribution coefficient. Nb is placed between Ba and La based on a bulk distribution coefficient determined for mantle mineralogies (Wood, 1979). Briqueu (1984) using a different method places Nb between La and Ce. Any model that attempts to explain the niobium depletion in arc basalts must be consistent with its non-depletion in MORB and OIB.

C. Models for Niobium Depletion

There are several models that attempt to explain Nb

TABLE 1

SELECTED NIOBIUM ABUNDANCES

LOCATION	NB PPM	REFERENCE
MORB		
Atlantic	1.28-6.97	1
Pacific	1.18-6.83	1
Tholeiite	4.6	2
Transitional	16	2
IAB		
Tholeite	1.7	2
Calc-alkaline	2.7	2
IAB	.28-3.9	3
OIB		
Tholeiite	13	2
Alkaline	84	2
OIB	13-48	1
Volcanoes/Arcs		
Okmok-basalts	2.4-3.7	4
Marianas	1-3	5
NE Japan Arc	.7-3.5	6
Andes (SVZ)	1.4-7.8	7
Kuriles	.9-7.7	8
Iceland	2-35	9
Sediment		
Pelagic mud	1.5	10
PAWNS (Pacific authigenic weighted mean sediment)	1.25	5

1. Hofmann, et al., 1986
2. Pearce, 1982
3. BVSP, 1981
4. Nye and Reid, 1986
5. Hole et al., 1984
6. Sakuyama and Nesbitt, 1986
7. Hickey et al., 1986
8. Bailey et al., 1989
9. Wood, 1979
10. Thompson et al., 1984

depletion in typical arc lavas: (1) An initial Nb depletion inherited from the source (Salters, 1989); (2) A depleted source (N-MORB or MORB residue) with LILE and LREE enrichments from the slab (Davidson, 1989) that are superimposed on a depleted mantle, creating an apparent Nb depletion because Nb is not added in the slab-derived fluids; (3) A residual Nb-bearing phase in the mantle (Morris and Hart 1983, 1986; Reagan and Gill, 1988).

1. Initial Depletion Model

Low Nb may be an inherent source characteristic, the result of some sort of previous depletion or mantle recycling (Ryerson and Watson, 1987; Salters and Shimizu, 1988; Thompson et al., 1984). According to Ryerson and Watson (1987), the source for IAB (island arc basalts) has been depleted by several stages of melt extraction. Thompson et al. (1984) suggest that Nb in a residual phase has migrated from sub-arc region to the source for OIB thus also explaining the high HFSE in OIB. Whatever the mechanism, in this model Nb has been previously removed from the mantle beneath the arc.

That HFSE depleted mantle exists is shown by the widespread occurrence of HFSE-depleted clinopyroxene in peridotite nodules (Salters and Shimizu, 1988; Salters 1989). Salters and Shimizu (1988) claim that the depletion in the clinopyroxene is representative of the whole rock, and that these HFSE-depleted peridotites are the source for IAB. However, according to Jochum et al. (1989), while the clinopyroxenes may be HFSE-depleted, the whole rock is not, and therefore cannot be a source of Nb depletion. Their study on spinel peridotite xenoliths shows uniform depletion in the highly incompatible elements. These xenoliths represent MORB source residue and not IAB residue. However, according to Hildreth and Moorbath (1988), it is possible that depleted peridotite could be the mantle source (rather than the residue) for Andean arc basalts. This model does not explain why Nb depleted mantle exists only beneath arcs and not in other tectonic environments.

2. Slab Fluids Model

In this model slab/sediment-derived fluids added to a depleted or N-MORB mantle create an apparent Nb depletion. These fluids are rich in LILE and LREE but are low in Nb. This is essentially what has been proposed for the Kuriles (Bailey et al., 1989), the NE Japan Arc (Sakuyama and Nesbitt, 1986) and the Mariana Islands (Hole et al., 1984). Fluid added to a high degree melt of an E-MORB source has also been proposed for Okmok volcano in the Central Aleutians (Nye and Reid, 1986). This model cannot explain the Nb depletion if the mantle beneath arcs is predominately like that beneath ocean islands.

3. Residual Nb Bearing Phase Model

If the mantle source has a large OIB component then a Nb retaining phase is required (Morris and Hart, 1983). According to Morris and Hart (1983, 1986) a TNT phase is necessary both because a slab component could not overwhelm an OIB source and because the absolute abundances of the HFSE are lower in arcs than in MORB or OIB.

A difficulty with this model is that the stability of a Ti-rich phase under mantle conditions is questionable. Both Green and Pearson (1986, 1987) and Ryerson and Watson (1987) determined experimentally that the TiO_2 contents of arc magmas are too low for rutile to be stable during melting of the mantle. There would have to be at least 7% TiO_2 to be in equilibrium with a Ti-rich phase. Variations in oxygen fugacity did not significantly alter the results. Perovskite did not appear in their experiments. If the bulk Ti were high enough, sphene, not perovskite, would be the stable phase in subduction zones (Arculus and Powell, 1986). Sphene, however, would fractionate the REEs and this has not been observed (Perfit et al., 1980).

In some arc lavas there is no correlation between Nb and Ti depletion (Briqueu et al., 1984). Therefore a phase other than a Ti-rich mineral such as kaersutitic amphibole or phlogopite may then cause the Nb depletion (Briqueu, 1984; Thompson et al., 1984). If the Nb distribution coefficient for a phase is high enough only a small amount need be present to cause a Nb depletion.

The stability of Nb bearing phases in a mantle that has been fluxed by large amounts of slab fluids has not been determined. According to the models of Reagan and Gill (1989) and Arculus and Powell (1986), a TNT phase is produced in the mantle beneath the forearc by metasomatizing fluids from the slab rich in LILEs and LREEs. Nb is retained in the slab because it is not mobilized during dehydration reactions. The fluids create enriched veins or pods containing a TNT phase. The veins are dragged downward by mantle convection. When the metasomatized mantle melts Nb is retained in a residual TNT phase and the Nb depleted lavas result.

D. Central American Models

There are only two studies that attempt to explain Nb contents in Central American lavas, and both give quite different explanations. Reagan and Gill (1989) propose a residual titanate, e.g. rutile, in an OIB source to account for the low Nb in calcalkaline basalts from Turrialba in Costa Rica. The absence of such a phase accounts for the one high Nb basalt (HNB) (35ppm). In this model all the samples result from a mixture of a large amount of a high degree melt of a MORB-like souce and a small amount of a small degree (1%) melt of an OIB-like source. For the Nb depleted samples, the OIB end member was previously metasomatized by slab-derived fluids to form a stable TNT phase. For the one undepleted sample, the OIB end member was not metasomatized.

Walker et al. (1990), in their study on high and low Ti lavas in Nicaragua, attributes the LILE/HFSE fractionation to the incorporation of pelagic sediment. The high Ti lavas that do not have a niobium depletion are from a relatively enriched type mantle. The low Ti, Nb depleted lavas are created by adding up to 5% pelagic sediment with varying composition to the high Ti source.

III. ANALYTICAL TECHNIQUES

125 samples were analyzed for Nb, Be and W. The samples are predominately mafic lavas, but several rhyolites from Guatemala are also included. Ba and Rb were measured for all samples. Approximately 60 samples were analyzed for REEs. Eight samples from San Miguel, El Salvador were analyzed for Nb and W. The complete data set is listed in Appendix VI. Sample preparation follows the procedure in Feigenson and Carr (1985). 0.2000gm of sample is mixed with 0.500gm $LiBO_2$ and fluxed at 1000C for 15 minutes. The mixture is then dissolved in 30 ml 1.5N HCl. The analysis was done on a DC Plasma Atomic Emission Spectrometer (DCP-AES) at Rutgers University. Settings for the DCP-AES are given in Appendix II. The procedure for separating the REEs is in Appendix III. Several USGS standards, BCR, BHVO, AGV, W1, GSP and our in-house standard, IZ, were run with the unknowns.

Most of the samples were ground in a tungsten carbide mixer/mill. Because the tungsten contains small amounts of miobium it is a possible source of niobium contamination (Hickson et al.,1986). Therefore all of the samples were also analyzed for tungsten which is present in very low abundances in basalts and andesites. Where tungsten was present a niobium correction was made. The tungsten standard was prepared by dissolving anhydrous sodium tungstate (Na_2WO_4) in distilled water over heat.

Niobium concentration is difficult to determine by atomic emission spectrometry because there is interference with nearby background lines. It was necessary to peak the DCP-AES very carefully and to make a background correction. The most troublesome parts of the analyses were the high standard deviations and the drift of the machine. Many of the samples were analyzed several times. The detection limit for niobium is approximately 2ppm, and the error is approximately 1ppm. In order to determine Be values it was first necessary to test for interference with Ti and V. No interference was found. The accuracy of the Be measurements depends on the accuracy of the standards and we lack standards with low Be values that are well accepted.

IV. RESULTS-NIOBIUM

The Nb data collected for this study are presented in Appendix VI. The data are plotted versus geographic position in Fig. 6. The filled symbols represent typical calcalkaline arc rocks. The Nb content in these rocks is low and near the detection limit everywhere except in central Costa Rica where the highest Nb concentrations occur. Nb is also high in the rhyolitic rocks in Guatemala probably because of enrichment by extreme differentiation. The other high Nb values occur in the behind-the-volcanic-

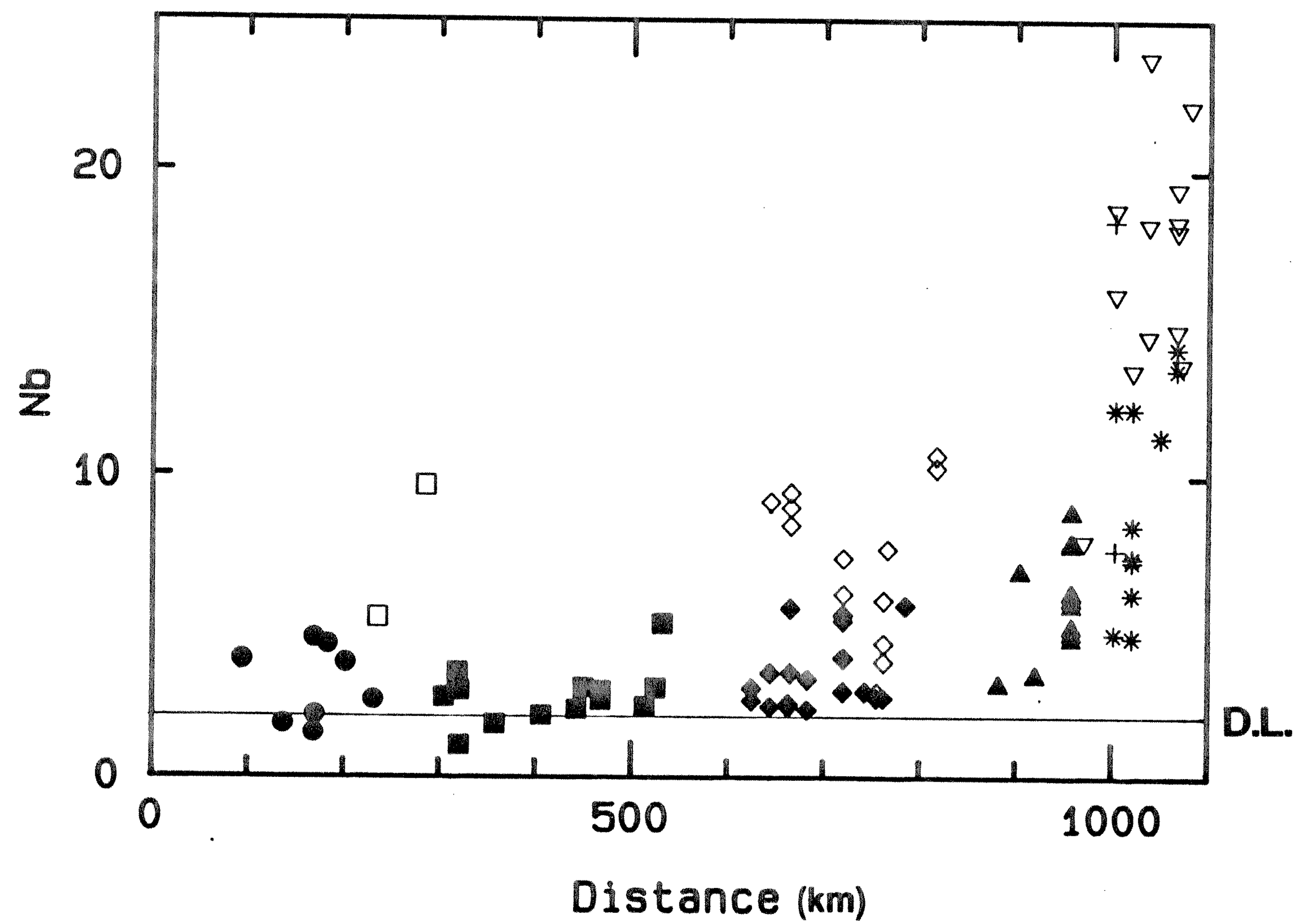


Fig. 6. Nb (ppm) versus distance along the arc. Symbols as in Fig. 3. D. L. is detection limit, approximately 2ppm.

front (BVF) samples in Guatemala and the high Ti samples from Nicaragua. There is no clear separation between the high Ti and normal rocks in Nicaragua which may indicate mixing betwseen these two magma types.

A. Depletion Shown on Spidergrams

The typical pattern of Nb depletion is best shown on spidergrams. Normalizing factors are given in Appendix IV. Along most of the arc Nb is depleted relative to Ba and La (Figs. 7, 8 & 9). In most of these samples there is also a positive Sr anomaly. In Nicaragua, however, Nb behaves differently in the normal and the high Ti lavas: Nb is depleted in the low Ti lavas but not depleted in the high Ti lavas. In spidergrams of the normal samples Nb depletion is accompanied by a Ti depletion.

B. Behavior During AFC

1. Nb versus K_2O

By plotting Nb against other incompatible elements it is apparent that Nb behaves differently during differentiation in four different geographic/geochemical groups. In central Costa Rica, Nb correlates positively with K_2O (Fig. 10). Here Nb acts incompatibly as it does in most arcs (Pearce and Norry, 1979). Nb also has a positive correlation with K_2O in the high Ti samples from Nicaragua, but the increase in Nb is not as great as it is in central Costa Rica. This may be because the more enriched high Ti lavas have mixed with low Ti, low Nb magmas that are

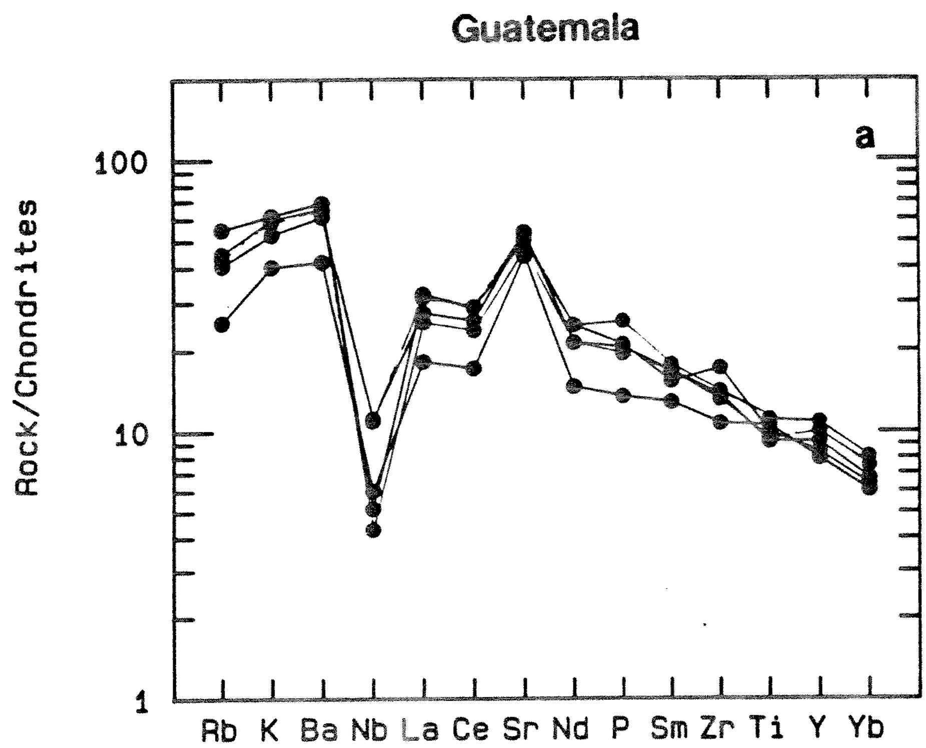


Fig. 7a. Representative spidergrams for Guatemala.

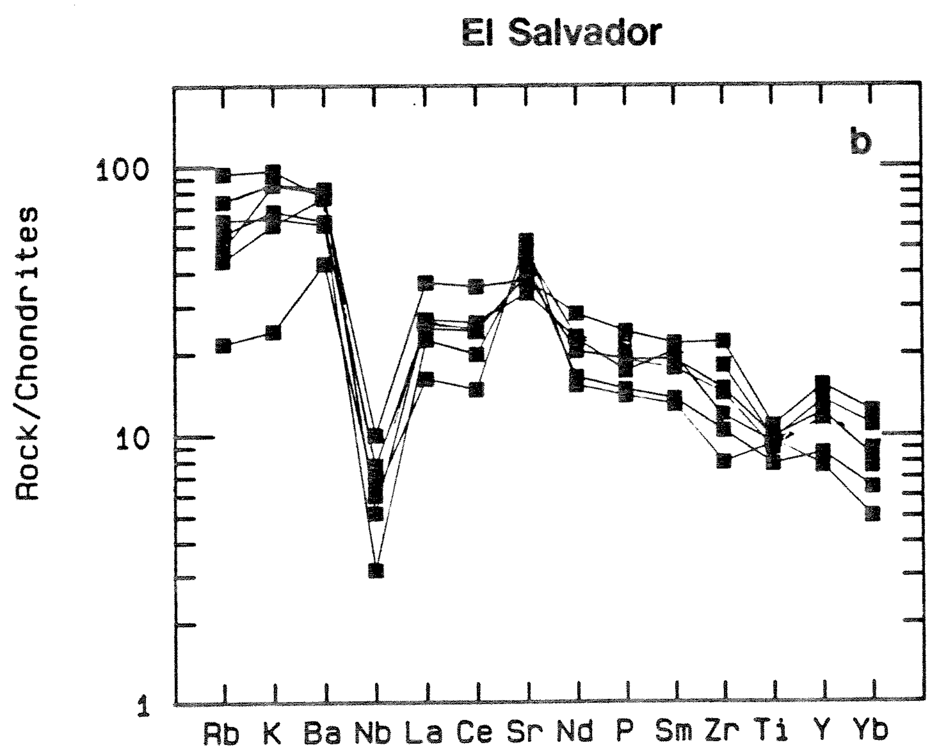


Fig. 7b. Representative spidergrams for El Salvador.

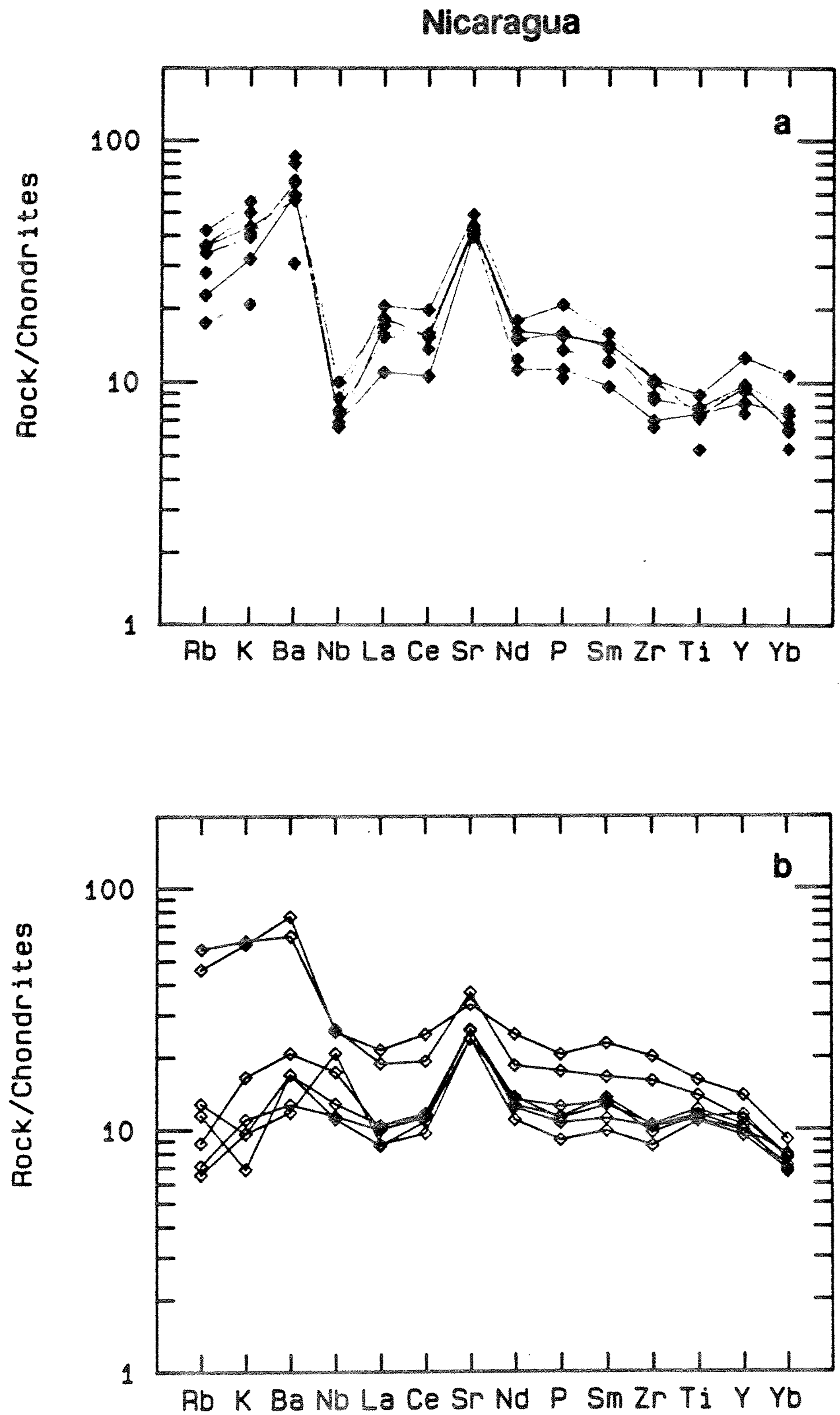


Fig. 8. Representative spidergrams for Nicaragua.
(a) normal lavas, (b) high Ti lavas.

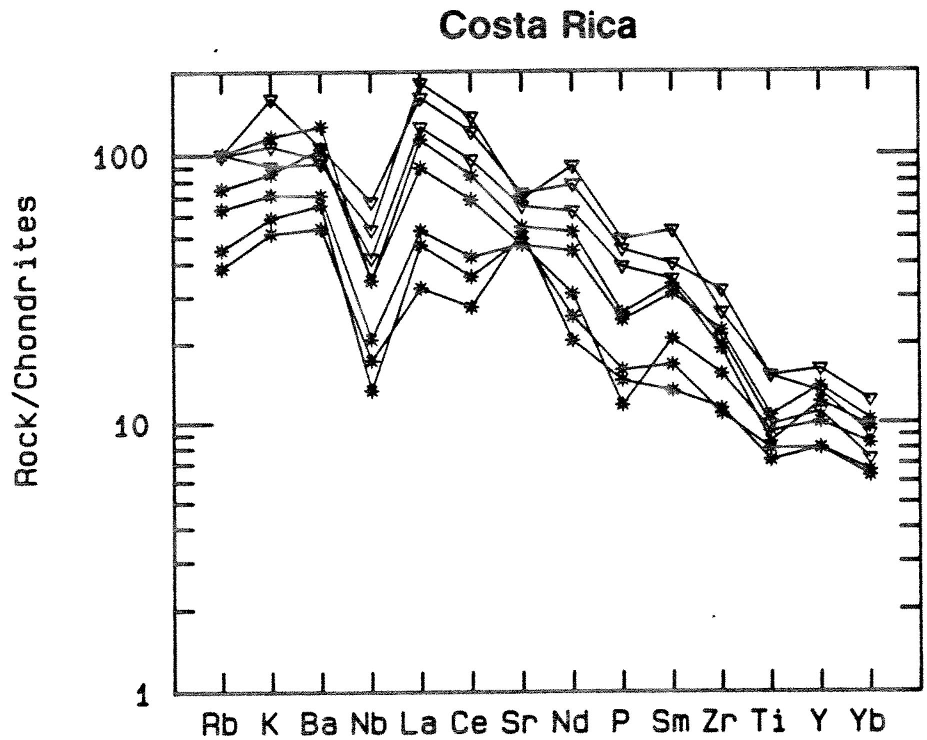


Fig. 9. Representative spidergrams for Costa Rica.

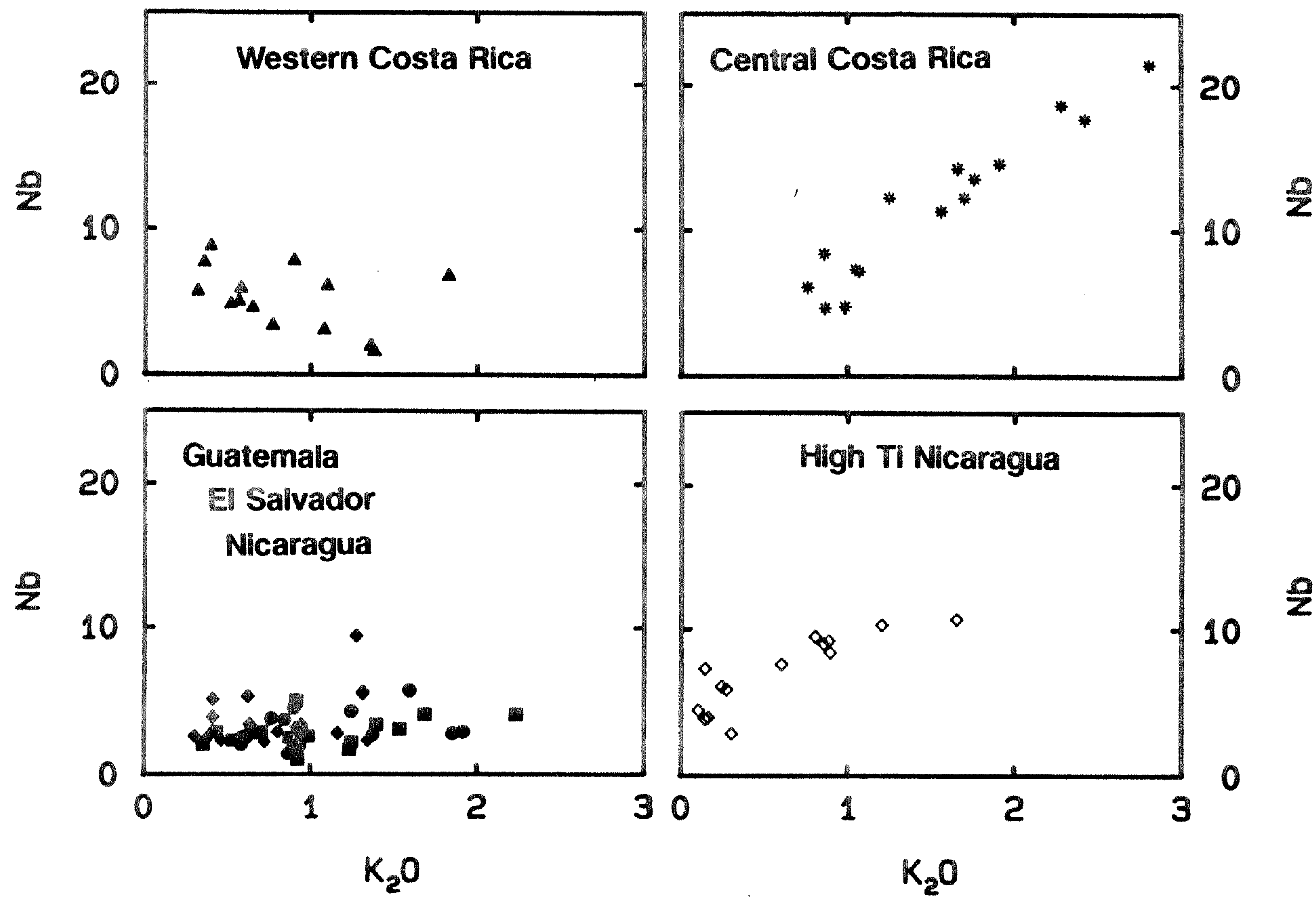


Fig. 10. Nb (ppm) versus K_2O (wt %).

present at the same volcanoes.

In western Costa Rica Nb displays an unusual decrease with increasing K_2O. Two possible explanations are: (1) Nb has an apparent bulk distribution coefficient greater than one implying that some phase is retaining Nb during fractional crystallization; or (2) there is mixing between normal arc magmas and high Nb alkalic magmas. In Guatemala, El Salvador, and Nicaragua Nb has little variation. It stays low, at or near our detection limit, over a wide range of K_2O. This suggests that Nb has a bulk distribution coefficient around one, or that the parental lavas have Nb contents of 1 ppm or less, below our detection limit. In the latter case the low slope of Nb versus K_2O is the result of the low initial concentration of Nb relative to K_2O.

2. Nb versus SiO_2

The variation of niobium versus SiO_2 is similar to that of Nb versus K_2O (Fig. 11). In central Costa Rica Nb increases with SiO_2. For these volcanoes and for most other Central American volcanoes, increasing silica means increasing extent of fractional crystallization and assimilation. In the high Ti samples Nb increases slightly. In western Costa Rica Nb decreases with increasing silica. In Guatemala, El Salvador, and Nicaragua Nb remains constant over a wide range of silica.

However, it is possible that our Nb values for the low SiO_2 and low K_2O lavas are too high and that the actual Nb

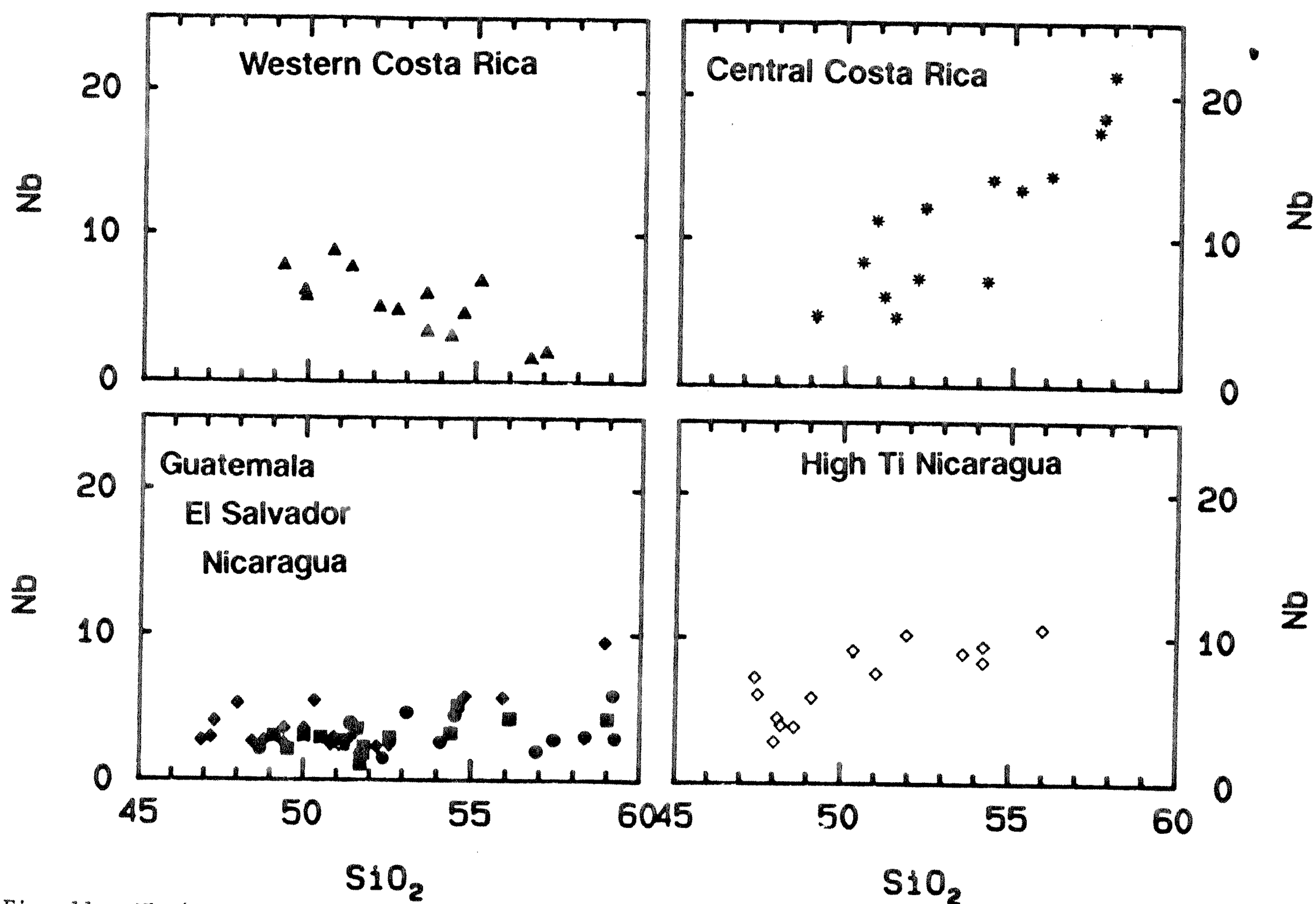


Fig. 11. Nb (ppm) versus SiO_2 (wt %).

values are lower. These measurements are close to our detection limit, 2 ppm, and because the error is ± 1 ppm, it is not possible to distinguish between measurements in this range. If the actual values for these low SiO_2, low K_2O lavas are lower than our values, then it may be that for these lavas Nb increases with differentiation.

3. Nb/Yb versus SiO_2

Plots of Nb/Yb versus SiO_2 for the four groups are given in Fig. 12. We formerly thought that Nb/Yb decreased in El Salvador (Bennett et al., 1989). However, as stated above, because the measurements are close to the detection limit, the low values of Nb/Yb in El Salvador may be an artifact, caused only by the measurable increase in Yb whereas Nb values are low random fluctuations about the detection limit.

Because of the possibility that Nb may be retained in a phase we examined representative minerals on the microprobe. In sample NE203 neither magnetite, hornblende, pyroxene nor olivine had Nb concentration above the detection limit estimated at 20 ppm.

V. DISCUSSION-NIOBIUM

We will now evaluate the models for Nb depletion described above in terms of our data. Because of the variations in geophysical and geochemical parameters along the arc there may be different causes of Nb depletion in different segments of the arc. In two of the models, slab

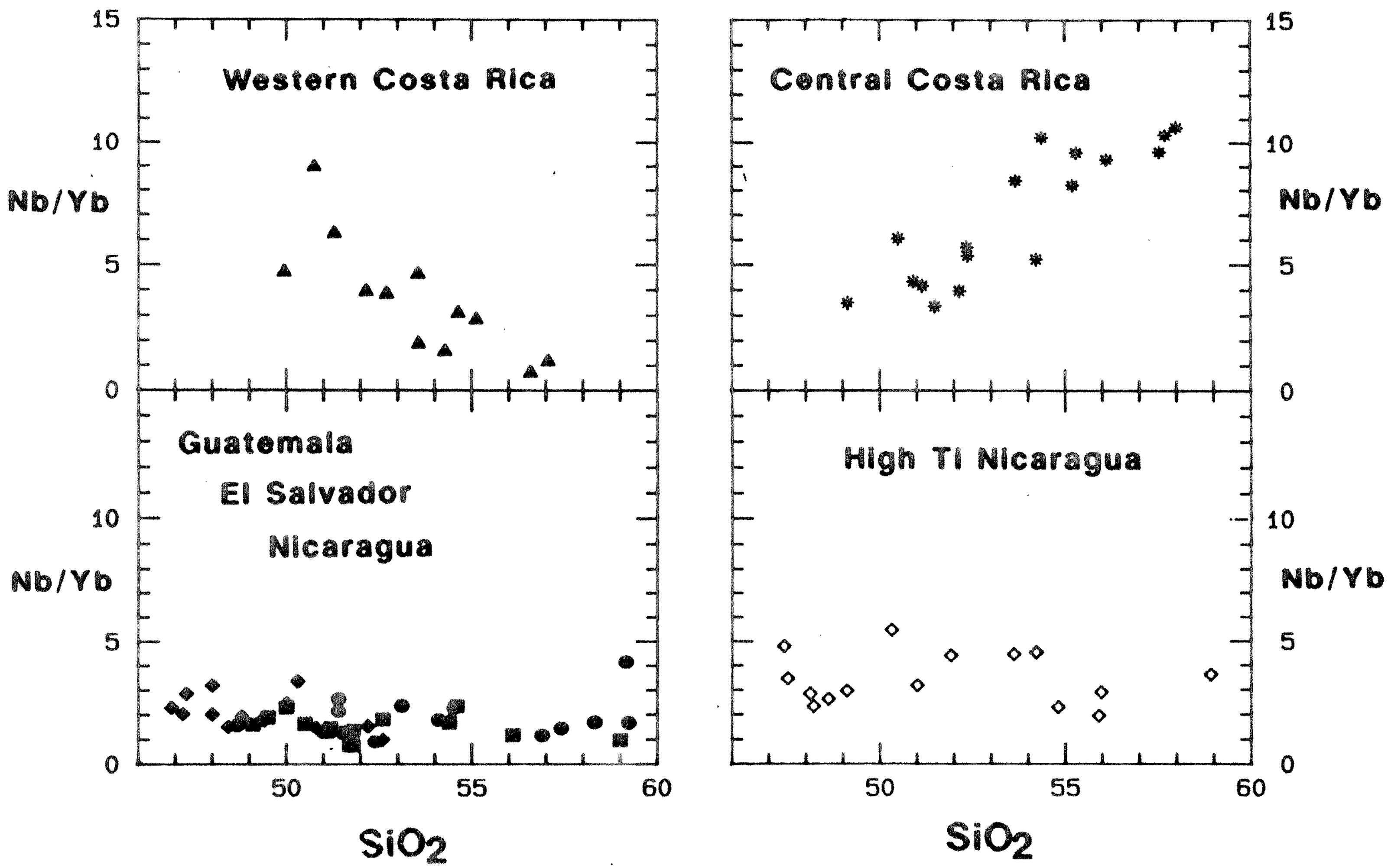


Fig. 12. Nb/Yb versus SiO_2 (wt %).

fluids and Nb bearing phase, a slab component is necessary. In the first model slab fluids are added directly to a depleted mantle to create an "apparent" depletion and in the second model, slab fluids create enriched veins with a Nb retaining phase.

A. Presence of Slab Component

We will first look at whether a slab component correlates with Nb depletion. We begin by assuming that Thompson's extended REE diagram is correct (Thompson et al., 1984), and that Nb has a bulk distribution coefficient between Ba and La, which is the generally accepted placement for Nb. Therefore, where Nb/La =1 there is no depletion, and where Nb/La <1 Nb is depleted. The Ba/La ratio is assumed to be positively correlated with the amount of the slab component.

Figure 13 shows a model for the relation between a Nb depletion and a slab component. If the slab fluids alone are responsible for the "apparent" depletion then the data should form a negative slope, i.e., the greater the slab component the greater the depletion.

When we look at the actual data (Fig. 14) we see that most of the samples lie in quadrant IV, Nb depletion with a slab component. The only samples that plot outside quadrant IV are the high Ti lavas from Nicaragua which are Nb-enriched and the alkalic samples from central Costa Rica which have a Nb depletion but do not show a significant slab component. These Costa Rican samples probably result

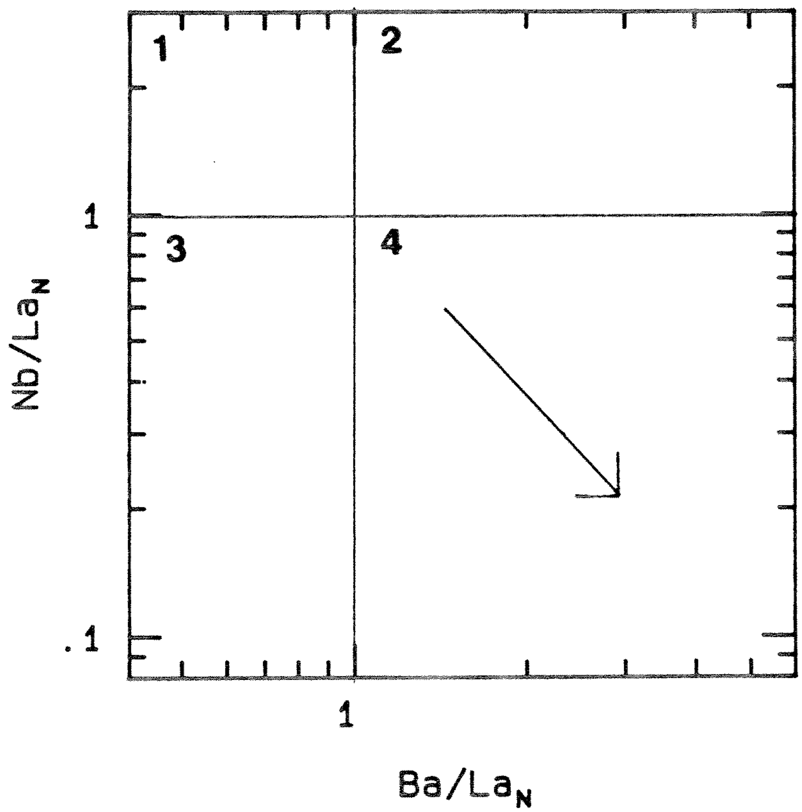


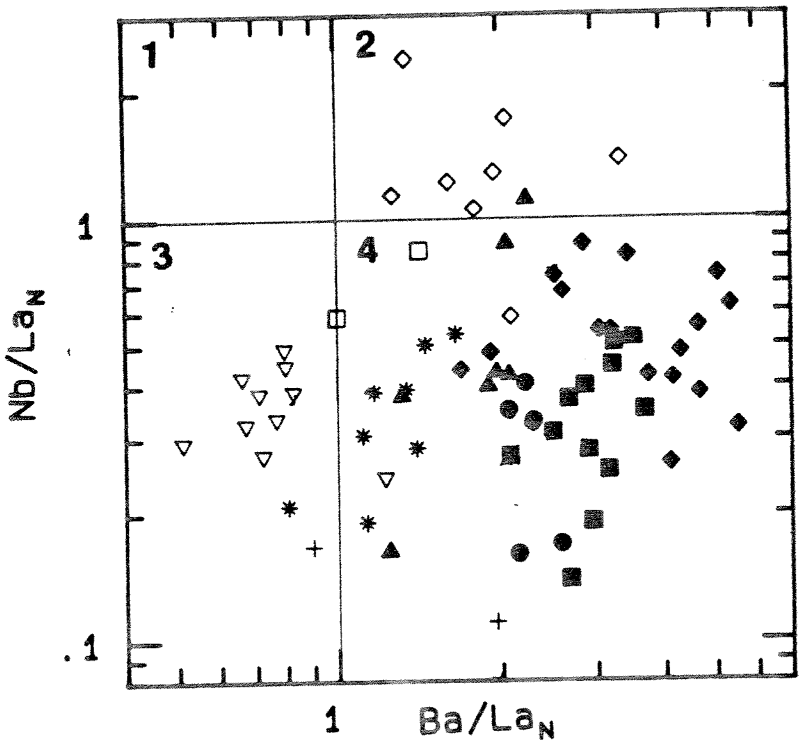
Fig. 13. Model of relationship of Nb depletion to slab component.

Quadrant 2 Nb/La >1 and Ba/La >1
Lavas falling in this quadrant have a slab component and no Nb depletion.

Quadrant 3 Nb/La <1 and Ba/La <1
Lavas falling in this quadrant have no slab component and Nb is depleted.

Quadrant 4 Nb/La <1 and Ba/La >1
Lavas falling in this quadrant have a slab component and Nb is depleted.

If the addition of slab derived fluids alone causes Nb depletion then the data will form a negative slope in quadrant 4, the greater the slab component the greater the Nb depletion.



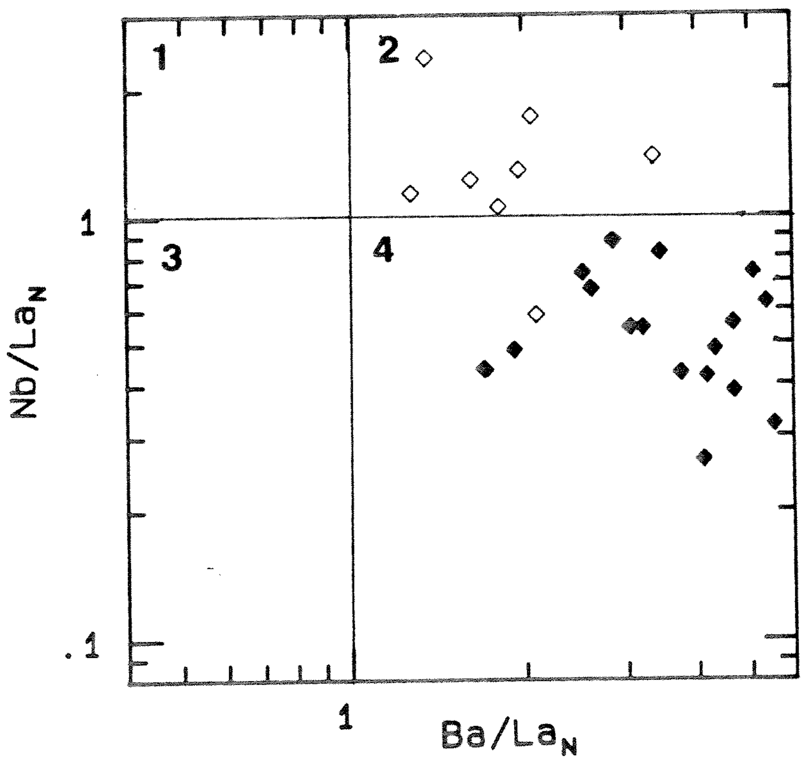


Fig. 14. Chondrite normalized Ba/La versus Nb/La. Symbols as in Fig. 3. (a) all lavas $SiO_2 < 53$ wt%. (b) Nicaraguan lavas $SiO_2 < 53$ wt%.

from a small degree of melting. The only samples that show even a slight negative correlation are the Nicaraguan lavas. Therefore, the normal Ti lavas in Nicaragua are the best samples to use in evaluating the role of slab fluids in causing the "apparent" depletion.

In the 'slab fluids' model one starts with a depleted or N-MORB mantle source, because, if the mantle source is enriched or OIB-like, then an unreasonably large proportion of LILEs and REEs must be added to create an apparent Nb depletion. In Nicaragua we see the clearest evidence for both a MORB source component and a slab component. The MORB source component is shown by the MORB-like Nd isotopic ratios and the slab/sed component is shown by the high Ba/La ratios, high ^{10}Be, positive Sr anomalies and high $^{87}Sr/^{87}Sr$ ratios.

The fluids fluxing the mantle may come from either the slab or the sediment cover or both and it may be difficult to distinguish between them. The composition of pelagic sediment is highly variable (Kay and Kay, 1988; Kay et al., 1984; Thompson et al., 1980; Hole et al., 1984; Ellam and Hawkesworth, 1988), and the sediment analyzed is not necessarily the sediment being subducted. In general, pelagic sediment has high LILE/HFSE, high $^{87}Sr/^{86}Sr$, and high Ba; it has low Nb and Ti, low Sr/Nd and low $^{143}Nd/^{144}Nd$. ^{10}Be may also be present in pelagic sediment. Fluids from altered oceanic crust are enriched in K, Rb, Ba, Sr, and have high LILE/HFSE, LILE/LREE, Sr/Nd, $^{143}Nd/^{144}Nd$ ratios, and are enriched in $^{87}Sr/^{86}Sr$. The most important point is that both pelagic sediments and slab fluids (Tatsumi et al., 1986) are depleted in Nb.

In Nicaragua the presence of high ^{10}Be suggests that there is a sediment component (Tera et al., 1986; Morris, 1990). ^{10}Be is highest in western Nicaragua and decreases both to the north and south. In Costa Rica ^{10}Be values are similar to MORB and OIB. Be is incompatible, but it is insoluble in most hydrothermal fluids (Ryan and Langmuir, 1988). Therefore, it is thought that Be is incorporated through sediment melting. However, Tatasumi (1988) found that small amounts of Be (approximately 5%) could be mobilized from serpentine through dehydration.

Carr et al. (1990), using marine sediments cored in DSDP hole 495, off Central America (Fig.2) show that mixing 0.45% sediment derived fluid with a depleted mantle source creates a modified mantle (MM). Melts of this modified mantle are the normal Ti lavas from western Nicaragua.

1. Slab Fluids Model - Nicaragua

To see if fluids alone are responsible for the Nb depletion in the normal Ti lavas from Nicaragua we construct a model showing the effects of the addition of sediment derived fluid to a depleted mantle (Fig. 15). See Tables 2 and 3 for assumptions for models. We use the MM (modified mantle) values for Ba, La, and Yb as our source. Because Nb is not added in the slab fluid we use a depleted mantle value of 0.31ppm for Nb (Wood, 1979). Using the

TABLE 2

Assumptions for Models

	Ba	Nb	La	Yb
DM	1.2	.31	.31	.4
EM	4.77	.72	.66	.3
MM	39.0	.31	.37	.41
Sediment	3200.	0	14.0	1.9
IRS	7500.	0	14.0	1.9

Sediment - weighted mean from DSDP site 495.
IRS - sediment with Ba content adjusted by about 2.3X.

TABLE 3

NICARAGUA

	Kd	mantle value (ppm)		
Figure 15		DM + 0.50% IRS		
Ba	.0005	39.0		
Nb	.01	.31		
La	.01	.37		
Yb	.2	.41		
Figure 16		DM+0.1% IRS	DM+0.30% IRS	DM+0.50% IRS
Ba.	.0005	8.1	23.7	39.0
Nb.	.01	.31	.31	.31
La	.01	.32	.35	.37
Yb	.2	.40	.40	.41
Figure 17		DM+0.50% IRS		
Ba	.0005	39.0		
Nb	.05	.31		
La	.01	.37		
Yb	.2	.4		
Figure 18		DM+0.08% IRS	DM+0.19% IRS	DM+1% IRS
Ba	.0005	7.5	15.4	76.2
Nb	.05	.31	.31	.31
La	.01	.31	.34	.45
Yb	.2	.4	.4	.42

COSTA RICA

Figure 20		EM (ex. Nb)		
Ba	.0005	4.77		
Nb	.01	.28		
La	.01	.66		
Yb	.2	.3		
Figure 21		EM (ex. Nb)		
Ba	.0005	4.77		
Nb	.035	.72		
La	.01	.66		
Yb	.2	.3		
Figure 22		EM	EM+0.40% IRS	EM+0.53% IRS
Ba	.0005	4.77	34.7	44.5
Nb	.035	.72	.72	.72
La	.01	.66	.72	.734
Yb	.2	.3	.31	.31
Figure 23		EM (ex Nb)	EM+0.2% IRS	
Ba	.0005	4.77	19.77	
Nb	.01	.28	.28	
La	.01	.66	.69	
Yb	.2	.3	.3	

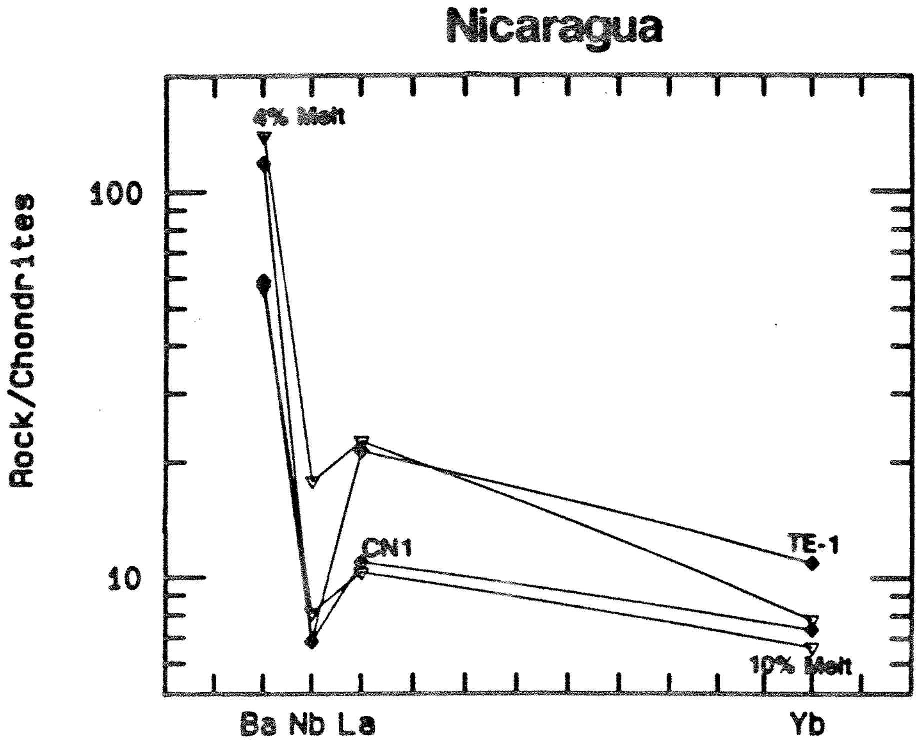


Fig. 15. Model showing effects of adding sediment derived fluid (0.50% IRS) to depleted mantle.

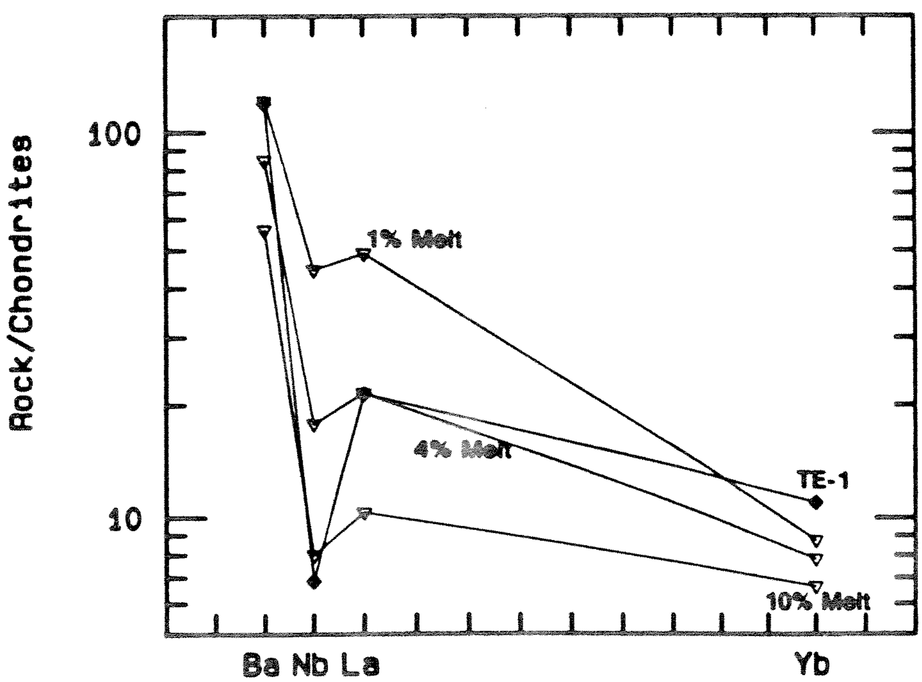


Fig. 16. Model showing effects of adding varying amounts of IRS to depleted mantle. 1% melt + 0.1% IRS, 4% melt + 0.3% IRS, 10% melt + 0.50% IRS.

generally accepted placement of Nb on spidergrams and assuming there is no Nb bearing phase we use a distribution coefficient for Nb similar to that of La. We assume batch partial melting, which may be an oversimplification; however, it allows us to see the various patterns created by incremental melting. We use the equation for batch partial melting, Cl=Co/D+F(1-D) where Cl is the concentration in the derived melt; Co, the concentration in the parent; D, the bulk distribution coefficient and F the melt fraction. For distribution coefficients that are less than .01 the results of fractional melting and equilibrium partial melting are similar (Smith, 1983). The spidergrams in figure 15 show the depletions produced by the addition of fluids to a depleted mantle, followed by 4% and 10% partial melting. Sample CN1 matches fairly closely the 10% melt spidergram. Sample TE1, whose Nb value is similar to CN1, has Ba and La values closer to the 4% melt spidergram. Even if we use different values for the source and different bulk distribution coefficients we cannot match the data.

Another possibility is to vary the amount of fluid with the degree of melting, i. e., the amount of slab fluid increases as the degree of melting increases. Increasing the slab fluid with the degree of melting affects the Ba values considerably and the La values to a smaller degree. As seen in Figure 16 this model does not explain the data. It appears that solely by adding a fluid component to a depleted mantle we cannot reproduce the depletions seen in the lavas from Nicaragua.

2. Nb Bearing Phase Model - Nicaragua

A niobium retaining phase in the mantle may explain the Nb depletion. We construct another model, this time with a Nb bearing phase. We use a MM source as above and increase the bulk distribution coefficient of Nb from .01 to .05 (Fig. 17). This model can reproduce nine of the normal Ti lavas between 4.6% (TE1) and 10% (CN1) melting. The samples that do not fit in this model, e.g. AP3, have relatively low Ba (200-400ppm), compared to their Nb and La values. It is possible that this model may accomodate these remaining normal Ti lavas if we take into account the following factors: the error in the Nb measurements, the fact that a small change in the amount of fluid can produce a large change in the Ba values, and the fact that a small change in the amount of a Nb phase in the source can produce a large change in the bulk distribution coefficient.

3. Nb Bearing Phase and Varying Fluids - Nicaragua

Another possibility is the combination of a Nb phase and varying amounts of fluid. As the degree of melting increases, the addition of fluids increase more or less systematically. This model is shown in Fig. 18. The slab fluids increase from 0.08% fluid at 1% melt to 1% fluid addition at 9% melt. This model reproduces only seven of the samples and the matches are not as close as in the

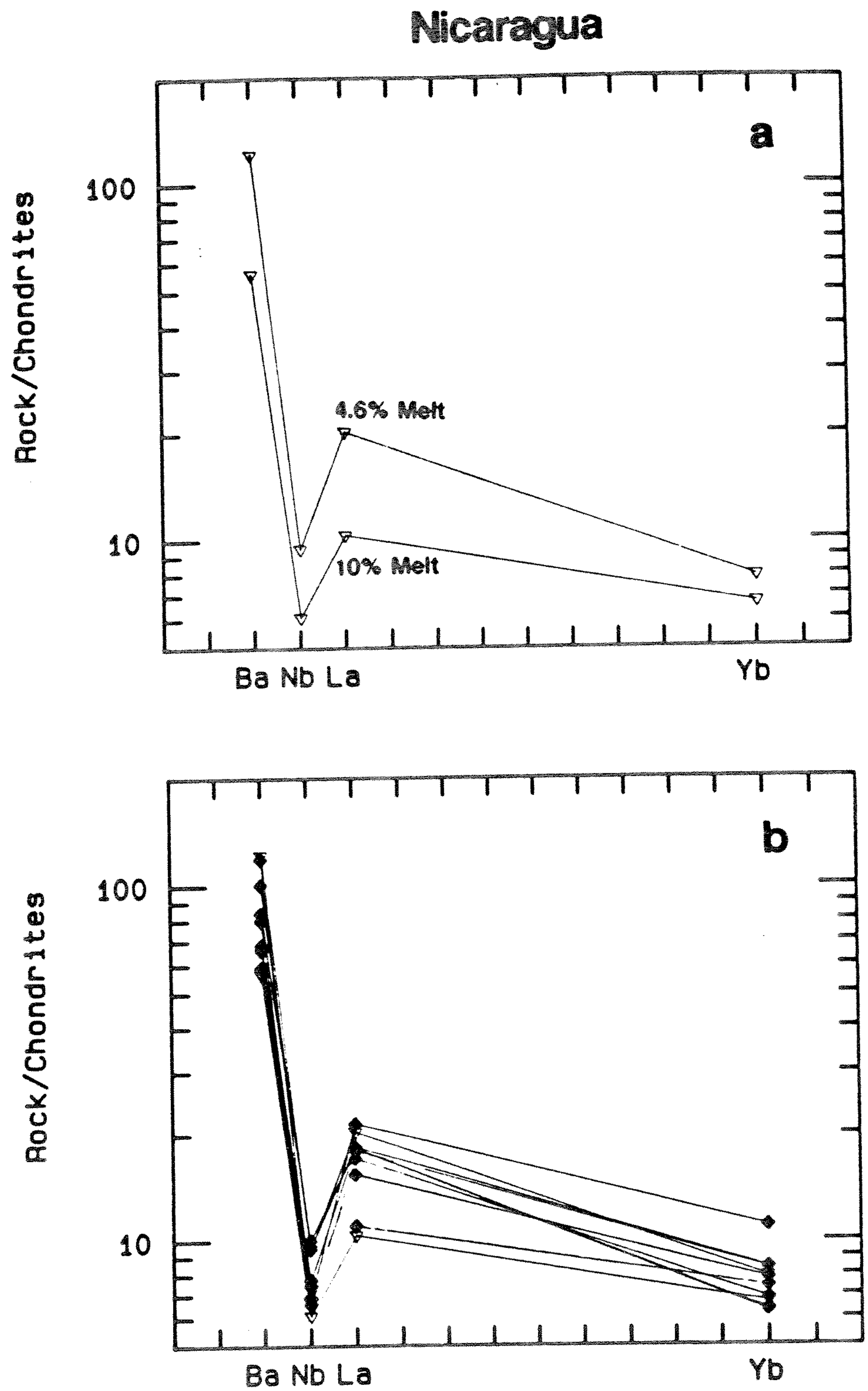


Fig. 17. (a) model of Nb bearing phase in a modified mantle (0.50% IRS added to depleted mantle). (b) 7 low Ti samples from Nicaragua.

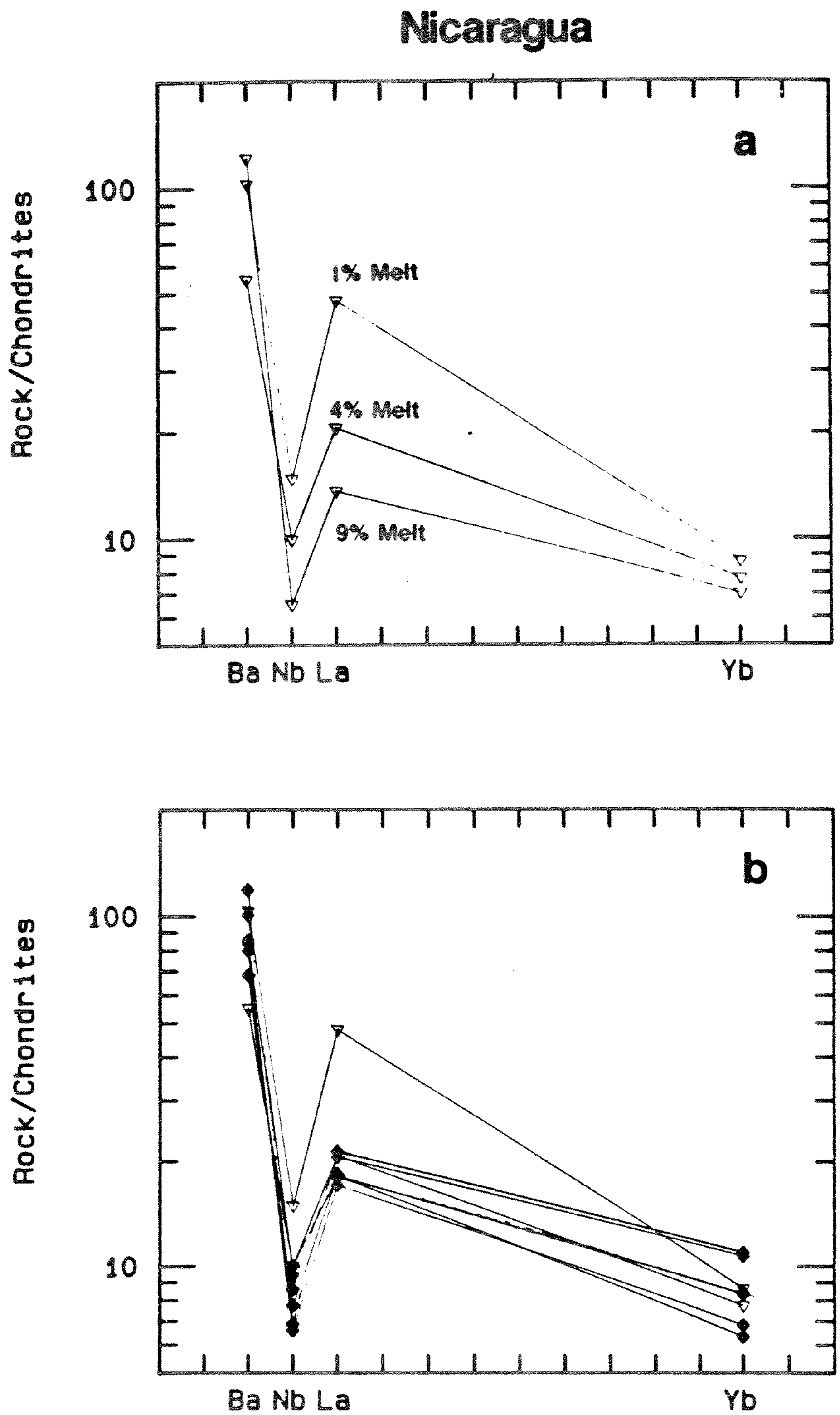


Fig. 18. (a) Model of Nb bearing phase. The amount of sediment derived fluid increases as the degree of melting increases - 1% melt + 0.08% IRS, 4% melt + 0.19% IRS, 9% melt + 1% IRS. (b) 6 samples.

previous model. However, because of the reasons stated above it is not possible to distinguish between a model with a constant source and a model where the amount of fluid increases with the degree of melting. What we can say is that there appears to be a phase beneath Nicaragua that is retaining Nb in the normal Ti lavas. The amount of fluid may be constant, or it may vary by a small amount as the degree of melting changes.

B. TNT Phase

Because negative Ti anomalies also occur in most samples it is possible that a TNT rather than a non-Ti phase is present. The Nb/La versus TiO_2/Y diagram (Fig. 19) shows the correlation between Nb depletion and Ti depletion. In Nicaragua there is a positive correlation between Nb depletion and Ti depletion suggesting a Nb-Ti phase. If the phase has a high distribution coefficient there has to be only a small amount present to have a bulk distribution coefficient of 0.05 as in our model. Whatever the phase, it has to have a lower distribution coefficient for La than Nb in order to produce the depletion. Amphibole has a distribution coefficient of 0.8 for Nb and 0.17-0.44 for La. Rutile has a D_{Nb} of 16, and ilmenite has a D_{Nb} of 0.6.

An arc suite in which the lack of a slab component seems to be correlated with a lack of a Nb depletion is the South Washington Cascades (Leeman et al, 1989). The basalts from this arc lack both an LILE enrichment and an

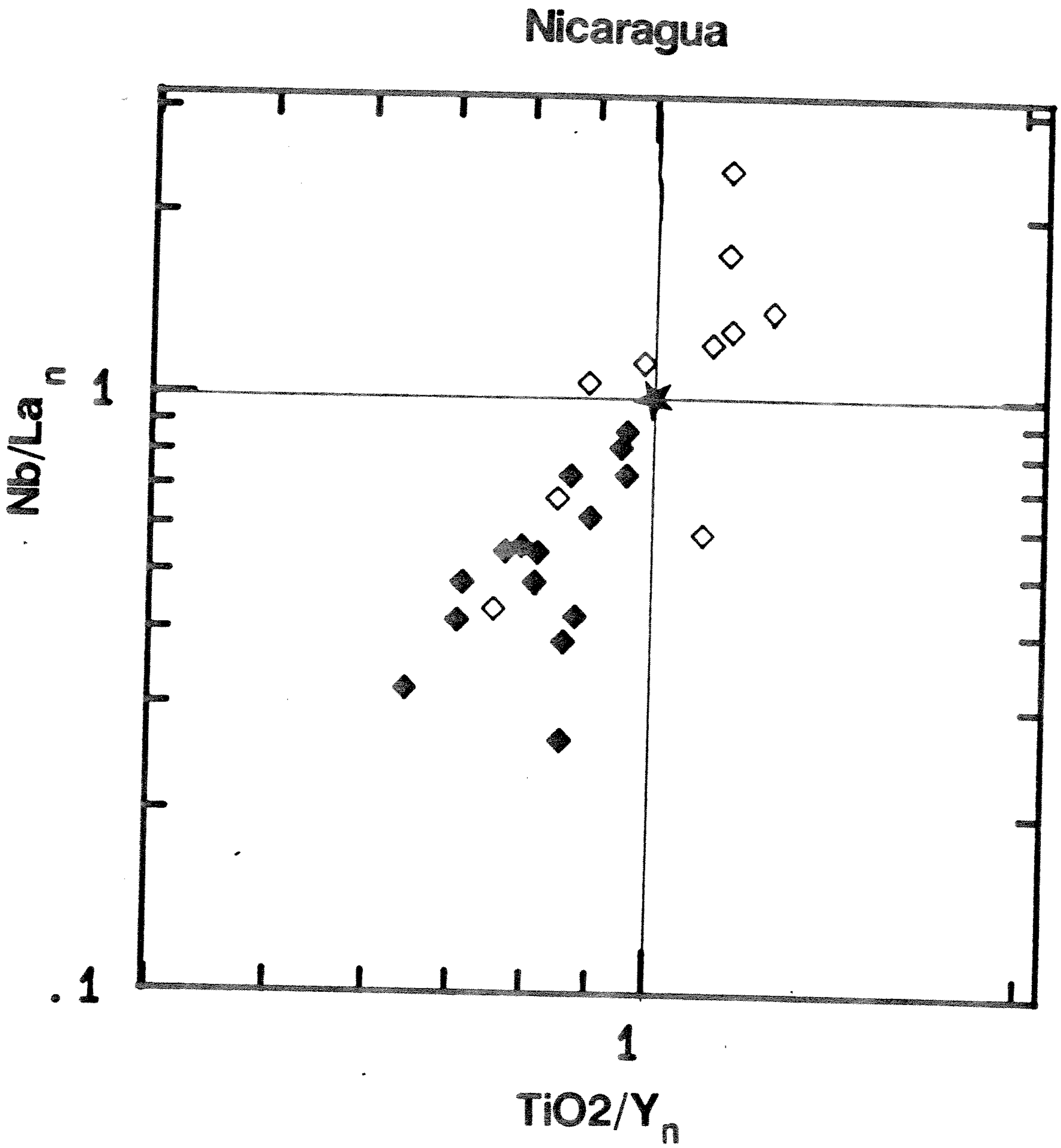


Fig. 19. Relationship between Nb depletion and TiO_2 depletion in Nicaragua. Open triangles - high Ti lavas, filled triangles - normal lavas. Star marks chondritic value.

HFSE depletion. What distinguishes this arc is that the subducting slab is very young and hot and dehydrates outboard of the volcanic front. Therefore, according to Leeman et al, (1989), the fluids play only a minor role in generating the arc magmas.

C. Initial Nb Depletion

In the initial depletion model Nb is depleted in the source. One area where we know there is no initial depletion is in Nicaragua where we show that the source for Nb is almost chondritic (Fig. 19). Several of the normal Ti lavas have little or no Nb depletion. However, there is one group of lavas that may have a depleted source. These are the samples from central Costa Rica. These samples do not have a strong slab component, yet they have a significant Nb depletion. All samples from central Costa Rica, including alkalic and calcalkaline, result from a relatively small degree of melting.

1. Initial Nb Depletion Model - Costa Rica

To see if we can reproduce the data from central Costa Rica we construct a model for initial Nb depletion (Fig. 20). Here we use an enriched mantle source and small degrees of melting. To produce the source depletion we use a Nb value of 0.28ppm. Sample B4B is similar to the 0.5% melt and five other samples fall approximately between 0.5% and 1% melt. For the other samples, e.g. PO8387, the Nb depletions are too large compared to the Ba values.

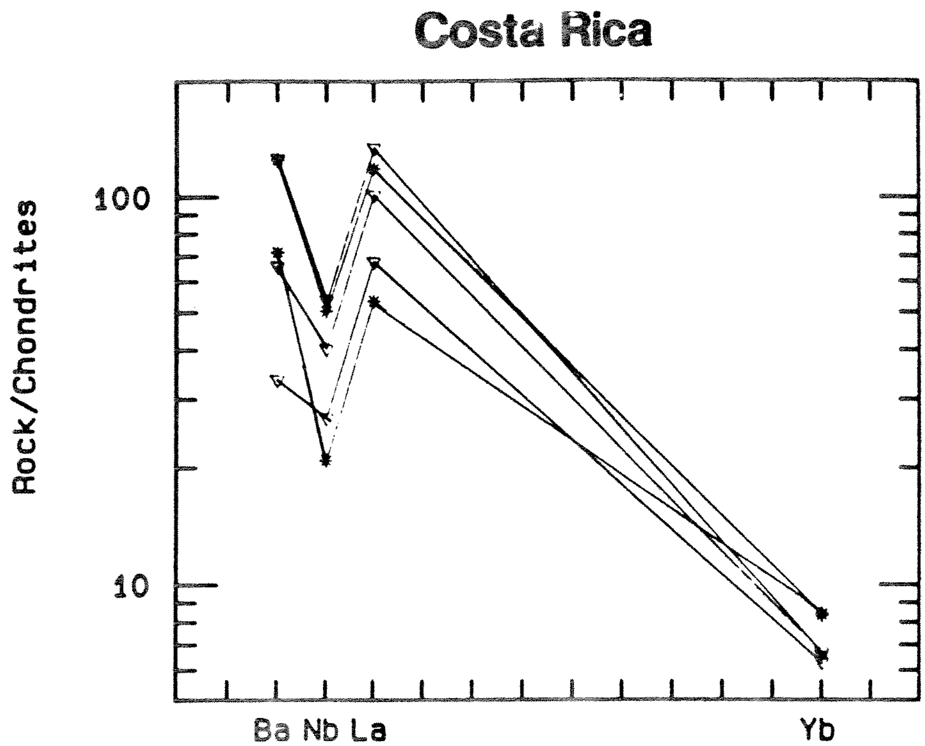


Fig. 20. Model of enriched mantle. Open triangles - 0.5% to 2% partial melting. Asterisks - samples B4B and PO8387.

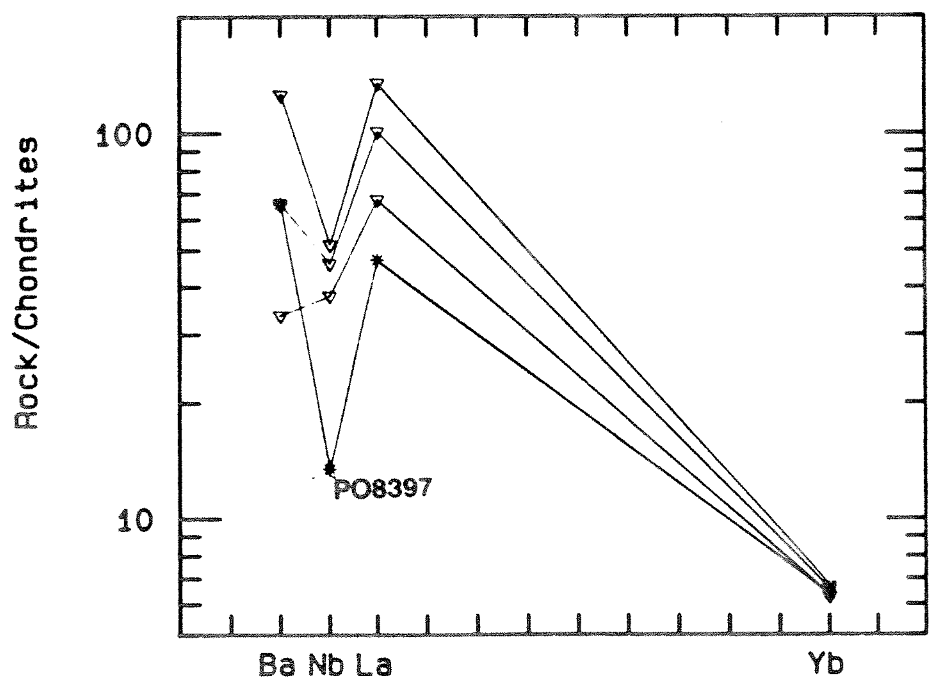


Fig. 21. Model of enriched mantle with Nb bearing phase. Open triangles - 0.5% to 2% partial melting.

2. Nb Bearing Phase Model - Costa Rica

Although we do not see a strong slab signature in central Costa Rica, it is nevertheless possible that a Nb phase is present. For this model we use an enriched mantle value for Nb of 0.72ppm (Wood, 1979), and a bulk distribution coefficient of 0.035 (Fig. 21). This is a different D than that used for the model in Nicaragua because it gives a better fit for the data. The spidergrams for a Nb phase model are similar to those of the initial depletion model for between 0.5% and 1% melt. This model does not provide a better match for those samples that do not fall between 0.5% and 1% melt. At small degrees of melting one cannot distinguish between a Nb-retaining phase and an initial Nb depletion.

3. Nb Bearing Phase Plus Slab Fluids Model - Costa Rica

As in Nicaragua it is possible that the depletions result from a combination of a Nb phase and varying amounts of slab fluids. Fig. 22 shows the spidergrams for small degrees of melting (0.5% and 1%) with no added fluid and for larger degrees of melting (7% and 10%) with added fluid. A fluid component is added to the 7% and 10% melt to match Ba values for actual samples. The resulting La values for 7% to 10% melting are, however, too low.

4. Initial Nb Depletion Plus Slab Fluids Model - Costa Rica

Another alternative is to add fluids to the Nb depleted source model (Fig. 23). If we assume that no or

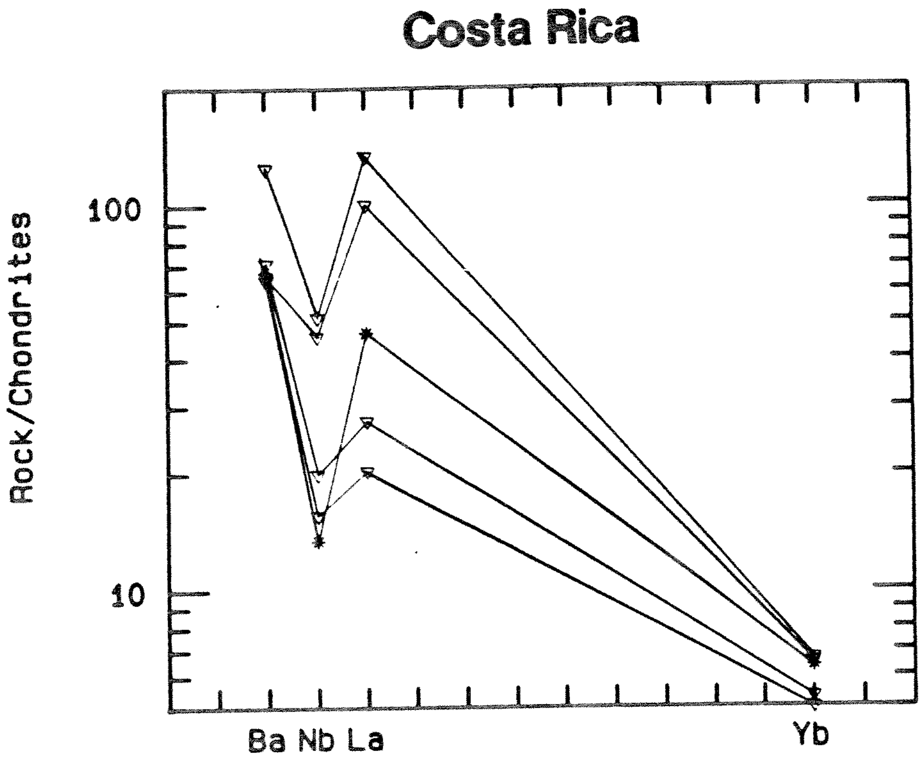


Fig. 22. Model of enriched mantle with Nb bearing phase. However, sediment derived fluid added to 7% (+0.40% IRS) and 10% (0.53% IRS) melts.

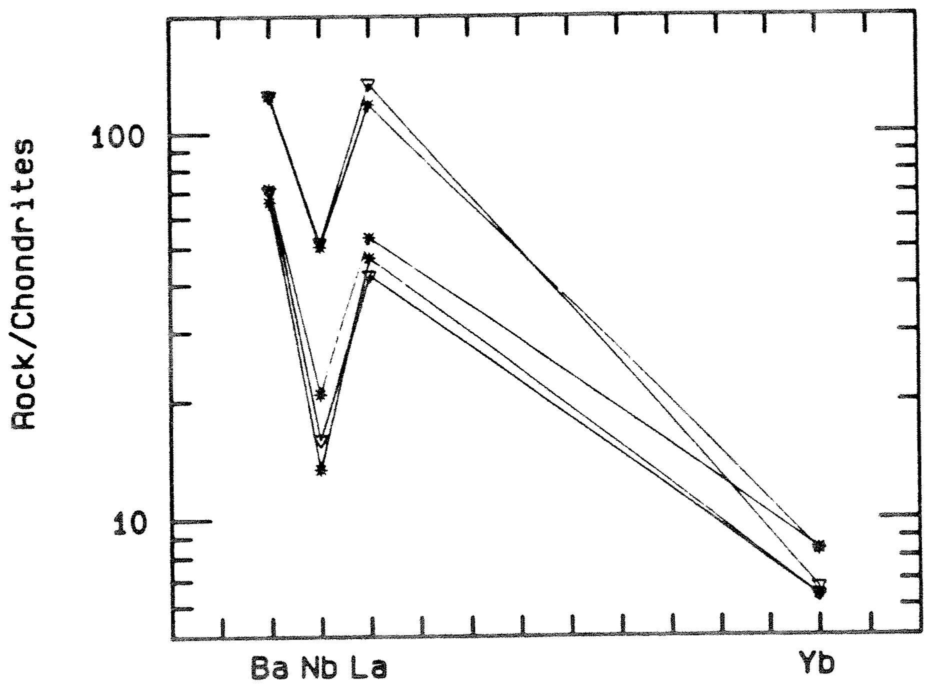


Fig. 23. Model of enriched mantle with initial Nb depletion. No IRS fluid added to .5% melt, 0.2% IRS added to 4% melt.

negligible amounts of fluid are added to the 0.5% and 1% melts and small amounts of fluid are added to 2%, 3%, and 4% melts we can accomodate most of the data. Sample PO8387 is now reproduced by the 3% melt spidergram. At low degrees of melting either a small change in the amount of fluid added or in the amount of melting produces a large change in the Ba values. At 2% melting, changing the amount of fluid added from 0.07% to 0.08% raises the Ba values from 488ppm to 528ppm. Or, a small change in the degree of melting with the same amount of fluid will also change the Ba values. By decreasing melting from 2% to 1.8%, Ba changes from 488ppm to 540ppm. So we see that while either a Nb phase or an initial depletion can reproduce the data at small degrees of melting, at larger degrees of melting an initial depletion plus sediment derived fluid is needed to reproduce the data.

The alkalic samples in Costa Rica (except PP7 and PP11) have a narrow range of Nb. All the samples can be reproduced by either an initial depletion or a Nb phase and small amounts of melting. The HNB of Reagan and Gill (1989) appears to come from a region of the mantle that does not have an initial Nb depletion.

D. <u>Rest of Arc</u>

It is more difficult to model the lavas from El Salvador. Many of the lavas are near the detection limit. However, with this is mind, and the fact that a small variation in the amount of fluid has a large effect on the

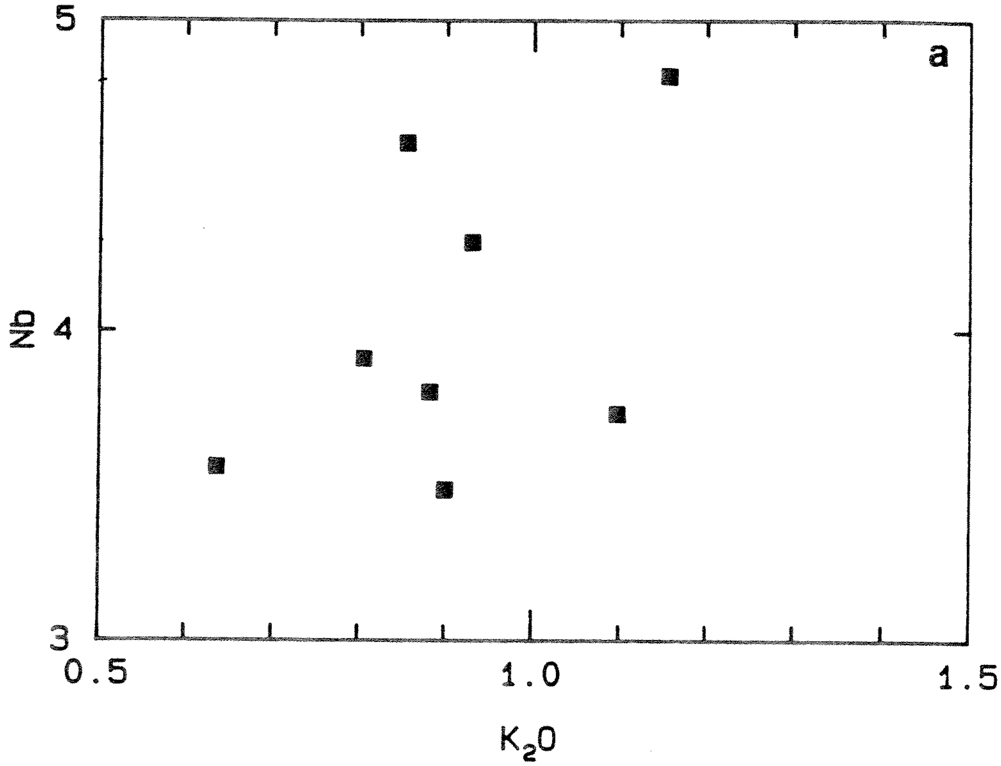
Ba values it appears that the data for Ba, La, and Yb can be reproduced by using a mantle source that is approximately 40% EM and 60% MM (i.e. Ba, 25ppm; La, 0.45ppm and Yb, 0.36ppm). All of the samples with SiO_2 <54wt% can be reproduced between 4% and 8% partial melting of this source. However, the Nb values can be modeled using either an initial Nb depletion or a Nb bearing phase. Therefore, with this model it is not possible to say anything more about Nb depletion in El Salvador.

The high Ti lavas do not have Nb depletion. These lavas may be produced when the Nb phase that has been retained in the mantle during a previous melting event is itself partially melted (Fig. 19).

E. Assimilation - Fractional - Crystallization

Niobium is considered to increase with differentiation in arcs. However, in Central America we see that in segments with a Nb depletion, Nb increases with fractionation, (central Costa Rica), decreases (western Costa Rica) or remains approximately constant (rest of arc). In the undepleted high Ti lavas from Nicaragua Nb increases with differentiation (Figs. 10, 11).

In central Costa Rica Nb increases with increasing K_2O and SiO_2. In Guatemala, El Salvador and the normal lavas from Nicaragua Nb values are near the detection limits and remain low while both SiO_2 and K_2O increase. To see if a phase is removing Nb, we looked at a suite from San Miguel, El Salvador (Fig. 24 and Appendix V). Although the



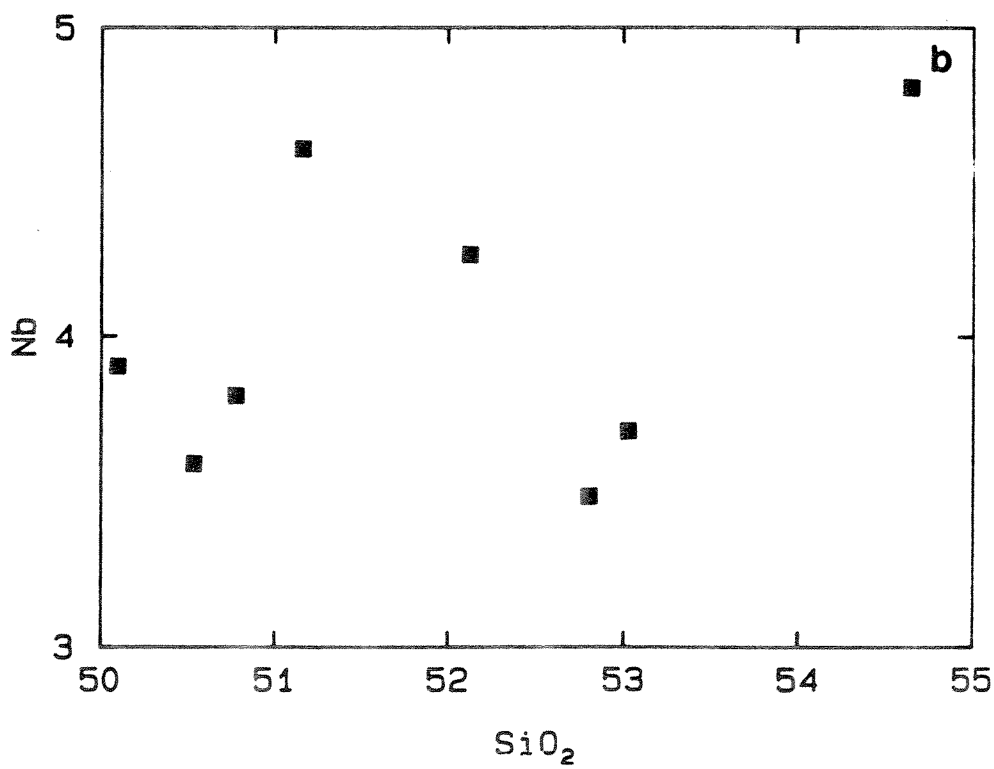


Fig. 24. Suite of lavas from San Miguel, El Salvador. (a) Nb ppm versus K_2O wt%, (b) Nb ppm versus SiO_2 wt%. Precision estimated at: Nb ± .5ppm, K_2O ± .05wt%, SiO_2 ± .3wt%.

measurements are near the detection limits and the error is large, Nb appears to increase with fractionation. In this instance, there does not appear to be a phase that is removing Nb.

The different Nb behavior with fractionation may be due either to different Nb contents of the sources or to magma mixing rather than to the presence of a Nb fractionating phase. In central Costa Rica the Nb content of the parental lavas may be greater than along the rest of the arc.

In western Costa Rica Nb is depleted and it decreases rapidly with differentiation. This could be the result either of fractionation or mixing. If a phase were removing Nb it would have Kd>1, and would have to be a phase that has not been observed elsewhere along the arc. A more likely possibility is that these lavas are mixtures of low Nb, normal arc magmas and the high Nb alkalic lavas like those found in central Costa Rica. The radiogenic isotopes are consistent with mixing (Carr et al., 1990).

VI. CONCLUSION

We can draw several conclusions about Nb in Central America:

In Nicaragua there appears to be no initial Nb source depletion. The depletions arise from a Nb-Ti retaining phase in the mantle. The source for these lavas is a depleted mantle which has been fluxed by sed/slab fluids.

In central Costa Rica the Nb depletions appear to result from melting an enriched source which is depleted in Nb. The alkalic lavas are reproduced by 0.5% to 1% melting. Small amounts of fluid added to an enriched source, followed by 2% to 4% melting, match the Ba values in the CAVF lavas.

The high Ti, high Nb lavas result from melting of a Nb phase which has been retained in the mantle during a previous episode of melt extraction.

Nb increases during differentiation in Costa Rica as it does in arcs in general. In Guatemala, El Salvador, and Nicaragua, Nb stays low with increasing K_2O and SiO_2. The apparent Nb decrease in western Costa Rica is likely due to magma mixing.

APPENDIX I

BERYLLIUM

BACKGROUND

Beryllium has gained importance because of the discovery of elevated ^{10}Be in some arc lavas (Brown et al., 1982: Tera et al., 1986: Monaghan et el., 1988: Tuniz et al., 1984). Be is a small cation that, according to Ryan and Langmuir (1988), acts most like Nd. Beryllium has not been widely measured in igneous rocks. Typical Be values for basalts and andesites are: MORB, 0.2-2.4ppm, IAB, 0.105-1.37ppm; OIB, 0.9-2.6ppm (Ryan and Langmuir, 1988). The mean earth value is 64ppb (Gregoryev, 1986). Although Be is higher in OIB, the Be/Nd ratio, 0.05, is similar in all three tectonic environments (Ryan and Langmuir, 1988). ^{10}Be is a short-lived (half life $1.5x10^6$ years) radioactive isotope of Be that is formed only in the atmosphere (Faure, 1986). Through rain, ^{10}Be is incorporated into marine sediments. Because ^{10}Be is formed only in the atmosphere, its presence in arc lavas can show the role of subducted sediments.

^9Be is the stable isotope of Be. By determining the $^{10}Be/^9Be$ ratio and the Be content of arc rocks and calculating the $^{10}Be/^9Be$ ratios of subducted sediment it may be possible to determine how much of the total Be came from sediment (Ryan and Langmuir, 1988). By knowing whether Be is incorporated via a melt or fluid phase it may be possible to tell the amount of sediment in the magma.

Tatsumi (1988) determined experimentally that only about 5% of Be is extracted from serpentinite by dehydration. Depending on the models used there may be anywhere from 1%-10% sediment in arc magmas (Tera et al., 1986).

RESULTS-DISCUSSION-CONCLUSION

Absolute values of Be vary from 0.50ppm to 2.08ppm and are given in Appendix VI. Beryllium versus distance is shown in Fig. 25. The data fall within the range for island arcs (Ryan and Langmuir, 1988). Be acts incompatibly as shown by plotting Be versus K_2O (Fig. 26). According to Ryan and Langmuir (1988) Be acts most like Nd with a Be/Nd ratio of 0.05; however, our data show that Be acts most like gadolinium (Fig. 27), and the Be/Nd ratios are more varied (Fig. 27). These Be data, by themselves, do not give any new information about the origin of Central American arc magmas. However, when these data are combined with ^{10}Be data they may show the role of subducted sediment (Tera et al., 1986; Morris et al., 1990).

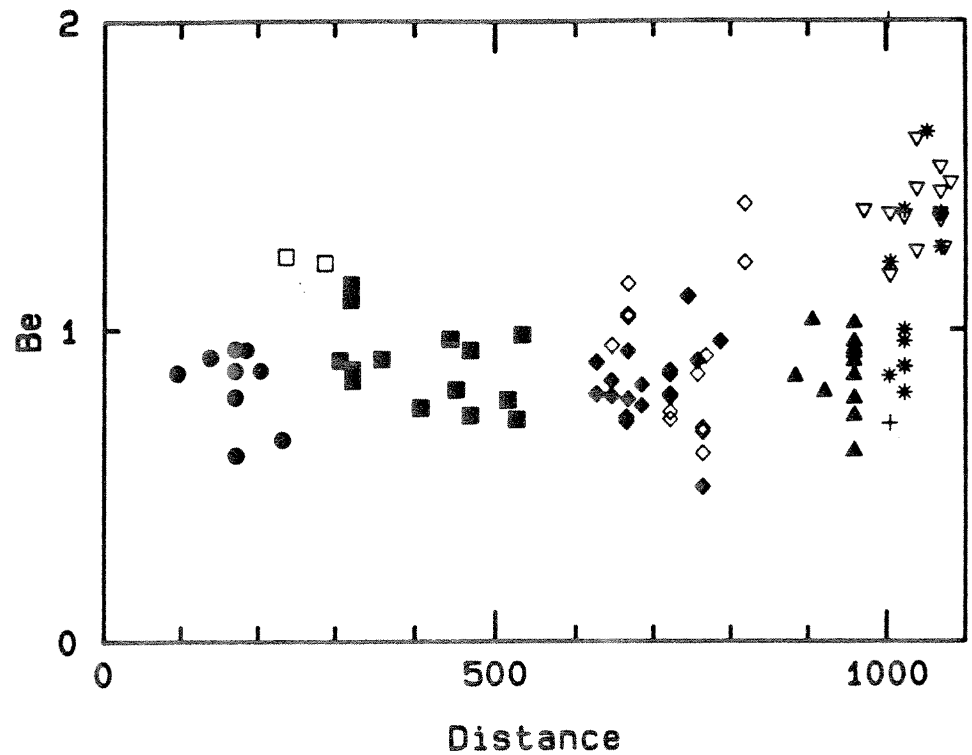


Fig. 25. Be (ppm) versus distance (km) along the arc. Symbols as in Fig. 3. $SiO_2 < 55$ wt%.

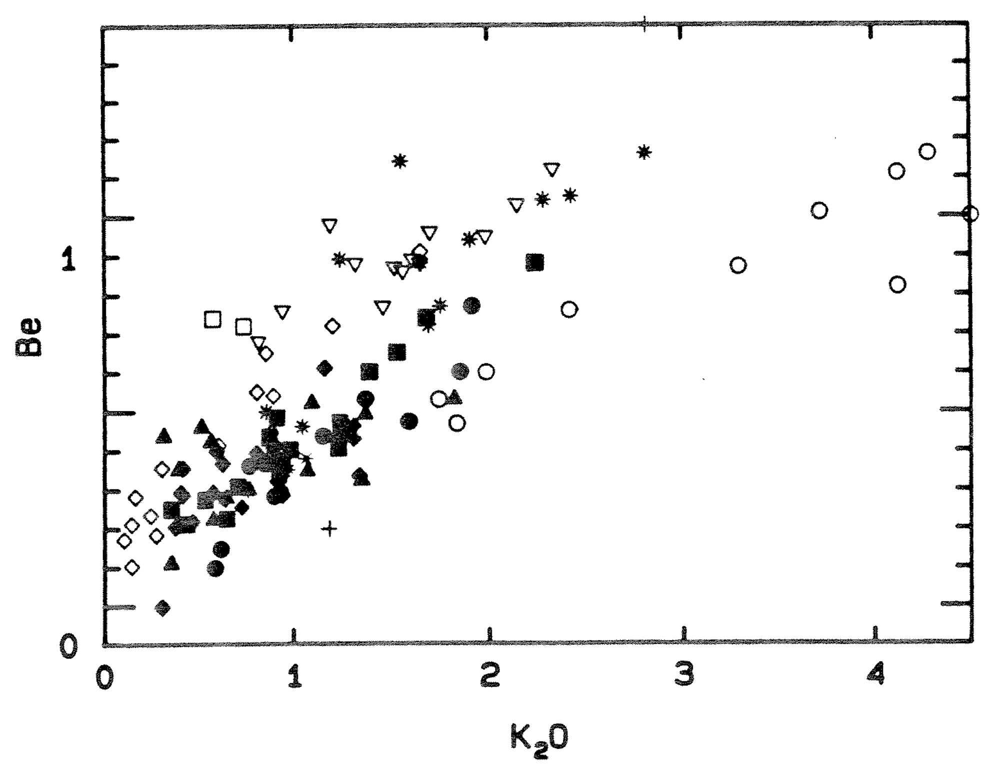


Fig. 26. Be (ppm) versus K_2O (wt%). Symbols as in Fig. 3.

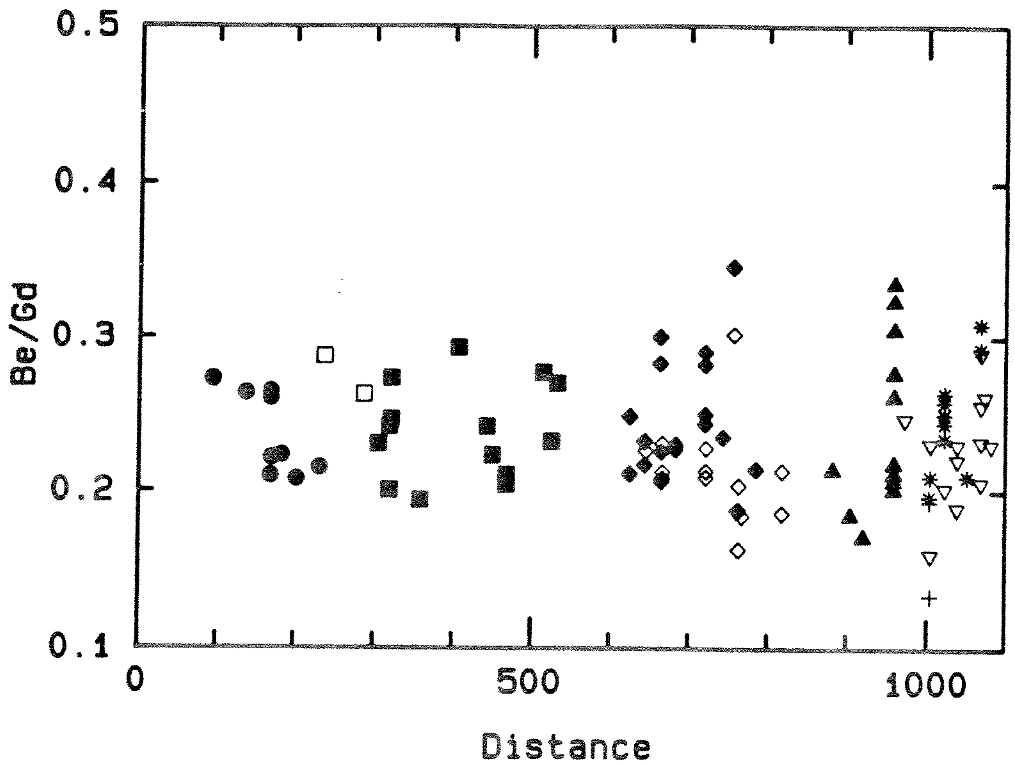


Fig. 27. Be/Gd versus distance (km) along the arc. Symbols as in Fig. 3.

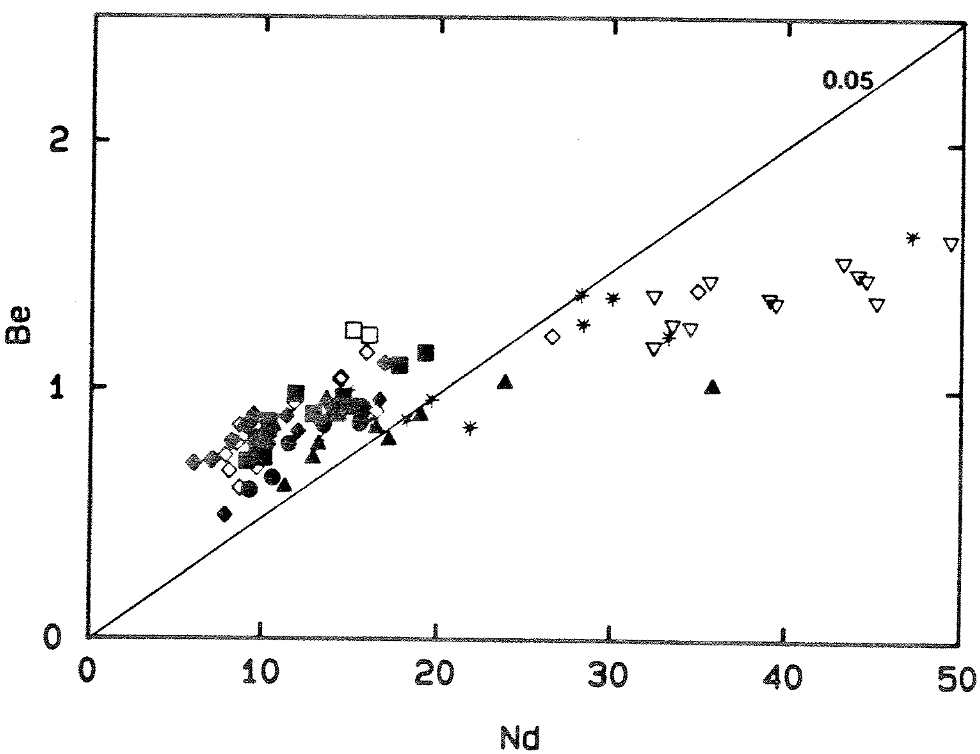


Fig. 28. Be (ppm) versus Nd (ppm). Symbols as in Fig. 3.

APPENDIX II

DCP-AES Settings

Niobium
- Peak - 3163A
- Slits - 25 by 100 microns
- Voltage - 5
- Background correction - Low 2
- High standard - 200ppb Nb in 1.5N HCL + LiBO2
- Low standard - 1.5N HCL + LiBO2
- Measurements - 3 per sample

Tungsten
- Peak - 4008A
- Voltage - 5
- High standard - 5ppm W in 1.5N HCL + LiBO2
- Low standard - 1.5N HCL + LiBO2
- Background correction - Low 3

Beryllium
- Peak - 3131A (Note strong line at 3130)
- Slits - 25 by 100 microns
- Voltage - 5
- High standard - 25ppb Be in 1.5N HCL + LiBO2
- Low standard - 1.5N HCL + LiBO2
- Measurements - 3 per sample
- No background correction

APPENDIX III

REE Separation Procedure (10/1/88)

1. Flux 0.2 g sample plus 0.5 g $LiBO_2$.
2. Fuse for 15 minutes.
3. Dissolve in 25 ml 1.5N HCL (from MDF lab) in Teflon (white) 100 ml beakers.
4. Put on stirring plate until dissolved (15 to 30 minutes).
5. Load 25 ml solution onto columns, collecting in waste beakers.
6. Let entire 25 ml drip through (about 30 minutes).
7. Add 1-2 ml 1.5 N HCL into each beaker with stir bar still in. Clean up all remaining sample, add to column (rinse). Repeat as necessary.
8. When rinse drips through add 1.5 N HCL up to 50 ml total.
9. When 50 ml has dripped through (eluted) change to 2.3 N HCL.
10. Add 60 ml 2.3 N HCL to columns 1, 2, and 4 and 50 ml 2.3 N HCL to column 3, 4, and 5.
11. Let 2.3 N HCL drip through. Through away waste.
12. Change to white Teflon beakers used in step 3.
13. Change to 7.3 N HCL.
14. Elute 100 ml 7.3 N HCL.
15. Place beakers on hot plate in clean air box at setting of 2.1 and let dry overnight.
16. Wash columns with 7.3 N HCL (fill to top). After this elution columns are ready for backwashing.
17. Next day, take beakers off hot plate and let dry.
18. Add 10 ml REE blank solution (clean 7% HNO_3). Use 5 ml Finnpipette from Carr's lab.
19. Scrape residue with Teflon stir rod and mix.
20. Pour into plastic bottles, label and cap.

The whole procedure takes approximately 7 hours from the time the furnace is turned on.

APPENDIX IV

Chondrite Normalization Factors

Ba	6.9
Rb	.35
K2O	.01466
Nb	.35
La	.328
Ce	.865
Sr	11.8
Nd	.63
P2O5	.01053
Sm	.203
Zr	6.84
TiO2	.1034
Y	2
Yb	.22

After Thompson, 1984.

APPENDIX V

Niobium

San Miguel, El Salvador

Sample	Nb ppm
SM1	3.7
SM3	3.5
SM4	4.8
SM5	3.9
SM7	4.6
SM8	3.6
SM9	4.3
SM10	3.8

APPENDIX VI

File name centsym5.ROC

Sample	TA-4C	TJ-1	SM126	CQ-1	AT-50	2566a	2540a	A-4
VN #	11.00	12.00	21.00	21.20	22.00	22.00	22.00	22.00
Qual	1	0	2	0	2	0	0	2
Key	8	8	8	8	8	8	8	8
Ref	0	0	0	0	0	0	0	0
SiO2	58.31	62.64	51.40	65.17	51.69	75.89	72.97	57.41
TiO2	0.75	0.63	0.95	0.54	1.03	0.16	0.28	0.79
Al2O3	18.90	17.46	18.69	16.37	19.37	15.04	15.38	19.97
Fe2O3	6.94	5.12	9.20	4.80	9.55	0.96	2.23	6.17
MnO	0.15	0.09	0.00	0.11	0.13	0.00	0.00	0.14
MgO	2.08	1.86	5.20	1.48	4.56	0.16	0.44	1.73
CaO	7.34	5.55	9.35	5.22	9.28	0.78	1.89	7.58
Na2O	3.12	3.98	3.60	3.92	3.24	2.87	3.51	4.52
K2O	1.91	2.40	0.76	1.98	0.89	4.12	3.29	1.37
P2O5	0.23	0.16	0.22	0.16	0.22	0.03	0.03	0.26
Total	99.74	99.89	99.37	99.75	99.96	100.01	100.02	99.94
Rb	43	58	14	48	19	108	110	27
Ba	678	843	420	808	474	926	821	561
Sr	569	469	631	379	590	86	226	591
V	125	106	218	110	227	7	22	117
Cr	2	9	27	12	101	8	7	2
Ni	3	6	19	9	41	3	4	3
Zr	128	159	93	149	118	77	137	136
Sc	12.9	12.5	25.0	9.8	23.3	2.9	3.6	15.0
Cu	12	17	64	25	67	5	9	61
87Sr/86Sr	0.70457	0.70439	0.70399	0.70395	0.70400	0.70407	0.70406	0.70387
143Nd/144Nd	0.00000	0.51275	0.51282	0.00000	0.51283	0.51286	0.00000	0.51287
Distance, k	22	47	94	85	137	137	137	137
Crust	51	51	50	50	46	0	0	46
Volume, km3	20	35	20	5	50	50	50	50
C-volume,km	20	35	70	70	370	370	370	370
Nb	3.0	5.5	3.9	8.7	1.8	5.3	5.1	2.8
Be	1.27	1.26	0.86	1.10	0.91	1.32	1.37	1.03
La	16.56	17.38	8.97	12.97	10.48	19.96	19.11	11.23
Ce	36.07	36.98	22.11	27.49	24.72	38.12	39.93	27.78
Nd	18.94	17.92	13.41	12.08	15.54	14.49	13.91	17.30
Sm	4.39	3.61	3.41	2.81	3.12	2.19	3.11	4.27
Eu	1.17	0.93	1.05	0.74	0.99	0.45	0.56	1.19
Gd	4.00	3.73	3.15	2.64	3.45	2.04	2.23	3.83
Dy	3.99	3.39	4.09	2.91	3.12	2.51	2.50	4.56
Er	2.18	1.84	1.87	1.53	1.49	1.23	1.39	2.33
Yb	1.77	1.77	1.47	1.68	1.40	1.24	1.34	1.93
Y	23.12	19.02	18.32	16.33	16.73	13.28	13.45	22.67
FeO*	6.24	4.61	8.28	4.32	8.59	0.87	2.01	5.55
Mg#	37	42	53	38	49	25	28	36
Density	2.47	2.42	2.54	2.41	2.54	2.31	2.34	2.47

File name centsym5.ROC

Sample	LK0.6A	A4.0B	VF74-2	ACT-5	YEP-2	ACT-10	A-27-1	AC-30
VN #	22.10	22.20	23.00	23.10	23.10	23.10	23.10	23.10
Qual	2	0	2	2	0	0	2	2
Key	8	8	8	8	8	8	8	8
Ref	0	0	0	1	1	1	1	1
SiO2	59.23	59.16	48.67	53.11	60.60	60.68	52.39	55.05
TiO2	0.75	0.68	1.09	1.16	0.81	0.80	0.97	0.86
Al2O3	18.44	17.95	17.97	20.34	17.54	17.77	18.91	19.21
Fe2O3	6.02	2.95	12.98	8.74	6.83	6.88	10.41	9.03
FeO	0.00	2.87	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.12	0.14	0.18	0.15	0.14	0.13	0.17	0.16
MgO	2.55	2.30	6.27	2.59	1.74	1.72	3.73	2.22
CaO	6.76	6.53	9.39	8.52	6.01	5.94	8.84	8.23
Na2O	4.02	3.99	2.68	4.23	4.22	4.03	3.48	3.84
K2O	1.85	1.59	0.58	0.90	1.83	1.74	0.86	1.15
P2O5	0.18	0.18	0.14	0.17	0.20	0.20	0.20	0.21
H2O+	0.00	0.96	0.00	0.00	0.00	0.00	0.00	0.00
H2O-	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.92	99.62	99.95	99.90	99.92	99.90	99.97	99.95
Rb	43	35	9	15	40	35	16	20
Ba	680	677	288	470	697	637	450	528
Sr	464	508	518	573	402	426	545	596
V	155	144	279	295	141	146	208	188
Cr	44	33	19	22	23	27	7	1
Ni	24	15	40	13	10	11	14	8
Zr	152	133	73	87	169	157	90	110
Sc	17.7	15.0	25.8	29.5	13.3	12.8	22.1	16.8
Cu	31	30	72	75	25	64	57	55
87Sr/86Sr	0.70401	0.70392	0.70388	0.70384	0.00000	0.00000	0.00000	0.00000
143Nd/144Nd	0.51283	0.51292	0.51291	0.00000	0.00000	0.00000	0.00000	0.00000
Distance, k	135	125	170	169	169	169	169	169
Crust	46	46	47	0	0	0	0	0
Volume, km3	60	10	40	70	70	70	70	70
C-volume,km	370	370	110	110	110	110	110	110
Nb	2.9	5.8	2.1	4.6	11.2	0.0	1.5	0.0
Be	1.10	0.97	0.60	0.78	0.97	1.03	0.87	0.94
La	13.43	11.26	5.94	6.91	13.27	11.21	8.27	9.34
Ce	31.02	25.84	14.78	18.15	29.34	27.30	20.37	22.35
Nd	16.61	12.84	9.23	11.43	17.60	14.96	13.37	15.35
Sm	3.34	3.21	2.61	3.29	3.83	3.28	3.40	3.31
Eu	0.96	0.88	0.87	1.04	1.01	1.01	1.04	1.05
Gd	3.48	3.00	2.69	3.71	4.01	3.40	3.27	3.59
Dy	4.20	3.14	2.82	3.80	4.17	3.52	4.01	3.70
Er	1.84	1.74	1.64	2.08	2.05	1.74	1.73	1.72
Yb	1.73	1.39	1.32	1.94	1.82	1.67	1.63	1.60
Y	19.85	17.81	15.84	22.03	23.23	18.62	20.05	19.47
FeO*	5.42	5.52	11.68	7.86	6.15	6.19	9.37	8.13
Mg#	46	43	49	37	34	33	42	33
Density	2.45	2.48	2.58	2.51	2.44	2.44	2.53	2.49

File name centsym5.ROC

Sample	T34B	T37-IV	AG-8	E1	R21LtM	9T	GUT102	GUM4
VN #	23.20	23.20	24.00	25.00	25.20	25.20	31.00	32.10
Qual	0	0	2	2	0	0	2	2
Key	8	8	8	8	8	8	8	8
Ref	0	0	0	0	0	0	0	0
SiO2	69.87	71.14	54.52	51.40	72.13	72.43	54.10	56.90
TiO2	0.38	0.41	0.92	1.15	0.44	0.36	0.83	0.72
Al2O3	14.98	14.67	19.71	19.85	15.50	15.70	19.00	18.80
Fe2O3	2.27	2.12	8.32	0.00	2.22	2.62	2.47	3.80
FeO	0.00	0.00	0.00	8.90	0.00	0.00	5.51	3.20
MnO	0.00	0.00	0.15	0.16	0.00	0.00	0.18	0.12
MgO	0.45	0.40	2.85	3.50	0.46	0.59	4.82	2.58
CaO	1.41	1.48	8.24	9.89	1.46	2.04	9.42	7.70
Na2O	3.89	4.17	3.76	3.57	4.03	4.04	3.47	3.90
K2O	4.50	4.12	1.24	0.84	4.28	3.72	0.61	0.93
P2O5	0.10	0.09	0.23	0.27	0.09	0.07	0.15	0.14
H2O+	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.37
H2O-	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.32
Total	97.85	98.60	99.93	99.87	100.61	101.57	100.56	99.48
Rb	97	96	21	15	102	79	7	16
Ba	1117	1136	534	442	1086	918	336	525
Sr	206	205	555	623	187	158	436	443
V	30	27	199	267	24	21	235	191
Cr	6	8	14	23	7	5	35	5
Ni	3	7	15	16	3	6	21	9
Zr	297	300	116	97	329	251	83	97
Sc	4.5	4.0	21.6	24.5	3.8	6.1	29.1	20.2
Cu	6	8	57	83	6	10	58	56
87Sr/86Sr	0.70401	0.70402	0.70386	0.70389	0.70404	0.70391	0.00000	0.00000
143Nd/144Nd	0.00000	0.00000	0.00000	0.51293	0.00000	0.51288	0.00000	0.00000
Distance, k	175	175	183	202	183	183	231	266
Crust	0	0	47	45	45	45	37	37
Volume, km3	10	10	65	45	45	45	14	10
C-volume,km	110	110	65	45	45	45	14	10
Nb	5.8	6.4	4.4	3.8	12.0	0.0	2.6	2.0
Be	1.50	1.61	0.93	0.87	1.66	1.51	0.65	0.79
10Be	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0
La	24.93	23.41	11.16	10.15	23.86	20.15	4.44	6.21
Ce	51.50	53.96	27.40	24.75	54.94	43.74	12.89	16.58
Nd	28.84	24.57	15.61	15.47	26.09	17.56	10.52	10.33
Sm	6.17	4.78	4.32	3.60	5.29	3.35	2.41	2.44
Eu	1.19	1.00	1.13	1.23	0.98	0.66	0.85	0.85
Gd	5.35	4.57	4.17	4.16	4.70	3.37	3.00	3.39
Dy	5.09	4.52	4.54	3.91	4.52	3.43	3.46	3.85
Er	3.00	2.81	2.12	2.17	2.67	2.03	1.80	1.91
Yb	2.98	2.92	1.93	1.77	2.64	1.91	1.44	1.71
Y	32.90	29.46	22.22	21.67	29.49	21.21	18.72	22.01
FeO*	2.04	1.91	7.49	8.90	2.00	2.36	7.73	6.62
Mg#	28	27	40	41	29	31	53	41
Density	2.34	2.33	2.50	2.62	2.34	2.34	2.58	2.51

File name centsym5.ROC

Sample	SALC1	SA22	SA204	IZ108	IZ112	B-6	B-21	SALC80
VN #	40.00	41.00	41.00	41.10	41.10	42.10	42.10	42.50
Qual	4	4	4	4	4	4	4	4
Key	4	4	4	4	4	4	4	4
Ref	0	2	2	2	2	0	0	0
SiO2	51.20	54.40	51.60	52.60	51.70	51.80	59.00	56.10
TiO2	1.02	0.87	1.12	0.81	0.81	1.00	1.14	1.23
Al2O3	18.20	18.30	18.10	19.60	19.10	16.70	14.80	17.20
Fe2O3	3.10	1.36	3.74	1.13	1.78	4.57	2.59	3.79
FeO	7.00	7.26	6.05	7.16	6.93	5.75	7.09	5.99
MnO	0.18	0.16	0.17	0.15	0.18	0.19	0.22	0.22
MgO	4.67	3.75	4.23	4.31	4.58	4.41	2.05	2.64
CaO	9.40	8.50	8.93	9.49	9.12	9.47	5.54	7.47
Na2O	3.38	3.51	3.38	3.54	3.40	2.98	4.42	3.77
K2O	0.98	1.53	1.39	0.94	0.92	1.23	2.23	1.68
P2O5	0.20	0.27	0.25	0.14	0.16	0.18	0.40	0.31
H2O+	0.42	0.25	0.36	0.07	0.05	0.54	0.15	0.00
H2O-	0.25	0.00	0.37	0.07	0.05	0.00	0.00	0.00
Total	100.00	100.16	99.69	100.01	98.78	98.82	99.63	100.40
Rb	20	41	33	22	22	17	48	35
Ba	427	576	526	410	415	546	931	766
Sr	461	502	441	491	518	395	348	411
V	309	225	322	276	257	339	106	207
Cr	17	8	3	12	10	13	1	2
Ni	20	13	9	16	16	11	4	7
Zr	101	145	151	71	71	123	212	172
Sc	31.5	23.1	32.6	25.2	23.1	37.5	28.6	32.8
Cu	133	130	147	114	105	220	64	166
87Sr/86Sr	0.00000	0.00000	0.70369	0.70365	0.00000	0.00000	0.70385	0.00000
143Nd/144Nd	0.00000	0.00000	0.51301	0.00000	0.00000	0.00000	0.00000	0.00000
Distance, k	305	319	319	321	321	358	358	358
Crust	38	38	38	38	38	37	37	37
Volume, km3	100	160	160	2	2	110	110	1
C-volume,km	100	165	165	165	165	110	110	1
Nb	2.7	3.2	3.5	2.9	1.1	1.8	4.2	4.2
Be	0.90	1.15	1.10	0.87	0.84	0.91	1.38	1.24
10Be	0.0	0.0	0.0	6.9	0.0	0.0	14.4	0.0
La	8.13	12.74	12.01	6.78	7.36	8.79	16.87	12.95
Ce	20.98	30.45	30.63	16.65	17.13	22.52	42.24	32.87
Nd	12.81	19.19	17.69	10.31	10.29	14.23	27.98	21.77
Sm	3.86	4.61	4.43	3.32	2.76	4.14	7.13	6.10
Eu	1.13	1.19	1.25	0.95	1.00	1.07	1.84	1.61
Gd	3.90	4.75	5.46	3.19	3.39	4.65	8.33	6.89
Dy	4.16	4.56	5.52	3.38	3.10	4.99	8.37	7.10
Er	2.15	2.50	3.13	1.94	1.74	2.70	5.22	4.30
Yb	1.84	1.90	2.70	1.60	1.42	2.40	4.32	3.56
Y	24.32	26.94	30.59	19.46	17.22	27.05	56.52	42.25
FeO*	9.79	8.48	9.42	8.18	8.53	9.86	9.42	9.40
Mg#	46	44	44	48	49	44	28	33
Density	2.61	2.58	2.59	2.59	2.60	2.59	2.53	2.55

File name centsym5.ROC

Sample	AP-3	TE-4	US-2	SM-7	SM-8	CO-3	IC1	IM1
VN #	44.10	45.00	45.10	46.00	46.00	47.00	48.00	49.00
Qual	3	3	3	3	3	3	5	5
Key	4	4	4	4	4	4	4	4
Ref	0	0	0	0	0	0	0	0
SiO2	49.50	51.80	49.10	51.10	50.50	51.20	50.00	54.60
TiO2	0.96	0.93	1.08	0.97	0.96	0.76	0.78	0.75
Al2O3	18.10	17.90	18.40	19.70	19.20	18.60	18.90	18.10
Fe2O3	3.00	5.34	3.39	2.45	3.38	2.95	1.83	1.14
FeO	7.90	4.60	7.90	6.57	6.62	7.25	7.76	6.69
MnO	0.21	0.14	0.19	0.18	0.17	0.15	0.21	0.13
MgO	6.00	4.53	5.10	3.38	4.78	5.53	4.90	4.11
CaO	11.50	9.32	10.41	10.31	10.97	10.35	10.61	8.62
Na2O	2.40	3.14	2.89	2.93	2.89	2.53	2.36	3.34
K2O	0.35	1.24	0.70	0.87	0.64	0.53	0.43	0.91
P2O5	0.15	0.20	0.17	0.22	0.17	0.16	0.13	0.20
H2O+	0.00	0.52	0.24	0.20	0.21	0.36	0.66	0.28
Total	100.07	99.66	99.57	98.89	100.49	100.37	98.57	98.87
Rb	8	26	11	16	13	11	11	14
Ba	297	568	379	526	411	498	399	565
Sr	619	564	593	524	514	571	562	489
V	302	282	343	303	333	281	293	202
Cr	84	7	4	14	21	9	14	25
Ni	47	13	12	13	19	16	16	19
Zr	54	97	69	82	69	53	61	90
Sc	35.4	28.0	25.8	33.2	36.7	33.1	31.7	25.9
Cu	130	113	113	213	183	164	147	62
87Sr/86Sr	0.70375	0.00000	0.70387	0.70387	0.00000	0.70396	0.00000	0.00000
143Nd/144Nd	0.51305	0.00000	0.51301	0.00000	0.00000	0.51302	0.00000	0.00000
Distance, k	406	443	450	468	468	514	525	532
Crust	38	35	35	35	35	33	32	33
Volume, km3	1	120	40	50	50	35	6	9
C-volume,km	1	270	270	101	101	35	6	9
Nb	2.1	2.3	3.0	2.6	2.9	2.4	3.0	5.1
Be	0.75	0.97	0.81	0.93	0.73	0.77	0.71	0.98
10Be	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0
La	5.28	8.51	5.52	8.61	6.05	6.41	5.37	9.03
Ce	12.71	21.33	15.57	20.93	14.85	14.96	12.22	19.53
Nd	9.61	14.52	9.56	14.60	10.06	10.04	9.05	11.81
Sm	2.63	3.58	2.95	3.98	2.86	2.73	2.53	3.17
Eu	0.85	1.11	1.02	1.15	0.96	0.85	0.88	0.98
Gd	2.55	4.00	3.60	4.55	3.43	2.79	3.06	3.63
Dy	3.19	4.17	3.47	4.66	3.40	2.76	2.72	3.68
Er	1.36	2.26	1.98	2.52	1.99	1.75	1.46	2.17
Yb	1.10	1.69	1.86	1.98	1.76	1.70	1.30	2.17
Y	15.46	23.13	20.73	23.96	19.88	16.33	16.93	22.99
FeO*	10.60	9.40	10.95	8.77	9.66	9.90	9.41	7.72
Mg#	50	46	45	41	47	50	48	49
Density	2.66	2.58	2.65	2.60	2.62	2.63	2.64	2.57

File name centsym5.ROC

Sample	COS9A	SC 2	SC 3	TE-1	TE-3	TE-6	LP1	LP2
VN #	51.00	52.00	52.00	53.00	53.00	53.00	54.00	54.00
Qual	5	6	6	6	6	0	0	6
Key	6	6	6	6	6	5	5	6
Ref	0	0	0	0	0	0	0	0
SiO2	58.90	48.44	51.45	52.60	49.40	50.30	53.60	50.00
TiO2	0.71	0.82	0.92	0.80	0.80	1.44	1.67	0.76
Al2O3	18.50	18.79	20.13	17.70	18.40	16.60	16.00	17.30
FeO	7.13	10.26	9.68	9.80	9.87	10.17	9.80	9.40
MnO	0.16	0.19	0.20	0.18	0.18	0.16	0.18	0.18
MgO	2.20	5.86	3.27	4.47	5.89	6.46	4.75	6.27
CaO	7.60	11.37	10.50	9.90	11.60	10.30	8.70	12.20
Na2O	3.88	2.40	3.10	2.77	2.43	2.83	3.03	2.14
K2O	1.27	0.57	0.80	1.34	0.94	0.88	0.85	0.63
P2O5	0.22	0.17	0.22	0.18	0.15	0.19	0.22	0.16
H2O+	0.10	0.00	0.00	0.20	0.10	0.20	0.48	0.62
Total	100.68	98.87	100.27	99.94	99.76	99.53	99.28	99.66
Rb	23	12	15	29	20	20	16	13
Ba	879	457	590	818	578	439	528	387
Sr	446	523	580	469	524	440	393	502
V	161	329	301	302	359	304	254	295
Cr	11	12	4	15	38	175	129	140
Ni	12	23	7	16	32	104	67	46
Zr	109	58	70	93	66	110	138	70
Sc	23.1	31.4	24.9	29.4	32.4	29.6	27.5	38.5
Cu	89	209	230	179	73	124	167	137
87Sr/86Sr	0.70390	0.70406	0.70390	0.70402	0.70408	0.70391	0.00000	0.00000
143Nd/144Nd	0.51311	0.51308	0.51309	0.51309	0.51306	0.51303	0.00000	0.00000
Distance, k	557	625	625	644	644	644	665	665
Crust	33	35	35	34	34	34	34	34
Volume, km3	30	50	50	28	28	28	19	19
C-volume,km	30	125	125	45	45	45	38	38
Nb	9.5	2.6	3.0	2.4	3.5	9.2	9.0	3.5
Be	0.94	0.79	0.89	0.83	0.79	0.95	1.15	0.78
10Be	14.5	0.0	0.0	10.7	0.0	0.0	0.0	0.0
La	8.61	5.03	6.73	7.02	5.89	6.20	7.07	6.02
Ce	21.86	13.17	17.10	17.72	14.54	16.73	21.65	13.24
Nd	15.01	9.42	11.32	11.97	10.28	11.67	15.79	10.24
Sm	4.50	2.80	3.23	2.64	2.46	3.37	4.66	2.91
Eu	1.20	0.91	1.13	0.92	0.92	1.22	1.45	0.86
Gd	5.25	3.18	4.21	3.83	3.37	4.18	4.97	3.43
Dy	5.56	3.39	3.98	3.73	3.29	3.89	4.87	3.49
Er	2.93	1.94	2.49	2.41	1.81	1.88	2.54	1.75
Yb	2.63	1.71	2.35	2.41	1.83	1.68	2.02	1.42
Y	30.43	19.57	25.22	24.07	19.55	22.27	27.87	19.12
FeO*	7.13	10.26	9.68	9.80	9.87	10.17	9.80	9.40
Mg#	35	50	38	45	52	53	46	54
Density	2.53	2.69	2.64	2.63	2.67	2.67	2.63	2.67

File name centsym5.ROC

Sample	AS1	AS2	AS4	CN1	CN10	MT8	MT101	NE3
VN #	54.20	54.20	54.20	54.10	54.10	55.00	55.00	56.50
Qual	0	0	0	6	6	6	6	0
Key	5	5	6	6	6	6	6	18
Ref	0	0	0	0	0	0	0	3
SiO2	54.20	54.20	55.90	50.80	49.40	52.20	54.40	50.30
TiO2	1.49	1.55	0.96	0.77	0.73	0.82	0.73	0.89
Al2O3	15.40	15.60	15.70	19.50	18.80	18.00	16.90	18.10
FeO	9.40	10.00	10.60	9.70	10.40	9.50	9.10	9.50
MnO	0.14	0.18	0.20	0.18	0.19	0.19	0.18	0.19
MgO	5.29	5.12	3.77	4.73	6.00	4.98	4.47	5.54
CaO	8.40	8.80	8.30	11.50	11.90	10.20	9.20	11.00
Na2O	2.91	2.80	2.84	2.20	2.00	2.65	2.89	2.55
K2O	0.80	0.89	1.31	0.46	0.37	0.72	0.91	0.62
P2O5	0.23	0.20	0.20	0.12	0.10	0.14	0.15	0.15
H2O+	0.35	0.83	0.61	0.25	0.18	0.26	0.20	0.44
Total	98.61	100.17	100.39	100.21	100.08	99.66	99.13	99.28
Rb	17	16	25	8	7	13	16	11
Ba	550	487	852	407	340	550	693	448
Sr	392	406	420	481	455	482	480	439
V	260	239	298	332	342	321	305	326
Cr	136	145	13	21	40	17	15	23
Ni	70	68	13	18	28	15	14	27
Zr	127	118	109	48	47	68	78	80
Sc	27.4	25.7	31.1	31.7	36.0	31.2	29.7	34.3
Cu	153	146	226	163	169	111	128	134
87Sr/86Sr	0.00000	0.00000	0.00000	0.70397	0.70392	0.00000	0.70405	0.70393
143Nd/144Nd	0.00000	0.00000	0.00000	0.51311	0.51309	0.00000	0.00000	0.51305
Distance, k	665	665	665	663	663	683	683	720
Crust	34	34	34	34	34	34	34	34
Volume, km3	1	1	1	1	1	18	18	1
C-volume,km	38	38	38	38	38	18	18	14
Nb	9.5	8.4	5.6	2.4	2.5	2.3	3.3	5.4
Be	1.05	1.04	0.93	0.72	0.70	0.75	0.82	0.87
10Be	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.0
La	7.40	7.06	7.41	3.60	3.18	5.59	6.03	6.17
Ce	20.38	20.99	19.65	9.15	7.78	13.30	14.77	14.71
Nd	14.35	14.31	13.89	7.10	6.00	9.61	10.08	9.29
Sm	4.19	4.19	3.94	1.95	1.69	2.49	3.13	2.34
Eu	1.40	1.35	1.11	0.77	0.69	0.90	0.94	0.90
Gd	5.02	4.88	4.48	2.53	2.34	3.27	3.61	2.98
Dy	5.22	4.64	4.60	2.95	2.39	3.26	3.86	3.12
Er	2.36	2.34	2.90	1.73	1.44	1.83	2.22	1.59
Yb	2.10	1.85	2.88	1.62	1.42	1.50	1.84	1.60
Y	26.06	25.04	29.20	16.63	14.76	18.55	22.64	18.19
FeO*	9.40	10.00	10.60	9.70	10.40	9.50	9.10	9.50
Mg#	50	48	39	47	51	48	47	51
Density	2.62	2.63	2.61	2.66	2.69	2.64	2.61	2.66

File name centsym5.ROC

Sample	NE5	NE6	NE201	NE202	NE203	CDP12	CDP14	MS4
VN #	56.50	56.50	56.50	56.50	56.50	56.50	56.50	61.00
Qual	0	0	0	0	0	0	0	0
Key	18	18	17	17	17	17	18	18
Ref	3	3	3	3	3	3	3	0
SiO2	48.00	47.20	47.90	47.50	47.40	48.20	47.30	50.90
TiO2	0.81	0.70	0.93	1.20	1.13	1.18	0.96	1.14
Al2O3	16.30	14.80	15.30	15.40	14.90	17.13	15.38	14.80
FeO	9.60	10.30	11.32	11.28	11.53	11.17	9.50	11.90
MnO	0.19	0.18	0.19	0.19	0.18	0.19	0.17	0.23
MgO	8.02	8.68	9.95	9.51	11.02	7.50	6.62	5.26
CaO	12.40	13.30	11.00	10.70	10.80	12.00	13.43	9.90
Na2O	2.22	1.58	2.30	2.51	2.19	2.35	2.00	2.82
K2O	0.41	0.40	0.19	0.24	0.14	0.16	0.41	1.16
P2O5	0.17	0.13	0.10	0.11	0.10	0.13	0.13	0.27
H2O+	0.15	1.72	0.20	0.40	0.10	0.40	2.59	0.55
Total	98.27	98.99	99.38	99.04	99.49	100.41	98.49	98.93
Rb	10	9	10	3	2	3	8	22
Ba	353	338	115	144	82	88	259	893
Sr	368	386	360	309	283	310	322	433
V	321	317	256	251	292	323	265	440
Cr	198	275	303	334	441	255	178	47
Ni	79	80	140	145	199	100	80	31
Zr	60	54	0	71	59	67	64	105
Sc	36.9	43.2	0.0	34.6	35.2	38.0	31.7	38.4
Cu	139	133	0	134	136	106	129	259
87Sr/86Sr	0.70407	0.70405	0.70375	0.70376	0.70362	0.00000	0.00000	0.70419
143Nd/144Nd	0.51307	0.51307	0.51302	0.51308	0.51299	0.51286	0.00000	0.00000
Distance, k	720	720	0	720	720	720	720	743
Crust	34	34	34	34	34	34	34	34
Volume, km3	1	1	1	1	1	1	1	60
C-volume,km	14	14	14	14	14	14	14	60
Nb	5.2	2.9	0.0	6.1	7.3	4.0	4.0	2.9
Be	0.79	0.79	0.00	0.74	0.71	0.78	0.86	1.11
10Be	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
La	6.64	4.99	0.00	3.31	2.87	3.28	4.29	10.32
Ce	14.93	12.07	0.00	9.75	8.41	10.02	11.27	23.67
Nd	10.18	8.19	0.00	7.81	6.96	8.47	9.00	16.87
Sm	2.80	2.00	0.00	2.27	2.02	2.66	3.23	4.24
Eu	0.93	0.77	0.00	0.93	0.90	0.99	0.92	1.28
Gd	3.22	2.80	0.00	3.22	3.34	3.74	3.42	4.71
Dy	3.05	2.70	0.00	3.19	3.44	3.94	3.62	4.93
Er	1.81	1.64	0.00	2.07	1.83	2.03	1.74	2.57
Yb	1.63	1.43	0.00	1.76	1.52	1.71	1.40	2.14
Y	18.15	16.63	0.00	20.22	19.01	23.19	19.42	25.86
FeO*	9.60	10.30	11.32	11.28	11.53	11.17	9.50	11.90
Mg#	60	60	61	60	63	54	55	44
Density	2.70	2.73	2.73	2.73	2.75	2.72	2.70	2.68

File name centsym5.ROC

Sample	AP3	AP5	GR3	GR5	GR6	GR101	MB101	N101
VN #	62.00	62.00	62.50	62.50	62.50	62.50	63.00	64.00
Qual	0	0	0	0	0	0	0	0
Key	17	18	17	17	17	18	18	18
Ref	0	0	5	5	5	13	0	0
SiO2	48.00	48.80	48.60	48.10	49.10	46.90	51.00	54.80
TiO2	0.99	0.74	1.26	1.15	1.03	0.55	1.19	0.93
Al2O3	15.60	20.40	16.40	16.10	16.40	15.90	18.60	18.03
Fe2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00
FeO	9.90	9.10	11.20	10.40	10.20	10.03	10.18	4.47
MnO	0.18	0.19	0.18	0.17	0.17	0.18	0.18	0.19
MgO	8.59	4.15	6.96	7.97	7.38	8.72	3.87	4.09
CaO	13.50	11.80	12.10	12.40	12.30	14.40	9.90	8.55
Na2O	2.07	2.36	2.40	2.19	2.08	1.46	3.06	3.42
K2O	0.30	0.59	0.14	0.10	0.27	0.30	0.60	1.31
P2O5	0.12	0.14	0.12	0.12	0.13	0.11	0.20	0.21
H2O+	0.41	0.35	0.19	0.18	0.55	0.50	0.90	0.00
Total	99.66	98.62	99.55	98.88	99.61	99.05	99.69	100.00
Rb	12	10	5	4	7	6	10	28
Ba	205	470	117	117	199	212	584	708
Sr	298	512	283	305	395	472	448	403
V	320	343	307	290	303	336	326	174
Cr	225	15	167	333	237	173	8	13
Ni	84	19	74	95	80	53	12	13
Zr	65	60	72	71	75	45	126	127
Sc	44.4	28.5	38.5	40.7	38.9	49.7	29.7	26.7
Cu	108	163	169	138	132	146	140	95
87Sr/86Sr	0.70388	0.70406	0.70384	0.70388	0.00000	0.70402	0.00000	0.00000
143Nd/144Nd	0.51301	0.51305	0.51301	0.51302	0.00000	0.51307	0.00000	0.00000
Distance, k	755	755	762	762	762	762	766	785
Crust	34	34	34	34	34	34	34	34
Volume, km3	10	10	1	1	1	1	25	33
C-volume,km	10	10	51	51	51	51	51	33
Nb	2.9	2.7	3.9	4.5	5.9	2.7	7.6	5.7
Be	0.86	0.90	0.60	0.67	0.68	0.50	0.91	0.96
La	4.64	5.95	2.83	3.44	5.23	5.24	10.58	13.23
Ce	11.86	13.70	9.40	10.12	13.56	11.82	25.82	28.32
Nd	8.62	9.43	8.64	8.02	9.59	7.83	16.41	16.60
Sm	2.63	2.46	2.58	2.76	3.09	2.46	4.67	4.37
Eu	0.94	0.86	1.01	0.98	0.94	0.74	1.38	1.22
Gd	2.83	2.59	3.70	3.56	3.35	2.64	4.95	4.47
Dy	3.10	2.92	3.92	3.40	3.87	2.85	5.20	4.97
Er	1.56	1.52	2.04	2.08	2.19	1.39	2.59	2.48
Yb	1.44	1.39	1.48	1.58	1.99	1.18	2.39	2.48
Y	17.35	16.39	21.06	19.91	22.41	14.95	27.30	28.81
FeO*	9.90	9.10	11.20	10.40	10.20	10.03	10.18	8.07
Mg#	61	45	53	58	56	61	40	47
Density	2.72	2.66	2.72	2.72	2.70	2.73	2.65	2.55

File name centsym5.ROC								
Sample	N146	N148	RV1	RV-203	MV4	TE1	TE9	52B
VN #	65.00	65.00	72.00	72.00	73.00	74.00	74.00	75.30
Qual	0	0	7	7	7	7	7	0
Key	18	18	16	16	16	16	16	16
Ref	0	0	0	0	0	0	0	0
SiO2	55.96	51.90	56.59	54.27	55.12	57.06	53.56	49.24
TiO2	1.14	1.13	0.69	0.71	0.77	0.61	0.77	0.77
Al2O3	17.66	19.03	16.90	17.80	17.23	17.24	18.97	18.78
Fe2O3	2.25	3.85	0.00	0.00	0.00	0.00	0.00	0.00
FeO	5.73	5.36	7.13	8.84	7.78	7.26	8.78	9.53
MnO	0.17	0.16	0.16	0.17	0.16	0.15	0.17	0.19
MgO	2.90	3.94	4.46	5.52	4.02	4.04	4.75	5.53
CaO	6.88	9.02	8.29	9.19	8.50	7.91	9.02	10.58
Na2O	4.06	2.88	3.01	2.70	2.76	2.94	2.94	2.50
K2O	1.65	1.20	1.37	1.07	1.82	1.35	0.76	0.89
P2O5	0.58	0.37	0.18	0.18	0.23	0.17	0.16	0.19
H2O+	0.71	1.01	0.31	0.21	0.75	0.42	0.21	0.00
H2O-	0.17	0.16	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.86	100.01	99.09	100.66	99.14	99.15	100.09	98.20
Rb	36	27	25	20	41	20	10	16
Ba	987	789	753	613	943	839	515	536
Sr	607	578	555	570	627	632	530	702
V	130	230	216	232	172	155	275	333
Cr	16	16	66	28	23	28	20	15
Ni	12	12	24	27	15	15	16	18
Zr	159	136	110	86	137	93	68	72
Sc	20.4	27.2	25.8	27.5	27.3	26.7	32.1	32.8
Cu	33	91	115	89	136	49	93	127
87Sr/86Sr	0.00000	0.00000	0.70391	0.00000	0.00000	0.00000	0.70379	0.00000
143Nd/144Nd	0.00000	0.00000	0.51304	0.00000	0.00000	0.00000	0.51302	0.00000
Distance, k	817	817	882	882	904	920	920	958
Crust	33	33	36	36	37	37	37	37
Volume, km3	46	46	200	200	140	70	70	12
C-volume,km	46	46	200	200	140	70	70	15
Nb	10.7	10.3	1.6	3.1	6.8	2.0	3.4	7.8
Be	1.41	1.22	0.99	0.85	1.03	0.82	0.80	0.90
La	27.04	22.05	18.28	13.38	19.75	21.06	11.19	19.27
Ce	56.17	44.68	37.31	28.67	41.45	41.42	22.30	35.04
Nd	34.83	26.45	21.60	16.42	23.81	25.60	17.13	18.94
Sm	7.35	5.73	4.99	3.77	5.06	4.96	4.08	4.41
Eu	2.26	1.69	1.34	1.12	1.40	1.38	1.34	1.29
Gd	7.56	5.71	4.99	3.95	5.56	4.52	4.66	4.24
Dy	6.45	5.14	4.76	4.04	5.08	4.03	4.59	4.10
Er	3.57	2.69	2.34	1.94	2.47	2.23	2.14	2.12
Yb	3.69	2.33	2.32	1.99	2.40	1.75	1.83	1.58
Y	40.21	28.99	27.66	20.08	26.64	24.25	27.81	23.85
FeO*	7.75	8.82	7.13	8.84	7.78	7.26	8.78	9.53
Mg#	40	44	53	53	48	50	49	51
Density	2.54	2.59	2.56	2.62	2.58	2.56	2.61	2.66

File name centsym5.ROC

Sample	127	153	C2	123LA	3	6	8	AR82
VN #	75.30	75.20	75.20	75.10	75.00	75.00	75.00	75.00
Qual	0	7	7	7	7	7	7	7
Key	16	16	16	16	16	16	16	16
Ref	0	7	7	7	7	7	7	7
SiO2	49.88	49.93	52.15	52.70	50.74	51.29	53.55	54.64
TiO2	0.72	0.65	0.61	0.66	0.58	0.65	0.61	0.61
Al2O3	19.75	18.81	18.75	19.11	20.72	18.98	18.77	19.04
FeO	8.57	8.42	7.93	8.14	7.47	9.54	8.44	7.19
MnO	0.18	0.18	0.16	0.16	0.14	0.17	0.21	0.15
MgO	4.91	6.01	5.42	5.09	4.70	5.53	4.46	4.76
CaO	9.90	9.36	9.64	9.48	10.82	9.74	9.15	9.04
Na2O	2.76	2.46	2.75	2.85	2.44	2.37	2.74	3.08
K2O	1.09	0.31	0.56	0.51	0.39	0.35	0.57	0.64
P2O5	0.27	0.17	0.18	0.19	0.14	0.15	0.19	0.17
Total	98.03	96.30	98.15	98.89	98.14	98.77	98.69	99.32
Rb	21	5	9	8	7	6	12	10
Ba	917	513	470	462	350	358	659	578
Sr	1028	728	729	740	733	689	628	748
V	233	206	186	202	194	197	164	191
Cr	11	76	60	28	40	41	19	48
Ni	20	44	40	33	28	40	19	42
Zr	74	59	60	54	51	54	55	62
Sc	26.0	28.2	26.7	24.8	24.6	27.4	21.2	22.8
Cu	144	101	71	101	95	114	91	106
87Sr/86Sr	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.70389
143Nd/144Nd	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.51302
Distance, k	958	958	958	958	958	958	958	958
Crust	37	37	37	37	37	37	37	37
Volume, km3	12	12	12	12	12	12	12	12
C-volume,km	15	15	15	15	15	15	15	15
Nb	6.1	5.7	5.0	4.8	8.8	7.7	5.9	4.6
Be	1.02	0.94	0.92	0.96	0.85	0.61	0.72	0.78
10Be	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
La	34.92	12.35	11.71	10.56	7.39	8.25	10.90	13.16
Ce	63.32	24.92	23.85	21.65	15.35	17.64	22.96	26.63
Nd	35.72	14.82	14.00	13.56	10.57	11.24	12.82	13.13
Sm	6.38	3.49	3.13	3.09	2.61	2.79	3.17	2.88
Eu	1.81	1.06	1.03	1.03	0.82	0.94	1.04	0.99
Gd	5.05	3.38	3.02	2.96	2.54	2.94	3.31	2.97
Dy	3.91	3.23	3.12	3.26	2.67	3.11	3.34	2.82
Er	1.99	1.61	1.78	1.49	1.24	1.58	1.73	1.54
Yb	1.70	1.21	1.27	1.25	0.98	1.23	1.28	1.49
Y	21.02	17.07	17.99	16.71	13.28	16.14	17.76	15.52
FeO*	8.57	8.42	7.93	8.14	7.47	9.54	8.44	7.19
Mg#	51	56	55	53	53	51	49	54
Density	2.64	2.64	2.62	2.61	2.62	2.65	2.61	2.58

File name centsym5.ROC

Sample	PLA68	PP3	PP11	PP7	PP8	PP9	PO2	PO4
VN #	81.10	81.00	81.10	81.50	81.50	81.50	82.00	82.00
Qual	8	8	0	0	0	0	8	8
Key	14	14	9	9	13	13	14	14
Ref	8	8	8	8	8	8	9	9
SiO2	49.12	52.34	49.76	44.80	47.11	49.70	51.13	54.21
TiO2	0.78	0.88	0.85	0.77	1.58	1.25	0.75	0.79
Al2O3	18.87	18.63	18.80	13.56	14.99	17.03	19.64	19.35
FeO	9.81	8.81	9.26	8.77	9.75	8.79	8.99	7.71
MnO	0.17	0.16	0.16	0.16	0.17	0.15	0.18	0.16
MgO	5.98	4.36	4.58	14.06	10.21	8.82	5.55	3.84
CaO	9.83	8.92	9.15	12.43	11.47	10.05	9.61	8.61
Na2O	2.20	2.86	2.83	1.06	2.23	2.81	2.89	3.09
K2O	0.97	1.69	2.81	1.18	1.32	0.81	0.75	1.06
P2O5	0.17	0.28	0.58	0.32	0.52	0.38	0.15	0.19
H2O+	1.38	0.28	0.32	2.12	0.23	0.20	0.30	0.24
Total	99.29	99.21	99.10	99.23	99.58	99.99	99.94	99.25
Rb	19	35	51	24	35	15	14	20
Ba	559	877	1944	2654	646	562	374	637
Sr	590	647	1582	2611	817	917	618	688
V	332	216	299	237	266	262	230	167
Cr	46	6	7	905	479	338	24	5
Ni	29	13	16	324	208	201	25	10
Zr	89	131	170	74	180	117	78	85
Sc	37.3	26.1	24.2	38.2	32.2	26.9	26.4	22.2
Cu	194	106	174	107	117	118	92	147
87Sr/86Sr	0.70374	0.70373	0.70375	0.70356	0.70376	0.70362	0.70375	0.00000
143Nd/144Nd	0.51291	0.51295	0.51291	0.51293	0.51294	0.00000	0.00000	0.00000
Distance, k	1002	1003	1002	1003	1003	1003	1021	1021
Crust	39	39	39	39	39	39	41	41
Volume, km3	165	165	165	165	1	1	240	240
C-volume,km	330	330	330	330	330	330	240	240
Nb	4.8	12.2	18.4	7.6	18.8	16.0	6.1	7.2
Be	0.85	1.22	2.00	0.70	1.38	1.18	0.80	0.88
La	23.47	37.40	103.00	64.39	59.90	33.40	10.71	19.71
Ce	37.85	73.04	186.90	125.10	118.90	66.60	23.95	36.82
Nd	21.80	33.17	82.50	59.57	57.50	32.30	13.05	18.13
Sm	4.73	6.84	14.20	7.53	10.80	6.10	2.71	4.14
Eu	1.30	1.69	3.70	2.16	2.90	1.80	1.01	1.14
Gd	4.31	5.80	10.30	5.19	8.60	5.10	3.18	3.59
Dy	3.73	4.95	6.30	3.43	6.10	3.60	3.58	3.60
Er	1.84	2.40	3.20	1.89	3.20	2.00	1.65	1.94
Yb	1.38	2.14	2.70	1.67	2.70	1.50	1.46	1.38
Y	20.52	24.17	33.50	16.64	32.30	18.90	16.19	20.63
FeO*	9.81	8.81	9.26	8.77	9.75	8.79	8.99	7.71
Mg#	52	47	47	74	65	64	52	47
Density	2.67	2.61	2.64	2.76	2.73	2.68	2.64	2.58

File name centsym5.ROC

Sample	PO10	PO8310	PO8317	PO8387	PO8397	B2B	B4B	B7
VN #	82.00	82.00	82.00	82.00	82.00	83.00	83.00	83.00
Qual	8	8	0	8	8	8	8	0
Key	14	14	13	14	14	14	14	13
Ref	9	9	9	9	9	16	10	14
SiO2	52.36	50.48	49.10	52.14	51.47	57.99	57.54	51.08
TiO2	1.11	0.77	1.05	0.97	0.83	0.81	0.78	1.57
Al2O3	18.24	17.41	15.52	17.93	18.32	17.38	17.86	16.39
FeO	9.92	6.80	9.47	9.38	10.09	6.17	6.31	8.51
MnO	0.19	0.18	0.15	0.16	0.17	0.12	0.12	0.15
MgO	3.89	5.01	7.11	4.38	5.59	3.66	3.78	6.39
CaO	8.25	9.98	9.44	8.78	10.23	6.65	6.99	9.57
Na2O	3.16	2.25	2.46	2.66	2.56	3.55	3.59	3.00
K2O	1.24	0.85	1.52	1.04	0.86	2.80	2.41	2.32
P2O5	0.26	0.13	0.42	0.12	0.17	0.27	0.26	0.48
H2O+	0.45	0.00	0.00	0.00	0.00	0.21	0.20	0.23
Total	99.07	93.86	96.24	97.56	100.28	99.61	99.84	99.69
Rb	26	17	34	22	16	83	69	35
Ba	728	480	702	494	455	964	862	738
Sr	555	580	741	559	587	695	714	860
V	351	294	266	165	271	151	150	237
Cr	6	58	264	21	24	38	42	198
Ni	9	32	117	15	21	24	26	73
Zr	155	85	164	106	75	246	201	218
Sc	33.9	30.9	29.2	31.7	31.0	18.9	18.9	27.6
Cu	159	161	53	165	111	92	91	89
87Sr/86Sr	0.70373	0.70374	0.70379	0.70369	0.70389	0.00000	0.00000	0.00000
143Nd/144Nd	0.51288	0.00000	0.51289	0.00000	0.00000	0.00000	0.00000	0.51299
Distance, k	1021	1021	1021	1021	1021	1037	1037	1037
Crust	41	41	41	41	41	41	41	41
Volume, km3	240	240	240	240	240	500	500	500
C-volume,km	240	240	240	240	240	500	500	500
Nb	12.2	8.4	13.5	7.3	4.7	21.5	17.6	23.8
Be	1.39	1.00	1.37	0.96	0.88	1.66	1.55	1.62
La	29.51	15.64	46.14	17.47	15.44	43.80	38.93	52.95
Ce	59.54	31.07	93.32	36.77	31.07	85.53	75.89	105.30
Nd	28.15	14.77	44.99	19.55	16.08	36.91	31.90	49.24
Sm	6.29	3.27	7.77	4.26	3.40	6.01	6.35	8.13
Eu	1.50	0.97	2.26	1.18	1.06	1.44	1.37	2.39
Gd	5.55	3.78	6.77	4.09	3.41	5.39	4.76	7.02
Dy	5.40	3.76	4.99	4.23	3.72	4.59	4.21	5.58
Er	2.62	1.54	2.39	1.99	1.69	2.29	2.07	2.71
Yb	2.28	1.39	1.98	1.85	1.40	2.02	1.83	2.01
Y	27.79	16.83	25.09	20.26	16.14	22.75	20.70	26.42
FeO*	9.92	6.80	9.47	9.38	10.09	6.17	6.31	8.51
Mg#	41	57	57	45	50	51	52	57
Density	2.62	2.61	2.67	2.62	2.66	2.52	2.53	2.64

File name centsym5.ROC

Sample	B8	B2	BHO-6A	IZ-63A	IZ84-1	I1	I2	D2
VN #	83.00	83.00	83.10	84.00	84.00	84.00	84.00	84.00
Qual	0	0	8	8	8	8	8	0
Key	13	13	14	13	14	14	14	13
Ref	14	14	16	11	11	11	11	11
SiO2	50.66	51.12	50.89	55.29	55.19	54.35	56.11	50.39
TiO2	1.68	1.15	1.13	0.94	0.90	0.95	0.89	1.02
Al2O3	17.83	16.82	18.20	17.34	17.80	18.22	17.82	15.84
FeO	9.42	8.32	9.48	6.84	6.60	6.96	6.68	7.96
MnO	0.16	0.16	0.16	0.12	0.11	0.12	0.12	0.14
MgO	6.12	7.88	3.82	5.70	4.27	4.47	4.77	8.99
CaO	9.44	9.25	9.30	8.15	7.63	8.20	7.95	9.10
Na2O	2.95	2.87	3.12	3.46	3.49	3.52	3.49	2.73
K2O	0.94	1.70	1.55	1.98	1.75	1.65	1.90	1.56
P2O5	0.32	0.44	0.37	0.35	0.33	0.35	0.31	0.41
H2O+	0.34	0.15	1.19	0.00	0.00	0.00	0.00	0.00
Total	99.86	99.86	99.21	100.17	98.07	98.79	100.04	98.14
Rb	16	36	29	46	39	36	36	35
Ba	534	748	857	806	757	699	695	669
Sr	795	805	761	805	885	887	758	770
V	259	222	311	195	152	188	196	231
Cr	89	341	13	208	58	34	98	420
Ni	44	157	13	96	42	34	47	152
Zr	161	201	153	175	148	149	160	144
Sc	31.9	29.0	34.8	23.0	21.0	21.1	21.6	27.3
Cu	134	76	215	134	123	92	102	108
87Sr/86Sr	0.00000	0.70367	0.70375	0.70366	0.00000	0.00000	0.00000	0.00000
143Nd/144Nd	0.00000	0.51295	0.51291	0.51296	0.00000	0.00000	0.00000	0.00000
Distance, k	1037	1037	1050	1067	1067	1067	1067	1067
Crust	41	43	43	45	45	45	45	45
Volume, km3	500	500	500	520	520	520	520	520
C-volume,km	500	500	500	740	740	740	740	740
Nb	14.6	18.3	11.3	18.1	13.5	14.2	14.5	14.8
Be	1.26	1.46	1.64	1.45	1.27	1.38	1.44	1.36
10Be	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0
La	35.64	52.90	50.60	40.61	31.84	34.26	34.91	41.44
Ce	61.76	99.00	98.30	79.29	62.40	67.21	67.93	83.24
Nd	34.40	44.40	47.00	35.50	28.25	29.94	29.57	39.31
Sm	7.03	7.70	9.20	6.45	5.43	5.81	5.29	7.12
Eu	2.27	2.10	2.40	1.64	1.43	1.52	1.42	1.88
Gd	6.63	6.60	7.80	4.99	4.33	4.46	4.15	5.31
Dy	5.18	4.70	5.60	3.99	3.90	4.00	4.18	4.62
Er	2.37	3.20	3.50	2.33	1.79	1.62	1.91	2.00
Yb	1.76	2.20	2.60	1.89	1.64	1.39	1.56	1.62
Y	26.17	25.60	30.50	21.69	17.75	17.94	19.20	22.18
FeO*	9.42	8.32	9.48	6.84	6.60	6.96	6.68	7.96
Mg#	54	63	42	60	54	53	56	67
Density	2.66	2.64	2.63	2.57	2.56	2.57	2.56	2.65

File name centsym5.ROC

Sample	D7	V2	TU6	TU8	PAC1	GUC303	GUC403	GUC302
VN #	84.00	84.00	84.50	84.50	89.00	80.00	81.40	80.00
Qual	0	0	8	8	0	7	7	7
Key	13	13	13	14	13	7	7	7
Ref	11	11	11	11	0	0	0	0
SiO2	50.69	53.78	53.65	57.69	45.33	49.90	48.60	50.30
TiO2	1.14	1.18	1.06	0.89	1.69	1.36	1.58	1.22
Al2O3	15.84	17.64	17.59	17.28	14.16	16.50	17.30	17.50
Fe2O3	0.00	0.00	0.00	0.00	0.00	3.40	1.20	1.80
FeO	8.23	7.46	7.83	5.90	9.60	5.90	8.10	7.00
MnO	0.14	0.14	0.14	0.11	0.16	0.16	0.16	0.24
MgO	8.41	4.81	6.49	3.89	12.30	7.68	6.73	5.39
CaO	8.95	8.86	9.49	6.66	8.66	9.80	10.90	10.20
Na2O	2.81	3.50	3.36	3.72	2.09	3.23	3.30	3.52
K2O	1.65	2.14	1.46	2.27	1.19	0.57	0.73	0.83
P2O5	0.47	0.45	0.39	0.32	0.68	0.24	0.24	0.33
H2O+	0.00	0.00	0.00	0.00	2.60	0.29	0.36	0.38
H2O-	0.00	0.00	0.00	0.00	0.00	0.14	0.25	0.15
Total	98.33	99.96	101.46	98.73	98.45	99.17	99.45	98.86
Rb	38	53	31	50	22	7	10	12
Ba	773	888	640	882	706	179	325	324
Sr	843	848	799	741	1141	482	517	534
V	237	239	233	134	218	241	242	212
Cr	342	91	154	60	480	147	246	147
Ni	170	48	66	32	331	72	73	34
Zr	176	216	150	197	167	131	144	0
Sc	28.1	23.5	26.8	17.6	24.2	30.8	34.1	0.0
Cu	123	115	101	72	90	71	51	0
87Sr/86Sr	0.00000	0.00000	0.00000	0.00000	0.00000	0.70321	0.70337	0.70356
143Nd/144Nd	0.00000	0.00000	0.00000	0.00000	0.00000	0.51299	0.51293	0.51294
Distance, k	1067	1067	1072	1072	1080	235	285	240
Crust	45	45	45	45	45	38	38	38
Volume, km3	520	520	220	220	1	1	1	1
C-volume,km	740	520	740	740	1	1	1	1
Nb	18.4	19.5	13.7	18.6	22.2	5.3	9.7	0.0
Be	1.38	1.53	1.27	1.54	1.48	1.24	1.22	0.00
La	44.38	48.99	36.02	42.38	42.22	8.48	10.80	16.53
Ce	90.00	98.52	73.01	82.30	82.54	24.08	27.17	31.68
Nd	38.96	43.12	33.36	33.81	43.95	15.02	15.92	21.13
Sm	7.89	8.44	6.53	6.14	8.04	4.03	4.01	4.82
Eu	2.08	2.19	1.74	1.50	2.24	1.27	1.37	1.56
Gd	6.68	6.57	4.85	4.47	6.41	4.30	4.64	5.29
Dy	4.82	5.29	4.48	4.28	5.02	4.68	4.81	5.19
Er	2.14	2.55	2.09	2.09	2.11	2.46	2.87	2.80
Yb	1.59	2.19	1.63	1.80	1.64	1.80	2.04	2.64
Y	23.21	26.93	21.45	21.37	25.94	25.12	29.63	34.16
FeO*	8.23	7.46	7.83	5.90	9.60	8.96	9.18	8.62
Mg#	65	53	60	54	70	60	57	53
Density	2.65	2.59	2.62	2.53	2.74	2.63	2.66	2.63

File name centsym5.ROC

Sample	GUC307	GUC304	GUC202	HONC3	HONC4	DM	MM	EM
VN #	80.00	80.00	81.70	84.00	84.00	1.00	1.00	1.00
Qual	7	7	7	1	1	0	0	0
Key	7	7	7	3	3	0	0	0
Ref	0	0	0	14	14	0	0	0
SiO2	49.90	48.70	51.20	51.40	53.20	0.00	0.00	0.00
TiO2	1.33	1.39	1.49	1.18	1.23	0.20	0.20	0.00
Al2O3	17.50	17.90	17.10	17.40	17.10	0.00	0.00	0.00
Fe2O3	2.30	3.20	2.90	3.52	3.20	0.00	0.00	0.00
FeO	6.80	6.40	6.10	6.03	5.61	0.00	0.00	0.00
MnO	0.16	0.15	0.14	0.15	0.14	0.00	0.00	0.00
MgO	6.30	5.93	5.88	5.36	4.76	0.00	0.00	0.00
CaO	9.80	10.50	9.70	9.07	8.63	0.00	0.00	0.00
Na2O	3.54	3.38	3.45	3.11	3.18	0.00	0.00	0.00
K2O	0.92	0.49	1.20	1.17	1.40	0.01	0.01	0.12
P2O5	0.30	0.15	0.21	0.21	0.24	0.02	0.02	0.02
H2O+	0.19	0.35	0.20	0.41	0.36	0.00	0.00	0.00
H2O-	0.01	0.50	0.13	0.42	0.36	0.00	0.00	0.00
Total	99.05	99.04	99.70	99.43	99.41	0.23	0.23	0.14
Rb	13	8	14	15	23	0	0	1
Ba	353	243	384	567	698	1	43	8
Sr	550	496	531	612	681	13	21	44
V	218	237	222	234	229	0	0	0
Cr	167	137	256	114	166	0	0	0
Ni	62	56	80	40	55	0	0	0
Zr	0	0	0	0	0	11	11	11
87Sr/86Sr	0.70368	0.70336	0.00000	0.00000	0.00000	0.70270	0.70410	0.70360
143Nd/144Nd	0.51290	0.51298	0.00000	0.00000	0.00000	0.51315	0.51313	0.51290
Distance, k	245	235	265	540	540	0	0	0
Crust	38	38	38	38	38	0	0	0
Volume, km3	1	1	1	1	1	0	0	0
C-volume,km	1	1	1	1	1	0	0	0
Nb	0.0	0.0	0.0	0.0	0.0	0.3	0.3	2.2
La	12.65	9.02	20.96	18.23	22.00	0.31	0.51	2.00
Ce	30.31	23.84	44.83	40.06	45.24	0.95	1.26	5.20
Nd	18.28	14.79	25.85	24.19	27.58	0.86	1.04	3.44
Sm	4.05	3.80	5.40	4.95	5.43	0.32	0.36	0.80
Eu	1.41	1.34	1.83	1.65	1.69	0.00	0.00	0.00
Gd	4.57	4.45	5.91	5.21	5.50	0.00	0.00	0.00
Dy	4.46	4.57	5.69	4.83	4.75	0.00	0.00	0.00
Er	2.50	2.50	3.20	2.60	2.60	0.00	0.00	0.00
Yb	2.34	2.36	2.82	2.29	2.29	0.20	0.23	0.30
Y	27.67	28.37	35.16	28.52	32.63	4.10	4.40	6.15
FeO*	8.87	9.28	8.71	9.20	8.49	0.00	0.00	0.00
Mg#	56	53	55	51	50	0	0	0
Density	2.63	2.63	2.61	2.60	2.58	3.92	3.92	2.45

File name centsym5.ROC

Sample	SED1	SED2	SED3
VN #	1.00	1.00	1.00
Qual	0	0	0
Key	0	0	0
Ref	0	0	0
SiO2	58.60	17.60	7.11
TiO2	0.48	0.05	0.00
Al2O3	11.00	0.95	0.20
Fe2O3	5.49	2.90	0.82
MnO	0.18	0.47	0.18
MgO	2.11	0.91	0.37
CaO	2.80	39.70	51.40
Na2O	2.01	0.40	0.13
K2O	1.70	0.26	0.08
P2O5	0.11	0.11	0.09
Total	84.48	63.35	60.38
Rb	10	10	10
Ba	3600	2997	1726
Sr	321	1408	1605
V	130	34	38
Cr	48	17	19
Ni	160	34	13
Zr	90	41	18
Sc	15.2	6.4	5.6
Cu	136	144	39
87Sr/86Sr	0.70763	0.70862	0.70854
143Nd/144Nd	0.51274	0.51243	0.51240
La	16.10	15.90	9.10
Ce	25.00	6.92	3.34
Nd	14.10	14.20	6.08
Sm	2.80	3.62	1.51
Eu	0.86	0.71	0.27
Gd	3.32	3.86	1.39
Dy	3.62	3.94	2.38
Er	0.00	2.14	1.46
Yb	2.32	1.84	1.25
Y	23.60	22.20	11.92
FeO*	4.94	2.61	0.74
Mg#	43	38	47
Density	2.40	2.99	3.27

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