Rev geol Amer Central 8: 77-109; San José, Costa Rica 1988

GEOCHEMISTRY OF VOLCANIC ROCKS IN A TRAVERSE THROUGH NICARAGUA

Jan Olov Nyström[1], Beatriz Levy[2], Björn Troëng[3], Jan Ehrenborg[3] & Giovanni Carranza[4]

[1] Swedish Museum of Natural History, S-10405 Stockholm, Sweden

[2] Department of Geology, University of Stockholm, S-1110691, Sweden

[3] Swedish Geological Company (SGAB),Box 801, S-95126 Lulea, Sweden

[4] Instituto Nicaragüense de la Minería (INMINE), Managua, Nicaragua

ABSTRACT

Major element composition and preliminar trace element data for 138 samples of mainly basic and intermediate volcanic rocks from a cross-section between the Pacific and Atlantic coasts of Nicaragua suggests that the present tectonic setting- subduction of an oceanic plate below the western margin of Central America- can be extrapolated back to the middle Tertiary.

The samples can be divided into three groups with regard to their chemistry: (a) the Recent to Tertiary volcanics from the entire traverse, (b) Cretaceous lavas from the Siuna mining district in NE Nicaragua, and (c) young basalts from Corn Island off Bluefields on the Atlantic coast. The first (and by far the largest) group are calc-alkaline volcanic arc lavas belonging to the high-alumina series. Many of them (especially those of the Tamarindo Formation and Recent lavas in NW Nicaragua) have tholeiitic affinities, consistent with the thin crust in this part of Central America. However, a common feature is an anomalous enrichment in Ba, which might reflect the Ba-rich active ridge sediments of the subducting oceanic plate. Crustal contamination is another possible explanation for the high values of Ba and other large-ion lithophile elements, especially for the volcanics in NE Nicaragua, where the influence of a Paleozoic basement is expressed by a trend of increasing evolution (calc-alkalinity) of the volcanics towards NE, away from the trench. Crustal contamination is clearly evident in the second group, the Siuna lavas, which have a shoshonitic affinity. The third group -the Corn Island basalts- have chemical features inconsistent with a subduction-related origin, being similar to some within-plate basalts of oceanic islands.

RESUMEN

La composición química -elementos mayores y datos preliminares de elementos traza -de 138 muestras de rocas volcánicas, en su mayoría básicas e intermedias, de un perfil entre las costas pacífica y atlántica de Nicaragua sugiere que el presente marco tectónico- subducción de una placa oceánica por debajo del margen occidental de América Central- puede extrapolarse hasta el Terciario medio.

Las muestras se pueden dividir en tres grupos en relación a su quimismo: (a) los volcánicos Recientes a Terciarios de todo el perfil, (b) las lavas cretácicas del distrito minero de Siuna del noroeste de Nicaragua, y (c) los basaltos jóvenes de Corn Island en el Atlántico. El primer grupo (formado por la gran mayoría de las muestras) corresponde a lavas calco-alcalinas del tipo 'high-alumina', típicas de arcos volcánicos. Muchas de ellas (especialmente las de la Formación Tamarindo y las lavas recientes de la parte noroeste de Nicaragua) tienen una afinidad toleítica, consistente con el espesor delgado de la corteza en esta parte de América Central. Sin embargo, todas estas lavas tienen una característica común, que es, un alto contenido de bario que podría deberse a la subducción de una placa oceánica con sedimentos muy ricos en bario formados en las dorsales activas. Una contaminación cortical es otra explicación posible para el alto contenido en bario y otros elementos litófilos del tipo 'large-ion' (LIL), especialmente en las rocas volcánicas de la parte noroeste de Nicaragua, donde la influencia del basamento Paleozoico se expresa por una tendencia a un aumento en el grado de evolución (calcoalcalinidad) hacia el noroeste, alejándose de la fosa oceánica. Las lavas del segundo grupo, las de Siuna, de afinidad shoshonítica, evidencian una clara contaminación cortical. El tercer grupo -los basaltos de Corn Island- tienen características químicas que son inconsistentes con un origen relacionado con una subducción; ellos son similares a algunos basaltos tipo intraplacas, de islas oceánicas.

INTRODUCTION

The Nicaraguan geotraverse, a joint Nicaraguan-Swedish project of geological, geophysical and isotope studies in a cross-section between the Pacific and Atlantic coasts, was started in 1984. The purpose of the project is to investigate the volcano-tectonic evolution of Nicaragua during the last 100 million years as a basis to understand the origin of its ore deposits. The most important ore type, epithermal gold-bearing quartz veins, is genetically associated with volcanic rocks, and volcanism -still intense- has been going on since the Cretaceous. At present, volcanoes form a narrow chain near the Pacific Ocean, but the existence of a thick pile of older lavas and pyroclastic rocks in other parts of Nicaragua shows that volcanism has shifted with time. Whether the volcanic arc has migrated step-wise in a regular fashion towards the west, as proposed by Lilljequist & Hodgson (1983), or the magmatic activity has shifted in a more complex pattern, remains unsettled. A petrological-geochemical- isotopic study of volcanic rocks from the geotraverse, combined with geophysical data, might solve this question and constrain the petrogenesis.

This paper deals with geochemistry of samples collected during 1985- 1986. A preliminary discussion of the origin of the Nicaraguan volcanics is also given here; a more thorough treatment of their formation history must wait for rare earth element (REE), stable isotope and geochronological data.

GEOLOGICAL BACKGROUND

Central America, forming the southernmost part of the Caribbean plate, is an active plate margin. The volcanism here is a consequence of the interaction between the Caribbean and Cocos plates, the latter being subducted below Central America (Fig. 1). The volcanic arc forming the backbone of Central America is composed of several segments (Carr et al, 1982). Two of them occur in Nicaragua (NW and SE of Managua; the displacement between

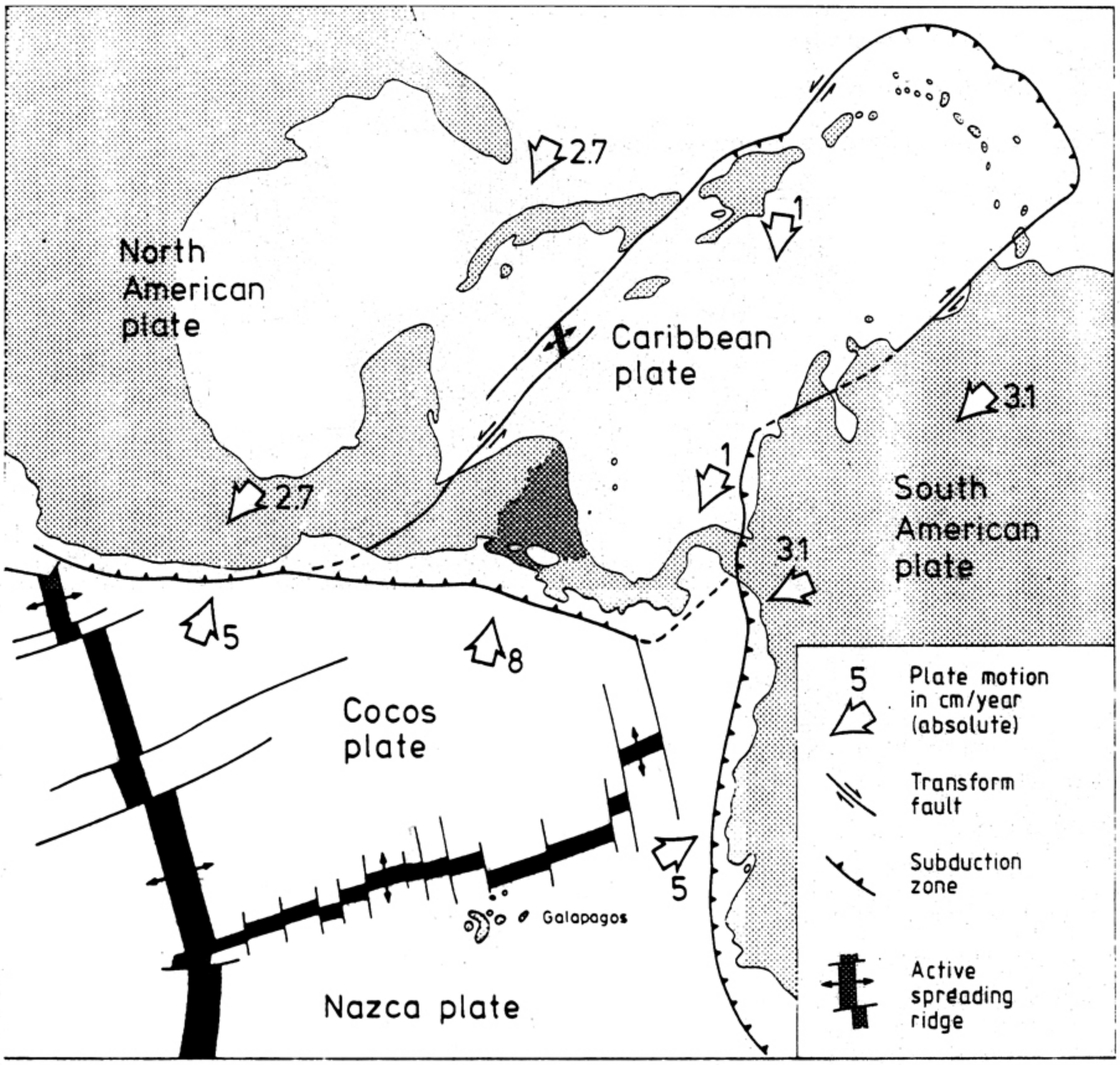


Fig. 1. Plate-tectonic setting of Nicaragua (indicated with dark stripple) and its surroundings (from Drummond, 1986).

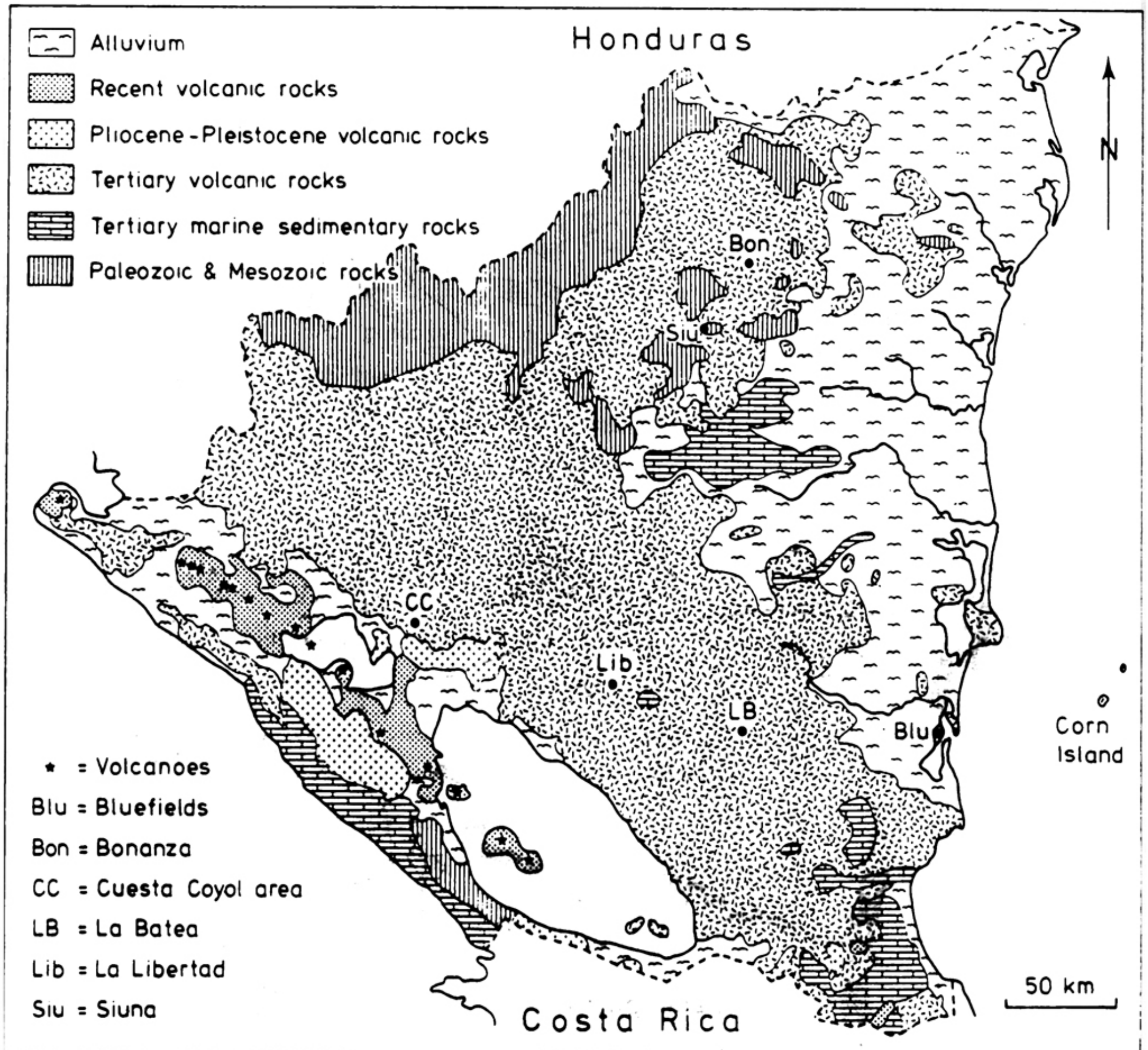


Fig. 2. Geologic map of Nicaragua (modified from "Mapa Geológico Preliminar 1: 1 000 000", Managua 1973); intrusions not shown. The Tertiary volcanics SW of the present volcanic arc (which is situated near the western boundary of the Nicaraguan Depression) constitute the Tamarindo Formation. The distribution of the Coyol and Matagalpa Groups, NE of the arc, is outlined in the "Mapa Geológico Preliminar".

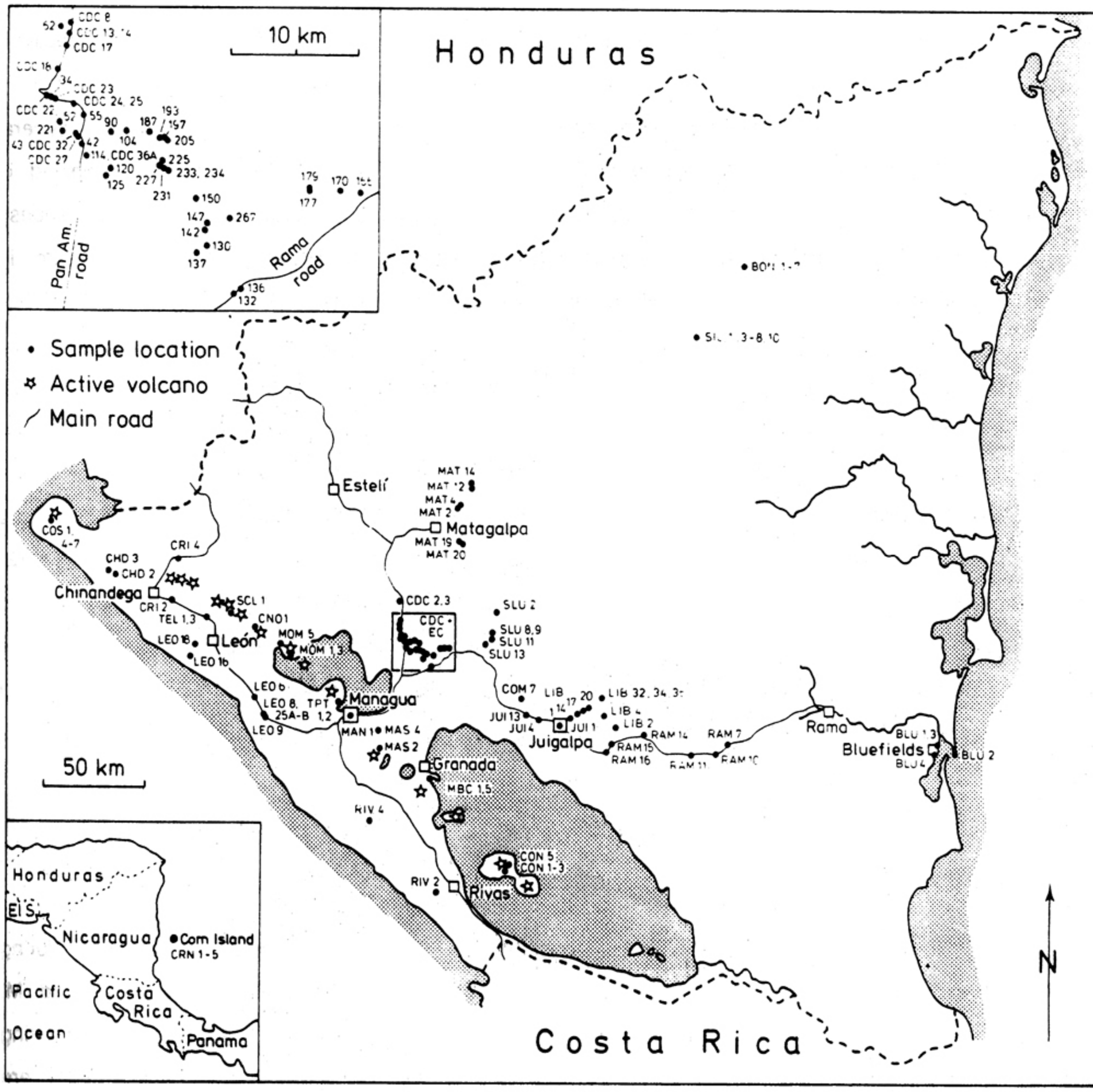


Fig. 3. Location of samples treated in this study. The upper inset includes the area mapped by Ehrenborg & Carranza (1986).

the segments is well seen in Figs. 2-3). The distance between the trench (at the subduction zone in Fig. 1) and the volcanic arc differs: 180 km for the NW segment and 190 km for the SE one. The dip of the subducting slab also varies: 65° and 75° respectively (Carr, 1984).

Nicaragua is the symmetry centrum of the volcanic arc with regard to several features. For example, the lavas are more basic here (the low SiO_2 content is reflected in the smaller proportion of pyroclastic rocks and relatively low altitude of the volcanoes), and the underlying crust is thinner (30 km in Nicaragua, in constrast with 30-45 km in Salvador/Guatemala and 30-40 km in Costa Rica; Carr, 1984, see also McBirney, 1969).

A simplified geological map of Nicaragua is given in Fig. 2. The Tertiary volcanic rocks have been assigned to several formations, but their ages and internal stratigraphy are poorly known in the central and eastern part of the country where there is virtually no paleontological control. Moreover, the volcanism probably took place in a caldera-type setting, as suggested by Lilljequist & Hodgson (1983), which makes correlations difficult without detailed mapping. K-Ar mineral data reported by Parsons Corporation (1972) suggest that Tamarindo Formation (Fig. 2) is roughly coeval with the lower part of the Coyol Group (Table 1). Descriptions of the units of relevance for this paper (Table 1) can be found in Bengoechéa (1963), McBirney & Williams (1965), Parson Corporation (1972), Weyl (1980). Darce (1983, 1987), Darce & Rodríguez (1983), Hodgson (1985), and references therein.

WORKING METHOD

This study is based on lavas of basaltic to andesitic composition collected during February-March 1985 (Nyström and Levi, partly accompanied by Carranza, G. Hodgson and M. Wilson) and March-April 1986 (Nyström, Levi and Troëng). A suite of samples taken during detailed mapping (Ehrenborg & Carranza, 1986) in the Coyol Group is also included. They are here called the EC series; the other samples have numbers starting with an abbreviation referring to their locality. We do not have material from all the volcanic formations of the geotraverse; the poorly known Matagalpa and pre-Matagalpa volcanics in eastern Nicaragua are underrepresented. All the samples from the Bonanza and Siuna mining districts and some from La Libertad are from drill cores. Location (Fig. 3), rock type and stratigraphic

	Age	West	Center	East	Northeast
Q.	Holocene	Volcanics & alluvium	Alluvium	Alluvial & residual deposits	
	Pleistocene	Las Sierras Group	Undifferent volcanics		
Tertiary	Pliocene	El Salto Fm	Coyol Group	Bluefields Fm	Coyol Group
	Miocene	El Fraile Fm / Tamarindo Fm			
	Oligocene	Masachapa Fm	Matagalpa Group	Cukra Fm	Matagalpa Group
	Eocene	Brito Fm			
	Paleocene		?	?	?
Cretac.	Upper	Rivas Fm	Pre-Matagalpa Group		
	Lower	(Nicoya Complex in Costa Rica)			Metapán Fm

Table 1. Preliminary stratigraphic correlation within the geotraverse (excluding Corn Island) based on Bengoechea (1963), Parsons Corporation (1972), Weyl (1980), Darce (1983), Darce & Rodriguez (1983), Hodgson (1985) and Darce (personal communication, 1987). The "West" column includes rocks from the Pacific Coast up to the NE margin of the Nicaraguan Depression (Fig. 2), "Center" refers to the broad belt of Tertiary volcanics NE of the Depression (excluding the pre-Matagalpa Group, represented in this study by a few samples from the La Batea Formation); "East" refers to the Bluefields area, and "Northeast" to the Bonanza-Siuna mining districts. The Bonanza volcanics are assigned to the Matagalpa Group, and those from Siuna to the Metapán Formation. Wavy lines represent unconformities.

position for the 138 samples used in this study are listed in Appendix 1. Stratigraphic positions are assigned according to 1: 50 000 scale geological maps (Parsons Corporation, 1972, and quadrangle mapping in progress) and Hodgson (1985).

Special care was taken in the field to select only parts of flows with a minimum of alteration and weathering for analytical work. Inspection of polished thin sections and X-ray diffractograms -prepared for all the samples- show that most of the lavas (excluding the Recent, unaltered ones) are at least incipiently altered (e.g. partial to complete replacement of olivine and devitrification of glass). The extent of alteration is generally higher, with replacement of groundmass minerales, in rocks from mining districts (Darce, 1987; Levi et al.,1987). Based on the variation in extent of alteration the samples have been divided into two categories: *'unaltered'* and *'partly altered'*. The 'unaltered' ones generally contain less than 0.3% CO_2 and 1% H_2O by weight (the Siuna lavas are more hydrated). They are plotted in discriminant diagrams including mobile elements, in contrast to the relatively few significantly altered samples which are used only in diagrams based on ratios between so-called immobile elements (e.g. Ti, Zr and Y).

The samples have also been grouped into two other categories *-basic* and *intermediate to acid* - since some diagrams are designed only for basalts. We have used screening criteria modified from Pearce (1987) for this division. The basic lavas have: (1) CaO+MgO > 12 wt.% (somewhat less in one shoshonite sample; a low MgO content is not uncharacteristic for this rock type), and relatively high Ti/Zr ratios (cf. Fig. 4 in Pearce, 1987). A consequence of the screening is that some lavas which are basaltic andesites according to the total alkali - silica (TAS) diagram (Fig.4) are sufficiently basic to be plotted in diagrams for basalts.

The samples were analysed for mayor and some trace elements with ICP optical emission spectrometry, and FeO, H_2O^+ and CO_2 with wet chemical methods, at the Centre de Recherches Pétrographiques et Géochimiques, Nancy (France). In addition, many trace elements were determined with X-ray fluorescence at the Open University , Milton Keynes (England). The major element analyses are listed in Appendix 2A-C.

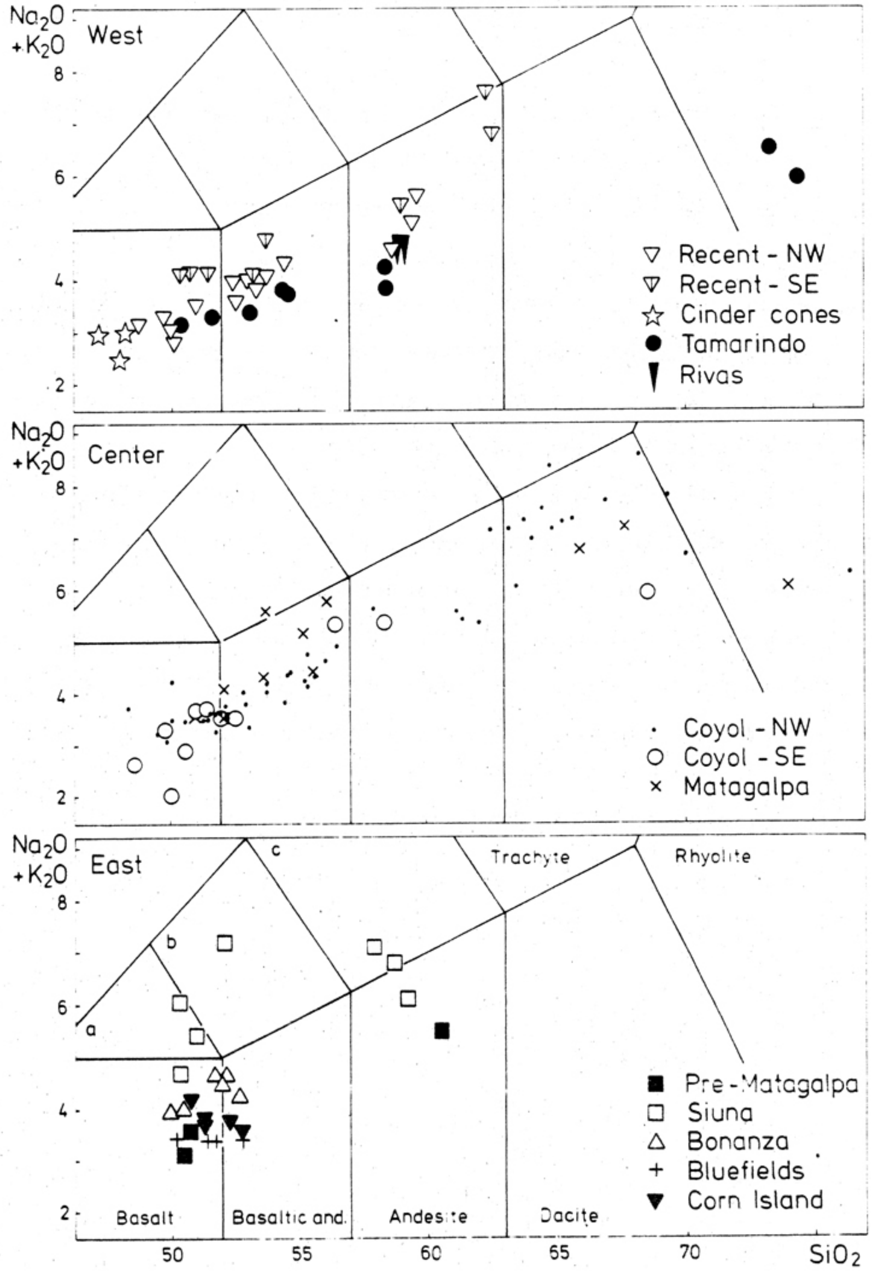


Fig. 4. Total alkali-silica (TAS) diagram for volcanic rocks from the Nicaraguan geotraverse, excluding significantly altered samples. Dividing lines after LeMaitre (1984). Samples falling in fields a - c are subdivided according to their relative propotions of alcalis: for Na_2O - 1.5 > K_2O, a= hawaiite, b= mugearite, c= benmoreite; for Na_2O - 1.5 < K_2O, a= potassic trachybasalt, b= shoshonite, c= latite (cf. Appendix 1). The sample groups are loosely named after their stratigraphic unit (Recent, Tamarindo, Coyol, Matagalpa, pre-Matagalpa) or locality. The volcanics are divided into a western, central and eastern group in order to enhance trends related to distance from the present trench. The pre-Matagalpa samples are plotted with the eastern volcanics in this and the following diagrams.

RESULTS

Almost all the analyzed volcanics from the Nicaraguan geotraverse are subalkaline, plotting below the inclined upper boundary of the basaltic andesite, andesite and dacite fields in Fig. 4 (see also Fig. 5). The significant exceptions are from Siuna, the only investigated locality with lavas of Cretaceous age. Figure 5 illustrates that the large majority of Nicaraguan volcanics belongs to the high-alumina series of Kuno (1965). The Siuna lavas of basic composition are relatively rich in potassium, some samples belonging to the shoshonite series (Fig. 6; Appendixes 1 and 2C). The lack of Fe enrichment shown in the AFM diagram is consistent with a shoshonitic affinity (Fig. 7).

Figures 6 and 8 taken at face value would suggest that some of the Nicaraguan lavas (basalts from Corn Island, and from cinder cones at N-S fractures in the Managua area) are ocean-floor tholeiites. However, other geochemical features contradict this suggestion. The contents of large-ion lithophile (LIL) elements like Ba, Sr, K and Rb are too high (Fig. 9), and preliminar data show that these lavas lack the REE distribution pattern typical of such primitive rocks. Neither does the geological setting support an ocean-floor tholeiite

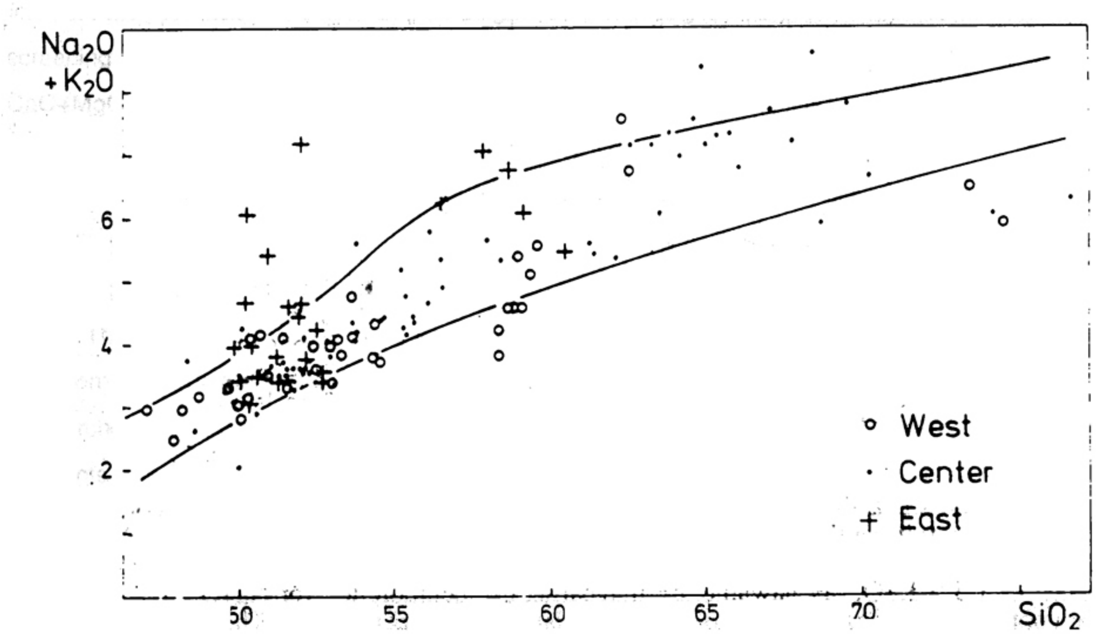


Fig. 5. The 'unaltered' volcanics from the geotraverse plotted in a TAS diagram with the boundary lines of Kuno's (1965) high-alumina field indicated.

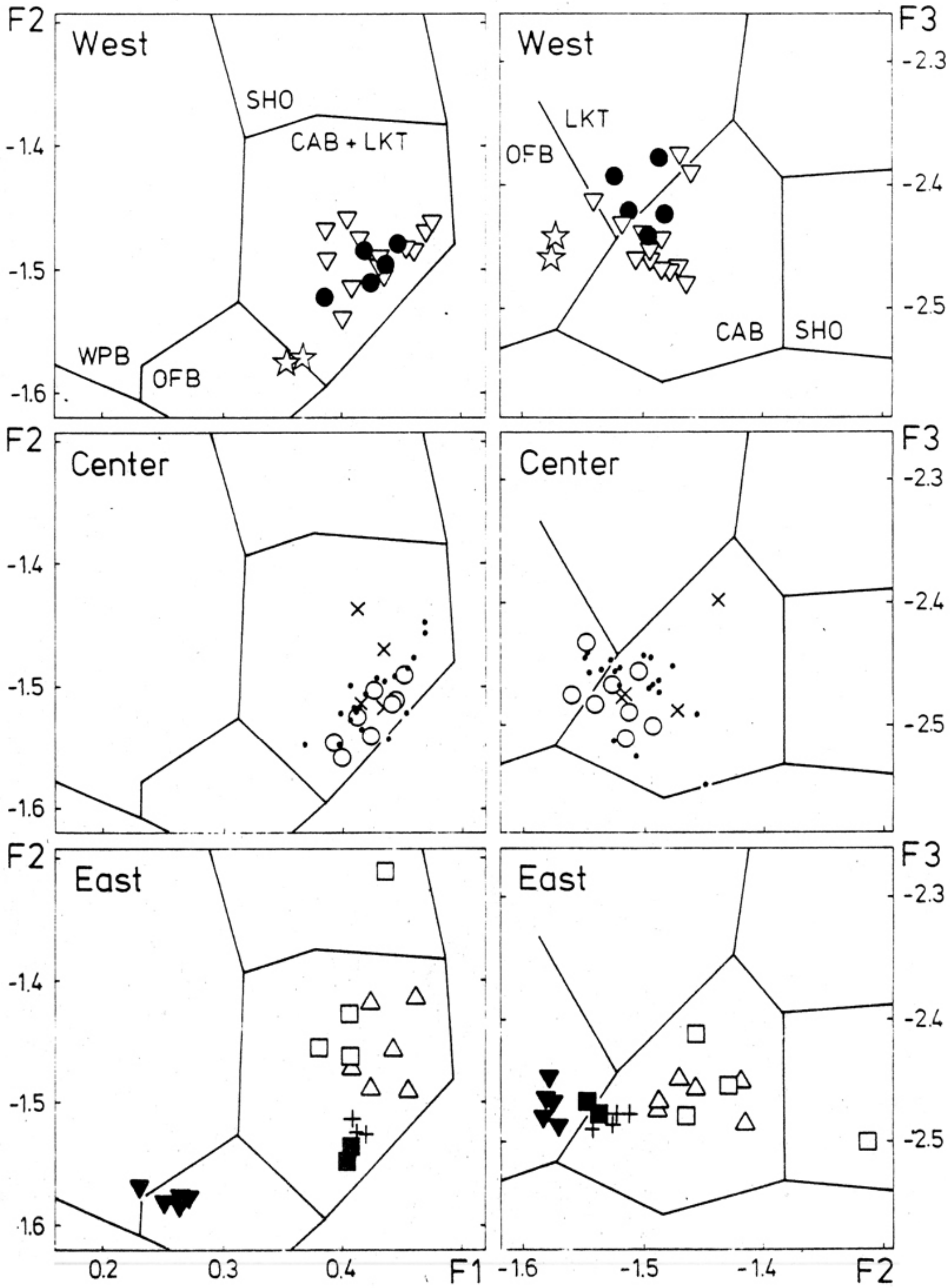


Fig. 6. 'Unaltered' basic lavas from the geotraverse plotted in Pearce's (1976) F1-F2 and F2-F3 diagrams. Symbols as in Fig. 4. **SHO** = shoshonites, **CAB** = calc-alkaline basalts, **LKT** = low-K tholeiites, **OFB** = ocean-floor basalts, **WPB** = within-plate basalts. **F1** = $0.0088SiO_2 - 0.0774 TiO_2 + 0.0102 Al_2O_3 + 0.0066FeO - 0.0017MgO - 0.0143CaO - 0.0155Na_2O - 0.0007K_2O$; **F2** = $-0.0130SiO_2 - 0.0185TiO_2 - 0.0129Al_2O_3$ $0.0134FeO - 0.0300MgO - 0.0204CaO - 0.0481Na_2O + 0.0715K_2O$; **F3** = $-0.0221SiO_2 - 0.0532TiO_2 - 0.0361Al_2O_3 - 0.0016FeO - 0.0310MgO - 0.0237CaO - 0.0614Na_2O - 0.0289K_2O$.

Para el terremoto de 1912, r = 144 km y de la ecuación (3) se obtiene que h = 17.5 km. Este dato ha sido obtenido con la escasa información existente debido al hecho de no tenerse informes donde no se sintieron los temblores. Sin embargo, se confirma el carácter superficial de la fuente ya expuesto, y se obtiene una estimación grosera de la profundidad hipocentral.

5.2.3 Estimación de la magnitud de los temblores

Para la estimación de las magnitudes, basadas en los datos macrosísmicos de los temblores de Bajos del Toro, se utilizará la relación que derivaron Gutenberg & Richter (1956) para el sur de California, donde la profundidad de los temblores es generalmente menor que 20 km:

$$M = 1 + (2/3)\, I_0 \qquad (4)$$

Para los eventos de 1851 y 1888 se estimó una I_0 de VIII, correspondiendo con una magnitud de 6.3. Para los tres terremotos (1911, 1912, 1955) se estimó una I_0 = VII, correspondiendo con M = 5.7.

Karnik (1968) obtuvo una relación válida para los países europeos mediterráneos луego de considerar un amplio conjunto de temblores:

$$M = 0.5\, I_0 + \log h + 0.35 \qquad (5)$$

Utilizando la relación (5) con I_0 = VII y h = 18 km, obtenemos para el caso de los temblores de 1911, 1912 y 1955, que M = 5.1.

Al utilizar la misma relación para el evento de 1851 y 1888, ambos con I_0 = VIII y h = 15.5 km y 15 km, resulta una magnitud de 5.5. Se pone en evidencia que estos valores serán directamente mayores o menores conforme aumenta o disminuya el valor asignado de la profundidad.

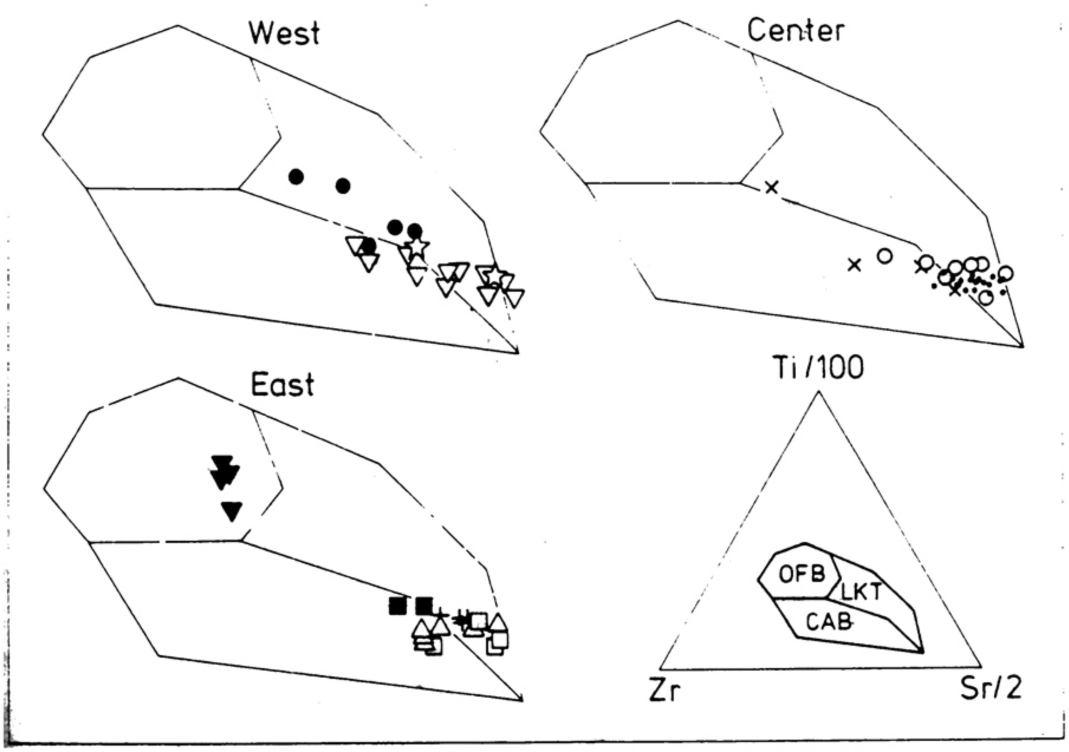
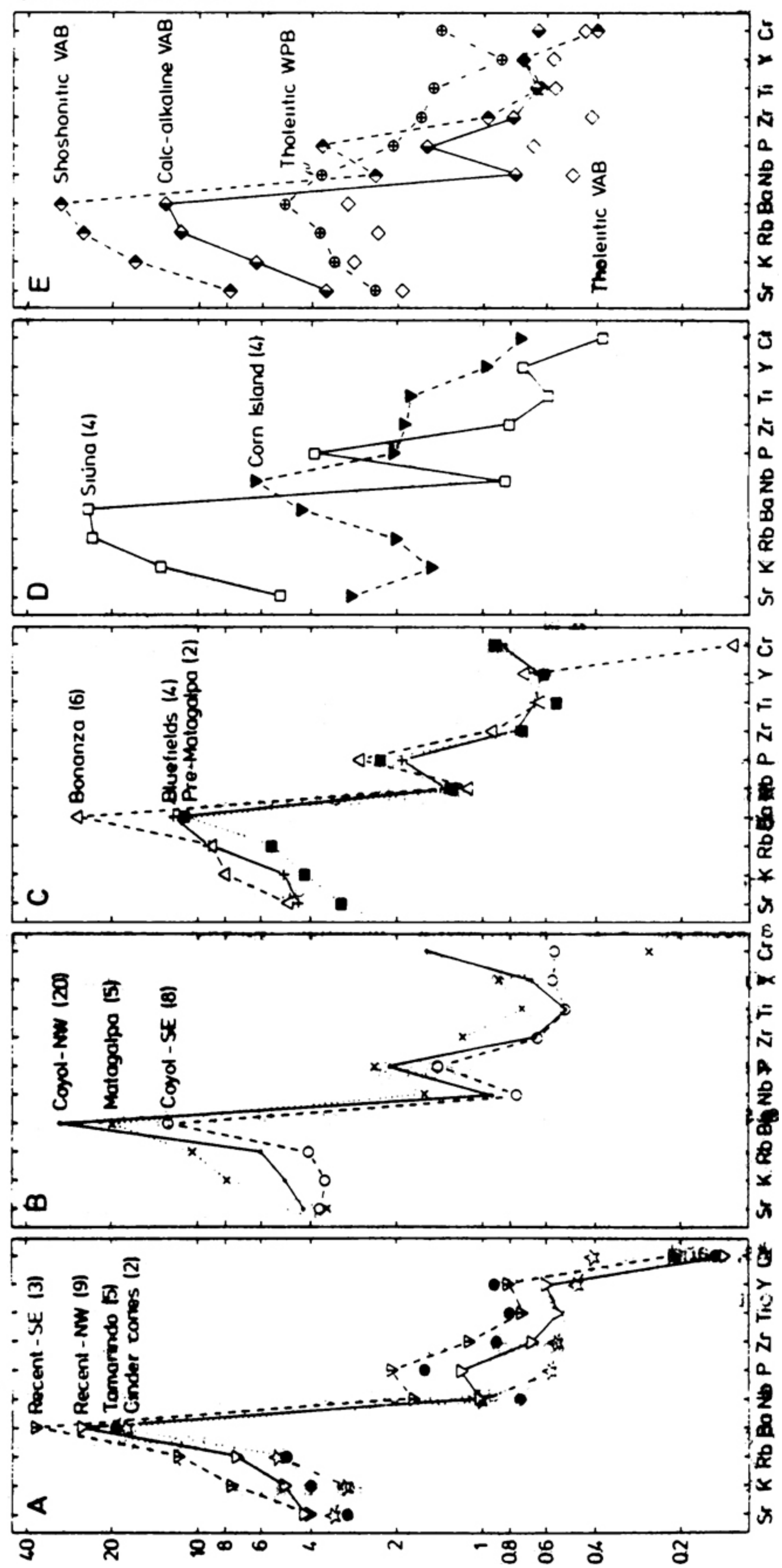


Fig. 8. 'Unaltered' basic lavas from the geotraverse plotted in Pearce & Cann's (1973) Ti-Zr-Sr diagram. See Figs. 4 and 6 for symbols and abbreviations.

character: the environment of the cinder cones rules it out, and the Corn Island basalts are not known to be associated with 'ocean type' material (pelagic sediments and ultramafic rocks). The chemistry of the Corn Island volcanics is more in agreement with a within-plate setting (Figs. 9-10; see also Fig. 6). Basalts of similar composition have, for example, been reported from the Galápagos Islands (Mc Birney &Williams, 1969).

The SiO_2 versus K_2O distribution (not shown here) of the Tertiary and Recent lavas indicates that they belong to the calc-alkaline series. Other geochemical features demonstrate, however, that many of them are transitional towards tholeiites (Figs. 6-8,10) The Tamarindo basalts, and the Recent flows from NW Nicaragua exhibit the strongest tholeiitic affinity (without being tholeiites). Some elements and elemental ratios that give a measure of the primitiveness/evolution (approximately corresponding to tholeiitic/calc-alkaline character), are plotted in Fig. 11 against distance to the present trench. It can be seen how the calc-alkalinity increases away from the trench. The concomitant dicrease in Cu should be pointed out. Among the Recent lavas there is an analogous trend from NW to SE


A
Recent - SE (3)
Recent - NW (9)
Tamarindo (5)
Cinder cones (2)
B
Coyol-NW (20)
Matagalpa (5)
Coyol - SE (8)
C
Bonanza (6)
Bluefields (4)
Pre-Matagalpa (2)
D
Siuna (4)
Corn Island (4)
E
Shoshonitic VAB
Calc-alkaline VAB
Tholeiitic WPB
Tholeiitic VAB
Sr K Rb Ba Nb P Zr Ti Y Cr
40
20
10
8
6
4
2
1
0.8
0.6
0.4
0.2

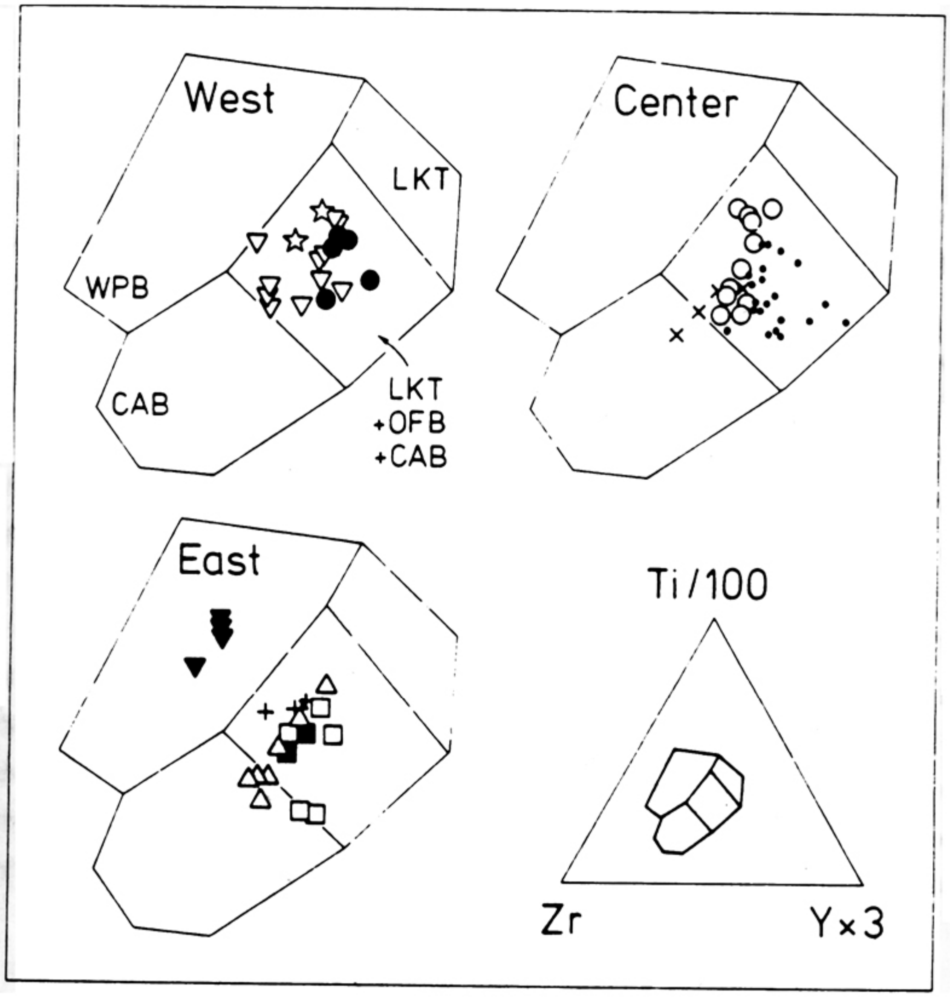


Fig. 10. Basic lavas from the geotraverse plotted in Pearce & Cann's (1973) Ti-Zr-Y diagram. See Figs. 4 and 6 for symbols and abbreviations.

Fig. 9. MORB- normalized geochemical patterns for 'unaltered' basic lavas from the geotraverse (A-D); number of samples averaged for each group is given in parenthesis. Normalized values (in ppm unless indicated) are: Sr = 120, $K(_2O)$ = 0.15%, Rb = 2, Ba = 20, Nb = 3.5, $P(_2O_5)$ = 0.12%, Zr = 90, $Ti(O_2)$ = 1.5%, Y = 30, Cr = 250 (**MORB** refers to an average N-type tholeiitic Mid-Ocean Ridge Basalt, cf. Pearce, 1982). Representative analyses (Pearce 1982) of tholeiitic, calc-alkaline and shoshonitic volcanic arc basalts (**VAB**) and a tholeiitic within plate basalt (**WPB**) are given in E for comparison.

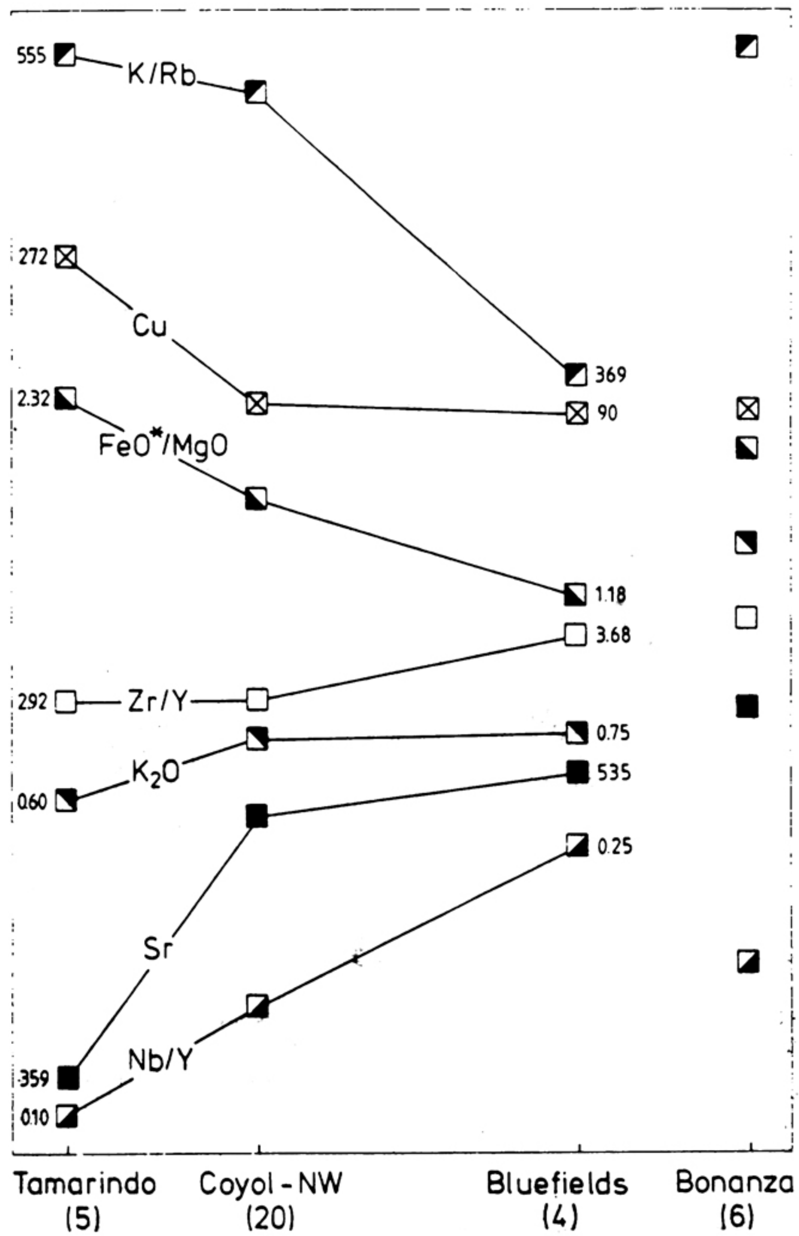


Fig. 11. Averages for selected elements and elemental ratios in some Tertiary basic lavas from the geotraverse samples at increasing distance from the present trench (situated west of the Tamarindo volcanics; cf. Figs. 1-2). Number of samples averaged for each group is shown in parenthesis. Scales can be inferred from the values (in pmm for Cu and Sr, and in wt.% for K_2O) given for the Tamarindo and Bluefields groups. FeO* = total iron as FeO. Increases in K_2O, Zr/Y, and a decrease in K/Rb across volcanic arcs and active continental margins away from the trench are often used as a measure of magmatic evolution.

(Figs. 4 and 9; Table 2). Such trend, although of opposite direction, can also be discerned for the Coyol volcanics (Fig. 9).

DISCUSSION

The Nicaraguan basalts and basaltic andesites within the geotraverse have chemical (and mineralogical) compositions which are in good agreement with their observed or inferred tectonic settings. With the exception of the Corn Island basalts they have compositions typical of volcanic arc lavas. The present setting for the Recent volcanism - subduction of an oceanic plate below the western margin of Central America- can be extrapolated back to the middle Tertiary, since the geochemical patterns of the Tertiary volcanics are similar to those of the Recent ones (Fig. 9). The unvarying low grade of the regional alteration (mordenite subfacies of the zeolite facies; Darce, 1987; Levi et al, 1987) over a large part of Nicaragua, in combination with the chemical similarities mentioned above, suggest that the geological history since the early Tertiary is characterized by volcanism in an extensional setting like, for example, that in the Nicaraguan Depression.

Volcanic arc lavas are enriched in LIL elements (e.g. Sr, K,Rb and Ba) relative to Ti, Y and sometimes Zr and Nb, as can be seen in Fig. 9E where representative examples of tholeiitic, calc-alkaline and shoshonitic arc lavas are plotted. Our samples resemble the

	Recent NW	Recent SE
SiO_2	51.3	50.8
Na_2O	2.74	2.99
K_2O	0.74	1.13
Sr	499	484
Ba	506	738
Cu	158	192
FeO*/MgO	2.03	2.15
K/Rb	423	410
Zr/Y	3.33	4.10
Nb/Y	0.19	0.25
n	9	3

Table 2. Averages for some elements and elemental ratios in Recent lavas from Nicaragua (excluding cinder cones) NW = Cosigüina to Momotombo, SE = Masaya to Concepción (n = number of samples averaged).

calc-alkaline example chemically, although as a rule they are much richer in Ba. The lavas with a tholeiitic affinity (strongest for the Tamarindo basalts) also have high Ba values, and our analyses of the relatively primitive cinder cone lavas in the Managua area (cf. Fig.6) confirm the high Ba (and Sr) concetrations reported for them by Bice (1980,1985) and Walker (1984). The samples with the highest contents of LIL elements are the Siuna lavas. They are also P-rich, in good agreement with their shoshonitic affinity (Fig.9).

The compositional variation displayed by the Tertiary volcanic rocks from the geotraverse can be explained by one or more of the following factors: (a) variation in character (oceanic versus continental) and thickness of the crust within the geotraverse; (b) nature of the subducted material; (c) changes in dip, rate, and direction of the subducting slab; and (d) accretion of oceanic ridges or crustal fragments at the western plate margin.

The character and thickness of the crust within the geotraverse is poorly known. The Paleozoic-Mesozoic basement in N and NE Nicaragua extends for an unknown distance towards the south. Trace element data for the Tertiary volcanics indicates that they are underlain by a thin continental crust which extends at least to the Nicaraguan Depression. A plot of Zr versus Zr/Y is considered to discriminate between oceanic and continental arc lavas (Pearce, 1983). The mayority of our samples fall in the continental field of this diagram (not included here), but many from the entire length of the traverse are transitional, and a few plot as weakly oceanic (Tamarindo lavas and some from the Coyol group). However, the large volume of acid ignimbrites in the Tamarindo Formation is not consistent with an oceanic source. The Corn Island samples are classified as ocean island basalts in the Zr versus Zr/Y diagram.

The influence of the pre-Tertiary basement appears to be reflected in the chemistry of the Bonanza lavas. Bonanza and Bluefields are both relatively distant from the present trench (Figs. 1 and 2). Volcanics from these localities have very similar geochemical patterns, with the exception of higher Ba and K and lower Cr in Bonanza (Figs. 9 and 11); the Cr content is of little consequence here, since it is very susceptible to changes in degree of fractional crystallization. As mentioned earlier, high contents of LIL elements contributed by the subduction process is one of the characteristics of volcanic arc lavas. The fact that Ba and K alone out of the LIL elements are enriched in the Bonanza flows, relative to those from Bluefields, suggests crustal contamination. This is hardly surprising since pre-

Tertiary rocks constitute a basement in the Bonanza area (Fig. 2) and Ba as well as K can easily be taken up from the surrounding crust by magmas. Lead isotope data for Nicaraguan gold deposits also suggest an increase in crustal contamination towards the northeast (Sundblad et al., 1985).

Crustal contamination of K could be the reason why Sr seems to be a better guide to distance from the trench (or height above the subducting plate) than K (Fig. 11). This is also indicated from studies in other volcanic arcs and in active continental margins (Hart et al.,1970; Palacios & Oyarzún, 1975). According to Carr (1984) there is no relationship between the K content (at 52 wt.% SiO_2) in Recent volcanic rocks and depth to the seismic zone (descending slab) in Central America.

The high contents of Ba in the subducted active ridge sediments of the Cocos plate (Boström, 1973,1976) might explain the anomaluos enrichment of this element in the Nicaraguan volcanic rocks. A discussion of this and other possible controls for the compositional variation and origin of the volcanics must, however, wait until stable isotope and additional trace element data are available.

ACKNOWLEDGEMENTS

We thank L. Aguirre (Université d'Aix, Marseille) and M. Darce (INMINE) for critical reading of the manuscript, which lead to its improvement. G. Hodgson's (INMINE) expertise of Nicaraguan geology enabled us to obtain good samples in eastern and central Nicaragua. A special thank is directed to Reynaldo Sevilla, also of INMINE, for his efficient and enthusiastic help in the field. The financial support of SAREC, is acknowledged. This publication is authorized by INMINE.

REFERENCES

(Unpublished INMINE/SAREC/SGAB reports can be obtained on request from Swedish Geological Company (SGAB), The Library, S-951128 Luleå, Sweden).

Bengoechéa, A.J., 1963: Distrito minero del noreste.- Bol. Serv. Geol. Nac. Managua, 7: 13-51.

Bice, D.C., 1980: Tephra stratigraphy and physical aspects of Recent Volcanism near Managua, Nicaragua.- 422 pp. University of California, Berkeley (unpublished Ph.D. thesis).

Bice, D.C., 1985: Quaternary volcanic stratigraphy of Managua, Nicaragua: correlation and source assignement for multiple overlapping plinian deposits.- Geol. Soc. Amer. Bull., 96: 553-566.

Boström, K., 1973: The origin and fate of ferromanganoan active ridge sediments.- Stockholm Contr. Geol., 27: 149-243.

Boström, K., 1976: Particulate and dissolved matter as sources for pelagic sediments. - Stockholm Cont. Geol., 30: 15-79.

Carr, M.J., Rose, W.I. & Stoiber, R.E., 1982: Central America.- In: Thorpe, R.S. (ed.): Andesites: orogenic andesites and related rocks: 149-166; Wiley & Sons.

Carr, M.J., 1984: Symmetrical and segmented variation of physical and geochemical characteristics of the Central American volcanic front.- J. Volcanol. Geotherm. Res., 20: 231-252.

Darce, M., 1983: Geología y recursos minerales de las cuencas Río Viejo-Estero Real y Volcano Pacífico (porción occidental de la República de Nicaragua).- 143 pp. Universidad Nacional Autónoma de México (unpublished M.Sc. thesis).

Darce, M., 1987: Geología del distrito minero La Libertad, Nicaragua.- Rev. geol. Amer. Central, 7: 65-82.

Darce, M. & Rodríguez, N., 1983: Geología del área de Bluefields, Zelaya, Nicaragua (Hojas 3452 III y 3451 IV, 1:50 000).- 37 pp. Inst. Nicaragüense de Acueductos y Alcantarillados (unpublished report).

Drummond, K.J., 1986: Plate-tectonic map of the Circum-Pacific region, northeast quadrant (1:10 000 000).- Circum-Pacific Council for energy and mineral resources, Am. Ass. Petroleum Geologists, Tulsa.

Ehrenborg, J. & Carranza, G., 1986: Semiregional mapping of the Cerro El Coyol-presa Las Canoas area, Nicaragua. Vol. 1; introduction, results and discussion.- 39 pp. INMINE/SAREC/SGAB Lulea, Sweden (unpublished report).

Elming, S. Å., 1985: A paleomagnetic investigation and K-Ar age determinations of volcanic rocks in Nicaragua.- 46 pp. INMINE/SAREC/SGAB, SGAB, Luleå, Sweden (unpublished report).

Hart, Sr., Brooks, C., Krogh, T.E., Davis, G.I. & Nava, D., 1970: Ancient and modern volcanic rocks: a trace element model.- Earth. Planet. Sci. Lett 10: 17-28.

Hodgson, G., 1985: Geología de un área de la provincia central este de Nicaragua.- 82 pp. Inst. Nicaragüense de Estudios Territoriales, Managua (unpublished report).

Kuno, H., 1965: Fractionation trends of basalt magmas in lava flows.- J. Petrol., 6: 302-321.

LeMaitre, R.W., 1984: A proposal by the IUGS Subcommision on the Systematics of Igneous Rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram.- Austral. J. Earth. Sci, 31: 243-255.

Levi, B., Nyström, J.O., Darce, M. & Troëng, B., 1987: Alteration patterns in volcanic rocks from a geotraverse through Nicaragua -a progress report. - 39 pp. INMINE/SAREC/SGAB, Luleå, Sweden (unpublished report).

Lilljequist, R. & Hodgson, G., 1983: Structures and rock formations related to precious metal vein deposits in Nicaragua.- 63 pp. INMINE/SAREC/SGAB, SGAB Luleå, Sweden (unpublished report).

McBirney, A.R., 1969: Compositional variations in Cenozoic calc-alkaline suites of Central America.- Proceedings of the Andesite Conference Internat. Upper Mantle Project Sci. Rep., 16: 185-189.

McBirney, A.R. & Williams, H., 1965: Volcanic history of Nicaragua.- Univ. Calif. Publ. Geol. Sci., 55: 1-69.

McBirney, A.R. & Williams, H., 1969: Geology and petrology of the Galápagos islands.- Geol. Soc. Am. Mem. 118: 1-197.

Nyström, J.O. & Levi, B., 1985: A reconnaissance study of the volcanic evolution of Nicaragua, part 2. Petrography of the unaltered volcanics.- 32 pp. INMINE/SAREC/SGAB, SGAB Luleå, Sweden (unpublished report).

Palacios, C. & Oyarzún, R., 1975: Relationship between depth to Benioff zone and K and Sr concentrations in volcanic rocks of Chile,- Geology, 3: 595-596.

Parsons Corporation, 1972: The geology of Western Nicaragua.- Vol. IV, 220 pp. Nicaragua Tax Improvement and Natural Resources Inventory Project, Final Technical Report (unpublished report).

Pearce, J.A., 1976: Statistical analysis of major element patterns in basalts.- J. Petrol. 17: 15-43.

Pearce, J.A., 1982: Trace element characteristics of lavas from destructive plate boundaries.- In: Thorpe, R.S. (ed.) Andesites: orogenic andesites and related rocks: 525-548, Wiley & Sons.

Pearce, J.A. 1983: Role of the sub-continental lithosphere in magma genesis at active continental margins.- In: Hawkesworth, C.J. & Norry, M.J. (eds.) Continental basalts and mantle xenoliths: 230-249, Shiva Publishing Ltd.

Pearce, J.A., 1987: A 'users guide' to basalt, discrimination diagrams.- In: Tarney, J. (ed.) Oceanic basalts, Shiva Publishing Ltd. (in press).

Pearce, J.A. & Cann, J.R., 1973: Tectonic setting of basic volcanic rocks determinted using trace element analyses.- Earth Planet Sci. Lett. 19: 290-300.

Sunblad, K., Cumming, G.L. & Krstic, D., 1985: Preliminary results on lead isotope composition in the Nicaraguan Au (Ag)-deposits -a progress report.- 9 pp. INMINE/SAREC/SGAB, SGAB Luleå, Sweden (unpublished report).

Walker, J.A., 1984: Volcanic rocks from the Nejapa and Granada cinder cone alignements, Nicaragua, Central America.- J. Petrol., 25: 290-342.

Weyl, R., 1980: Geology of Central Amenca.- 371 pp., Gebrüder Borntraeger, Berlin.

GEOCHEMISTRY OF VOLCANIC ROCKS IN A TRAVERSE THROUGH NICARAGUA

by Jan Olov Nyström, Beatriz Levi, Björn Troëng, Jan Ehrenborg & Giovanni Carranza

Appendixes 1-2

Comment to Appendix 1

Rock types are indicated with the following abbreviations:

A = andesite

B = basalt

BA = basaltic andesite

D = dacite

Haw = Hawaiite

ign = ignimbrite

Lat = latite

Mug = mugearite

R = rhyolite

Sho = shoshonite

T = trachyte

The samples are lavas unless something else is specified.

Appendix 1. Rock type, stratigraphic position and location.

Sample	Type	Group	Location
Bluefields			
BLU 1	B	Cukra	Great Old Bank point
BLU 2	BA	Cukra	El Bluff
BLU 3	B	Cukra	Great Old Bank point
BLU 4	B	Cukra	Bluefields, south end
Bonanza Mine			
BON 1	BA	Matagalpa	drill core (INMINE 8431054)
BON 2	BA	Matagalpa	drill core (INMINE 8431062)
BON 3	B	Matagalpa	drill core (INMINE 8431066)
BON 4	B	Matagalpa	drill core (INMINE 8431032)
BON 5	B	Matagalpa	drill core (INMINE 8431049)
BON 6	B	Matagalpa	drill core (INMINE 8431035)
BON 7	BA	Matagalpa	drill core (INMINE 8431028)
Cuesta Coyol area			
CDC 2	BA	Coyol up	1394.6/602.8 hill
CDC 3	B	Coyol up	1394.6/602.9 hill
CDC 8	D ign	Coyol low	1385.6/603.2 road cut
CDC 13	D ign	Coyol low	1384.8/603.0 small hill
CDC 14	D ign	Coyol low	1384.8/603.0 small hill
CDC 17	T ign	Coyol low	1383.8/602.9 road cut
CDC 18	D	Coyol low	1382.0/602.2 road cut
CDC 22	D ign	Coyol low	1380.2/601.4 road cut
CDC 23	A	Coyol low	1379.8/601.9 road cut
CDC 24	BA	Coyol low	1379.6/603.6 road cut
CDC 25	BA	Coyol low	1379.6/603.6 road cut (below 24)
CDC 27	D	Coyol low	1377.1/604.0 road cut
CDC 32	BA	Coyol low	1379.1/604.0 road cut
CDC 36A	A	Coyol low	1375.8/604.7 quarry
EC 34	D	Coyol low	1380.1/601.7
EC 42	D	Coyol low	1376.6/604.3
EC 43	D	Coyol low	1377.3/603.8
EC 52	B	Coyol up	1378.2/602.5
EC 55	B	Coyol low	1378.6/604.4
EC 62	B	Coyol low	1385.7/602.3
EC 90	BA	Coyol up	1377.5/606.6
EC 104	B	Coyol up	1377.6/607.9
EC 114	A	Coyol up	1375.8/604.7
EC 120	BA	Coyol up	1374.7/606.7
EC 125	A	Coyol up	1374.2/606.3
EC 130	BA	Coyol up	1368.9/614.3
EC 132	D ign	Coyol up	1365.2/616.3
EC 136	BA	Coyol up	1365.6/616.9
EC 137	BA	Coyol up	1368.4/613.5
EC 142	B	Coyol up	1370.1/614.1
EC 147	BA	Coyol up	1370.6/614.2
EC 150	BA	Coyol up	1372.4/613.3
EC 166	D ign	Coyol up	1372.9/626.2
EC 170	R ign	Coyol up	1373.2/624.6
EC 177	B	Coyol up	1373.1/622.2
EC 179	BA	Coyol up	1373.2/622.2
EC 187	BA	Coyol up	1377.5/609.7
EC 193	BA	Coyol up	1377.1/610.5
EC 197	B	Coyol up	1377.0/610.9

Appendix 1 Rock type, stratigraphic position and location (cont'd).

Sample	Type	Group	Location
EC 205	R ign	Coyol up	1376.8/611.1
EC 221	B	Coyol up	1377.5/602.7
EC 225	B	Coyol up	1375.3/610.7
EC 227	BA	Coyol up	1374.9/610.6
EC 231	BA	Coyol up	1374.7/610.9
EC 233	BA	Coyol up	1374.6/611.1
EC 234	B	Coyol up	1374.6/611.2
EC 267	B	Coyol up	137[illegible].0/616.0
Chinandega area			
CHD 2	BA	Tamarindo	Potosí road km 150.0 quarry
CHD 3	BA	Tamarindo	Potosí road km 156.4 quarry
Vn. Cerro Negro			
CNO 1	B	Recent	Cerro Negro, 1971 lava
Comalapa road			
COM 7	D ign	Matagalpa	1351.1/659.6 road cut
Vn. Concepción			
CON 1	A	Recent	S slope of the volcano
CON 2	B	Recent	S-SE slope of the volcano
CON 3	A	Recent	E-SE slope of the volcano
CON 5	BA	Recent	E-SE slope of the volcano
Vn. Cosigüina			
COS 1	BA	Recent	S-SE slope of the volcano
COS 4	A	Recent	S-SE slope of the volcano
COS 5	A	Recent	S-SE slope of the volcano
COS 6	BA	Recent	S-SE slope of the volcano
COS 7	BA	Recent	S-SE slope of the volcano
Vn. S. Cristóbal			
CRI 2	B	Recent	1393.6/494.2 quarry
CRI 4	B	Recent	1413.5/497.9 flow
Corn Island			
CRN	B	late TT/Q	E shore
CRN 2	B	late TT/Q	SE shore
CRN 3	B	late TT/Q	SE shore
CRN 4	BA	late TT/Q	SE shore
CRN 5	BA	late TT/Q	SE shore
Juigalpa road			
JUI 1	B	Coyol up	1338.4/677.7 road cut
JUI 4	BA	Coyol up	1341.6/666.5 road cut
JUI 13	D	Coyol up	1344.0/661.1 quarry
León road			
LEO 6	R ign	Tamarindo	1349.7/534.5 road cut
LEO 8	BA	Tamarindo	1341.1/538.6 road cut
LEO 9	B	Tamarindo	1340.5/539.4 road cut
LEO 16	R ign	Tamarindo	1368.8/503.1 outcrop at dirt road
LEO 18	B	Tamarindo	1372.9/506.7 quarry
LEO 25A	A	Tamarindo	1342.6/537.8
LEO 25B	A	Tamarindo	1342.6/537.8

Appendix 1. Rock type, stratigraphic position and location (cont'd).

Sample	Type	Group	Location
La Libertad Juigalpa road			
LIB 1	BA	Coyol up	km 139.2 road cut
LIB 14	B	Coyol low	km 143.2 quarry
LIB 17	B	Coyol low	km 145.8 road cut
LIB 20	B	Coyol low	km 146.7 road cut
La Libertad - Santo Tomás road			
LIB 2	BA	Coyol low	1339.7/703.1 roadside blocks
LIB 4	A	Coyol low	1342.9/698.5 quarry
La Libertad mine			
LIB 32	B	Coyol low	S Juan drill core 84003, 72 m
LIB 34	B	Coyol low	S Juan drill core 84003, 94 m
LIB 36	B	Coyol low	S Juan drill core 84003, 128.5 m
LIB 39	B	Coyol low	Sta Elena drill core 12, 60 m
Managua			
MAN 1	B	Recent	1340.8/575.6 cinder cone quarry
Vn. Masaya			
MAS 2	B	Recent	1328.0/592.8 lava field
MAS 4	B	Recent	1337.5/593.1 cinder cone flow
Matagalpa Siuna road			
MAT 2	BA	Matagalpa	km 150.4 road outcrop
MAT 4	Mug	Matagalpa	km 152.6 quarry
MAT 12	BA	Matagalpa	km 169.7 quarry
MAT 14	BA	Matagalpa	km 170.5 roadside blocks
Matagalpa Muy Muy road			
MAT 19	BA	Coyol low	0.9 km N bridge Samulali, local bl.
MAT 20	BA	Coyol low	1.8 km SE bridge Samulali, road cut
Vn. Mombacho			
MBC 1	BA	Recent	1315.4/616.5 block in avalanche
MBC 5	A	Recent	1315.4/616.5 block in avalanche
Vn. Momotombo			
MOM 1	A	Recent	S slope of the volcano
MOM 3	BA	Recent	S slope of the volcano
MOM 5	BA	Recent	W-NW slope of the volcano
Rama road			
RAM 7	B	La Batea	1329.9/756.4 river outcrop
RAM 10	B	La Batea	1327.4/749.6 road cut
RAM 11	A	La Batea	1326.2/738.3 road cut
RAM 14	BA	Matagalpa	1333.7/717.4 outcrop at dirt road
RAM 15	B	Coyol low	1330.9/702.2 road cut
RAM 16	BA	Matagalpa	1327.5/699.7 below bridge
R area			
RIV 2	A	Rivas?	ca 1261/621 hill (local blocks)
RIV 4	A	Brito?	1296.8/590.6 hill (local blocks)
Vn. Santa Clara			
SCL 1	B	Recent	1388.3/521.9 roadside blocks

Appendix 1 Rock type, stratigraphic position and location (cont'd)

Sample	Type	Group	Location
Siuna mine			
SIU 1	Sho	Metapán	drill core S-79, 113 m (INM 6945)
SIU 3	Sho	Metapán	drill core S-79?
SIU 4	Haw	Metapán	drill core S-79
SIU 5	Haw	Metapán	drill core 75,117 m (INM 8331428)
SIU 6	B	Metapán	Cerro Guerrero S-2 (INM 8431144)
SIU 7	Lat	Metapán	drill core 72, 37 m (INM 8331416)
SIU 8	A	Metapán	open pit, secc. 9N (INM 8431176)
SIU 10	Lat	Metapán	open pit (INMINE 8431175)
Sta Lucia area			
SLU 2	BA	Matagalpa	within area 1386-1391/648-650
SLU 8	R ign	Matagalpa	1380.6/645.6 quarry
SLU 9	B	Matagalpa	1380.6/645.6 quarry (below 8)
SLU 11	A	Coyol low	1378.1/645.4 road cut
SLU 13	D	Matagalpa	1375.8/642.9 road cut
Vn. Telica			
TEL 1	B	Recent	1385.2/511.9 flow
TEL 3	BA	Recent	1385.1/511.7 quarry
Vn. Talpetas			
TPT 1	B	Recent	1349.4/573.4 cinder cone quarry
TPT 2	B	Recent	1349.4/573.4 cinder cone quarry

Wt. %	CHD 2	CHD 3	CNO 1	CON 1	CON 2	CON 3	CON 5	COS 1	COS 4
SiO2	52.37	52.53	49.21	61.81	50.89	61.62	52.92	52.07	59.05
TiO2	1.09	1.13	0.85	0.80	1.24	0.75	0.99	0.77	0.77
Al2O3	16.07	15.75	19.71	17.12	18.07	16.34	18.39	17.09	17.77
Fe2O3	4.85	3.45	3.03	1.56	3.78	1.83	3.61	5.60	1.80
FeO	5.80	6.77	6.80	3.81	6.31	4.04	4.61	3.68	5.29
MnO	0.18	0.18	0.18	0.18	0.21	0.18	0.18	0.18	0.17
MgO	5.44	4.33	4.58	1.70	4.59	1.80	4.00	4.14	2.00
CaO	9.60	8.37	11.05	4.77	9.36	4.47	8.90	8.09	6.42
Na2O	2.76	2.88	2.33	4.55	3.13	4.75	3.41	3.13	3.96
K2O	0.59	0.70	0.45	2.13	0.93	2.74	1.27	1.02	1.57
P2O5	0.19	0.22	0.07	0.38	0.37	0.44	0.37	0.24	0.26
H2O+	0.37	0.55	0.16	0.22	0.23	0.18	0.30	0.61	0.27
CO2	0.22	0.31	0.05	0.07	0.07	0.05	0.07	0.14	0.06
Total	99.53	97.17	98.47	99.10	99.18	99.19	99.02	96.76	99.39

Wt. %	COS 5	COS 6	COS 7	CRI 2	CRI 4	LEO 6	LEO 8	LEO 9	LEO 16
SiO2	58.20	51.66	51.25	48.88	48.23	71.07	53.08	50.02	70.12
TiO2	0.77	0.82	0.87	0.86	0.95	0.34	1.46	1.02	0.36
Al2O3	17.60	17.88	18.30	18.69	18.38	13.99	14.70	18.06	13.06
Fe2O3	1.28	3.48	3.46	4.07	2.61	2.42	4.34	3.63	0.93
FeO	5.40	6.67	6.26	6.73	8.56	0.31	7.75	6.78	1.27
MnO	0.16	0.20	0.19	0.20	0.22	0.06	0.23	0.19	0.07
MgO	2.05	4.62	4.18	5.13	5.71	0.31	4.13	4.03	0.48
CaO	7.24	9.38	9.29	10.36	10.90	2.20	8.01	9.87	2.14
Na2O	3.65	2.80	3.08	2.60	2.54	3.75	3.08	2.68	3.93
K2O	1.35	0.73	0.77	0.66	0.59	2.53	0.64	0.51	1.64
P2O5	0.20	0.13	0.16	0.21	0.18	0.01	0.32	0.13	0.16
H2O+	0.24	0.29	0.33	0.09	0.25	1.01	0.75	0.49	3.77
CO2	0.06	0.06	0.07	0.07	0.07	0.06	0.08	0.06	0.05
Total	98.20	98.72	98.21	98.55	99.19	98.06	98.57	97.47	97.98

Appendix 2A. Analyzed volcanics from western Nicaragua.

Wt. %	LEO 18	LEO 25A	LEO 25B	MAN 1	MAS 2	MAS 4	MBC 1	MBC 5	MOM 1
SiO2	49.41	56.92	56.37	47.51	49.39	50.03	52.08	57.86	57.59
TiO2	1.35	1.12	1.21	0.87	1.17	1.09	0.95	0.77	0.69
Al2O3	16.05	14.10	14.20	18.16	15.02	15.63	17.28	16.04	16.12
Fe2O3	3.46	4.05	3.52	4.79	3.73	3.49	2.93	2.76	2.63
FeO	8.75	6.46	6.36	6.79	8.76	8.56	6.39	4.79	5.20
MnO	0.20	0.22	0.24	0.22	0.24	0.21	0.20	0.16	0.17
MgO	5.60	3.07	3.20	6.60	5.46	5.53	4.67	3.35	3.46
CaO	10.04	7.23	7.59	11.72	10.05	9.71	9.31	7.05	7.66
Na2O	2.60	3.19	3.17	2.10	2.87	2.84	2.95	3.45	3.17
K2O	0.49	0.93	0.53	0.39	1.17	1.25	1.05	1.86	1.32
P2O5	0.08	0.21	0.21	0.03	0.19	0.20	0.09	0.05	0.10
H2O+	1.41	0.45	1.00	0.09	0.28	0.30	0.24	0.31	0.74
CO2	0.06	0.08	0.06	0.06	0.05	0.06	0.03	0.06	0.05
Total	99.50	98.03	97.66	99.33	98.38	98.90	98.17	98.51	98.90

Wt. %	MOM 3	MOM 5	RIV 2	RIV 4	SCL 1	TEL 1	TEL 3	TPT 1	TPT 2
SiO2	53.01	52.58	57.82	56.18	49.68	50.39	52.88	46.31	48.20
TiO2	0.74	0.77	1.00	1.02	0.90	1.23	1.02	0.95	0.85
Al2O3	18.19	18.07	16.11	15.31	20.08	17.20	17.15	17.20	16.68
Fe2O3	2.64	2.53	2.10	2.28	3.31	2.94	2.96	4.29	3.55
FeO	6.29	6.79	5.15	5.97	6.76	6.88	6.99	6.08	6.81
MnO	0.18	0.19	0.14	0.14	0.20	0.18	0.19	0.21	0.19
MgO	4.51	4.76	3.75	2.95	4.07	5.64	4.69	8.07	8.34
CaO	8.92	9.04	7.08	7.02	11.33	10.59	9.64	12.23	12.24
Na2O	3.02	2.85	3.59	3.46	2.47	2.61	2.82	2.44	2.46
K2O	1.02	0.93	0.89	0.93	0.55	0.87	1.19	0.49	0.52
P2O5	0.08	0.06	0.22	0.27	0.12	0.27	0.21	0.10	0.11
H2O+	0.16	0.17	1.80	2.20	0.42	0.25	0.10	0.19	0.13
CO2	0.07	0.07	0.04	0.10	0.04	0.05	0.06	0.05	0.07
Total	98.83	98.81	99.69	97.83	99.93	99.10	99.90	98.61	100.15

Appendix 2A Analyzed volcanics from western Nicaragua (cont'd).

Wt. %	CDC 2	CDC 3	CDC 8	CDC 13	CDC 14	CDC 17	CDC 18	CDC 22	CDC 23	CDC 24	CDC 25	CDC 27	CDC 32
SiO2	52.67	50.93	63.26	61.94	63.61	62.64	62.57	59.91	60.84	52.92	54.71	63.62	52.77
TiO2	0.80	0.79	0.57	0.70	0.63	0.69	0.80	0.62	0.76	0.83	0.81	0.76	0.80
Al2O3	16.36	19.93	16.00	16.23	15.09	16.13	15.19	16.50	15.78	19.47	19.77	15.22	16.86
Fe2O3	5.30	5.44	2.92	3.66	4.92	5.00	4.87	3.39	4.88	6.12	5.00	4.79	3.89
FeO	4.20	3.16	1.57	1.63	0.26	0.34	1.71	1.79	2.04	2.11	2.86	1.24	4.82
MnO	0.17	0.16	0.11	0.16	0.13	0.12	0.13	0.13	0.11	0.15	0.13	0.12	0.16
MgO	6.79	4.69	1.13	1.22	0.58	0.76	1.19	1.88	1.39	2.34	2.41	0.96	4.28
CaO	9.56	10.14	3.64	2.92	2.38	2.79	4.06	4.59	4.48	8.87	8.41	4.02	8.86
Na2O	2.84	2.82	2.95	3.26	3.31	3.89	3.79	2.94	3.90	3.40	3.47	4.02	3.16
K2O	0.48	0.39	4.10	3.99	3.99	4.20	3.03	2.78	3.03	0.84	0.82	2.99	1.06
P2O5	0.17	0.10	0.15	0.33	0.28	0.32	0.45	0.12	0.29	0.22	0.17	0.41	0.14
H2O+	0.54	0.52	2.90	2.61	1.55	0.99	0.75	2.75	0.66	0.64	0.62	0.72	0.49
CO2	0.12	0.04	0.05	0.17	0.11	0.07	0.05	0.10	0.06	0.06	0.04	0.04	0.48
Total	100.00	99.11	99.35	98.82	96.84	97.94	98.59	97.50	98.22	97.97	99.22	98.91	97.77

Wt. %	CDC 36A	COM 7	EC 34	EC 42	EC 43	EC 52	EC 55	EC 62	EC 90	EC 104	EC 114	EC 120	EC 125
SiO2	60.59	65.55	61.68	63.84	62.42	51.31	49.06	47.35	54.02	50.62	59.28	53.03	59.54
TiO2	0.78	0.71	0.86	0.78	0.77	0.97	0.92	1.08	0.90	0.93	0.77	0.98	0.68
Al2O3	16.79	14.95	15.03	14.78	15.77	16.43	22.03	20.83	19.11	16.70	17.01	17.70	17.92
Fe2O3	6.46	3.81	4.24	4.68	5.31	6.78	4.15	5.14	4.93	5.74	5.76	6.77	4.43
FeO	0.55	0.68	2.61	1.26	1.07	3.12	4.48	4.27	2.88	3.72	1.09	3.83	1.63
MnO	0.20	0.14	0.14	0.11	0.12	0.15	0.16	0.19	0.16	0.17	0.17	0.19	0.11
MgO	1.38	0.93	1.40	1.08	0.86	6.34	4.33	5.81	2.56	6.86	1.56	3.43	1.43
CaO	5.90	2.98	4.34	3.87	4.16	10.00	8.65	9.56	8.99	9.92	5.74	8.67	6.02
Na2O	3.88	4.27	3.89	3.98	4.05	2.84	3.02	2.89	3.31	2.72	3.89	3.37	4.05
K2O	1.34	2.70	3.08	3.14	3.12	0.70	1.15	0.77	0.73	0.81	1.34	0.77	1.37
P2O5	0.16	0.25	0.40	0.45	0.48	0.36	0.20	0.33	0.25	0.25	0.22	0.18	0.26
H2O+	0.78	0.84	0.79	0.65	0.79	0.66	0.65	0.51	0.80	0.69	0.85	0.63	0.78
CO2	0.07	0.10	0.10	0.10	0.09	0.11	0.08	0.06	0.09	0.06	0.06	0.07	0.07
Total	98.88	97.91	98.56	98.72	99.01	99.77	98.88	98.79	98.73	99.19	97.74	99.62	98.29

Appendix 2B. Analyzed volcanics from central Nicaragua.

Wt. %	EC 130	EC 132	EC 136	EC 137	EC 142	EC 147	EC 150	EC 166	EC 170	EC 177	EC 179	EC 187	EC 193
SiO2	50.94	66.63	55.80	52.94	48.70	53.83	50.80	67.55	74.97	48.87	51.33	53.78	54.90
TiO2	0.95	0.61	0.91	1.10	0.85	0.98	0.78	0.92	0.66	0.98	0.97	1.18	0.96
Al2O3	16.10	14.39	17.88	16.39	16.43	18.10	18.58	13.42	11.10	17.17	16.10	16.10	18.23
Fe2O3	4.68	4.03	4.14	6.57	5.96	4.85	5.93	4.60	2.97	6.78	5.74	5.79	6.26
FeO	4.49	0.32	4.15	3.07	4.17	3.62	3.87	0.11	0.19	3.57	4.02	4.38	2.37
MnO	0.21	0.19	0.17	0.17	0.17	0.15	0.17	0.09	0.06	0.19	0.16	0.19	0.18
MgO	6.83	0.74	2.49	3.96	7.63	2.94	3.79	0.93	0.14	5.34	5.50	3.39	2.39
CaO	9.67	2.11	8.15	9.09	10.86	8.65	10.02	2.23	1.54	10.44	9.17	7.71	8.22
Na2O	2.84	4.05	3.59	2.92	2.43	3.15	2.84	3.62	3.89	2.62	2.87	3.66	3.51
K2O	0.83	4.34	1.23	0.82	0.58	1.00	0.63	2.78	2.26	0.74	0.81	0.94	1.04
P2O5	0.30	0.28	0.32	0.53	0.27	0.31	0.24	0.28	0.21	0.31	0.45	0.24	0.22
H2O+	0.49	0.66	0.56	0.99	0.60	0.58	0.57	1.40	0.64	0.88	0.74	0.52	0.71
CO2	0.07	0.07	0.09	0.08	0.08	0.07	0.07	0.10	0.08	0.05	0.11	0.07	0.08
Total	98.40	98.42	99.48	98.63	98.73	98.23	98.29	98.03	98.71	97.94	97.97	97.95	99.07

Wt. %	EC 197	EC 205	EC 221	EC 225	EC 227	EC 231	EC 233	EC 234	EC 267	JUI 1	JUI 4	JUI 13	LIB 1
SiO2	47.23	67.59	50.52	50.36	51.37	50.70	52.84	51.03	48.67	46.78	50.73	66.24	50.32
TiO2	0.88	0.73	1.00	0.90	0.94	0.85	0.85	0.87	0.92	0.88	0.80	0.49	1.00
Al2O3	14.79	14.52	16.53	16.53	17.31	18.96	19.03	18.22	16.90	17.66	19.49	14.61	16.66
Fe2O3	5.49	3.71	4.57	5.49	5.44	6.42	4.85	4.24	6.15	4.58	4.31	3.96	2.95
FeO	4.16	0.27	5.55	4.43	4.27	3.29	4.09	5.25	3.90	5.94	4.28	0.62	6.30
MnO	0.16	0.14	0.21	0.20	0.18	0.15	0.17	0.17	0.19	0.23	0.15	0.08	0.19
MgO	8.70	0.44	6.51	6.41	4.90	3.39	3.16	4.97	6.70	6.17	4.11	0.92	5.30
CaO	10.85	2.27	9.97	9.99	8.80	9.95	9.32	10.23	10.52	11.59	10.13	3.03	9.41
Na2O	2.28	4.57	2.80	2.84	3.12	2.83	3.10	2.81	2.63	2.20	2.81	3.94	2.72
K2O	0.82	3.01	0.64	0.59	0.80	0.58	0.89	0.73	0.77	0.33	0.65	2.72	0.66
P2O5	0.29	0.22	0.30	0.23	0.30	0.12	0.18	0.18	0.26	0.10	0.16	0.12	0.26
H2O+	1.06	0.65	0.53	0.35	0.66	0.93	0.62	0.82	0.78	0.88	0.42	0.85	1.06
CO2	0.10	0.10	0.33	0.10	0.06	0.08	0.06	0.79	0.33	0.59	0.08	0.07	0.08
Total	96.81	98.22	99.46	98.42	98.15	98.25	99.16	100.31	98.72	97.93	98.12	97.65	96.91

Appendix 2B. Analyzed volcanics from central Nicaragua (cont'd).

Wt. %	LIB 2	LIB 4	LIB 14	LIB 17	LIB 20	LIB 32	LIB 34	LIB 36	LIB 39	MAT 2	MAT 4	MAT 12
SiO2	55.75	56.93	47.13	48.13	49.41	48.73	47.38	48.87	45.84	49.78	52.90	52.75
TiO2	1.33	0.98	0.95	0.83	0.96	0.71	0.99	1.12	1.00	1.02	1.39	0.91
Al2O3	15.29	16.33	16.60	16.56	16.41	21.92	18.31	17.49	18.73	17.67	18.59	17.76
Fe2O3	4.86	4.78	3.65	5.02	4.16	3.78	3.63	3.93	3.64	3.71	4.63	6.89
FeO	5.37	3.41	5.71	4.12	5.35	3.95	6.45	6.16	6.23	5.32	4.06	1.52
MnO	0.20	0.16	0.17	0.15	0.17	0.14	0.19	0.21	0.18	0.16	0.18	0.13
MgO	3.40	2.90	7.66	7.00	6.44	3.68	4.77	4.13	3.25	5.08	3.07	3.04
CaO	7.05	6.76	9.59	9.12	9.49	12.55	11.10	9.92	10.33	8.67	7.84	7.77
Na2O	3.56	3.42	2.60	2.80	2.83	1.87	2.47	2.45	2.02	2.88	3.44	3.34
K2O	1.70	1.78	0.53	0.65	0.73	0.13	0.19	0.34	0.67	1.03	2.09	1.62
P2O5	0.31	0.24	0.20	0.20	0.15	0.12	0.20	0.21	0.24	0.24	0.37	0.22
H2O+	0.49	0.68	1.38	0.98	0.81	1.45	2.17	2.11	2.73	0.94	0.74	1.00
CO2	0.17	0.11	0.17	0.09	0.12	0.58	1.39	1.22	4.35	0.16	0.10	0.08
Total	99.48	98.48	96.34	95.65	97.03	99.61	99.24	98.16	99.21	96.66	99.40	97.03

Wt. %	MAT 14	MAT 19	MAT 20	RAM 14	RAM 15	RAM 16	SLU 2	SLU 8	SLU 9	SLU 11	SLU 13
SiO2	54.94	52.19	54.56	52.90	49.65	49.84	53.93	72.66	49.00	56.27	64.64
TiO2	1.11	1.02	0.94	1.46	0.83	0.82	0.86	0.34	0.99	1.09	0.78
Al2O3	17.22	16.12	16.29	15.23	20.09	16.84	18.12	13.80	17.54	17.77	15.92
Fe2O3	4.56	3.51	4.13	5.35	2.86	5.02	3.76	2.28	3.17	4.40	4.87
FeO	2.52	5.49	4.64	6.43	6.04	3.92	4.11	0.26	6.17	2.55	0.45
MnO	0.20	0.18	0.19	0.20	0.18	0.13	0.17	0.04	0.15	0.20	0.09
MgO	3.65	4.76	3.29	4.20	4.90	6.41	3.46	0.40	5.78	2.22	0.44
CaO	7.85	8.18	7.22	8.28	10.65	9.31	8.03	2.33	9.72	6.97	4.21
Na2O	3.68	2.53	3.26	3.06	2.41	2.67	3.60	3.83	2.74	4.01	4.15
K2O	1.97	0.45	1.74	1.21	0.43	0.74	0.70	2.11	0.69	1.48	2.48
P2O5	0.43	0.22	0.32	0.38	0.14	0.18	0.38	0.05	0.23	0.27	0.14
H2O+	0.58	2.64	2.10	0.49	0.60	0.91	1.43	0.97	0.70	0.59	0.64
CO2	0.08	1.46	1.70	0.06	0.13	0.16	0.07	0.04	0.15	0.33	0.19
Total	98.79	98.75	100.38	99.25	98.91	96.95	98.62	99.11	97.03	98.15	99.00

Appendix 2B. Analyzed volcanics from central Nicaragua (cont'd).

Wt. %	BLU 1	BLU 2	BLU 3	BLU 4	BON 1	BON 2	BON 3	BON 4	BON 5	BON 6	BON 7	CRN 1	CRN 2	CRN 3
SiO_2	49.34	50.24	50.17	50.39	51.93	50.65	48.31	49.88	49.57	50.90	50.23	50.06	50.03	49.31
TiO_2	0.98	1.08	0.97	1.15	1.05	1.21	1.12	0.90	1.03	0.92	0.95	3.18	2.84	3.01
Al_2O_3	17.32	16.35	16.82	17.04	18.08	16.75	17.52	16.85	18.43	19.54	17.33	14.73	14.83	14.31
Fe_2O_3	3.40	2.66	3.34	2.79	3.69	4.83	5.45	4.72	5.01	4.64	4.01	2.67	2.92	2.01
FeO	5.77	5.57	5.50	6.20	5.13	5.44	5.19	5.25	5.47	5.19	5.70	8.70	8.02	9.46
MnO	0.18	0.17	0.19	0.19	0.28	0.23	0.20	0.21	0.20	0.20	0.24	0.16	0.15	0.16
MgO	7.90	6.67	7.49	6.74	3.98	5.12	5.38	5.18	4.96	3.52	4.96	6.09	6.50	5.78
CaO	9.95	8.97	9.76	9.38	8.55	8.24	9.52	8.46	9.51	8.82	7.82	8.51	8.40	8.00
Na_2O	2.66	2.59	2.52	2.56	3.33	2.94	2.75	3.04	3.05	3.15	3.22	3.65	3.32	3.43
K_2O	0.73	0.63	0.78	0.76	0.50	1.57	1.06	1.21	0.86	1.40	0.82	0.44	0.26	0.20
P_2O_5	0.14	0.28	0.23	0.24	0.39	0.38	0.35	0.34	0.26	0.29	0.28	0.28	0.22	0.24
H_2O+	0.59	1.50	0.57	0.99	1.58	1.96	1.49	1.82	1.42	1.22	2.36	0.37	0.32	0.49
CO_2	0.10	0.15	0.15	0.19	0.16	0.31	0.14	0.14	0.11	0.20	0.23	0.11	0.07	0.06
Total	99.06	98.84	98.49	98.62	98.65	99.63	98.48	98.00	99.88	99.99	98.15	98.95	97.88	96.46

Wt. %	CRN 4	CRN 5	RAM 7	RAM 10	RAM 11	SIU 1	SIU 3	SIU 4	SIU 5	SIU 6	SIU 7	SIU 8	SIU 10
SiO_2	51.47	51.99	48.97	48.87	58.81	52.05	50.94	48.85	48.96	49.14	55.74	56.11	56.26
TiO_2	3.02	2.83	1.03	0.96	0.84	0.88	0.92	0.93	0.83	0.86	0.50	0.58	0.58
Al_2O_3	13.85	14.32	17.02	16.67	16.74	17.69	17.46	15.56	13.27	17.54	16.19	16.48	16.65
Fe_2O_3	2.06	2.05	2.88	2.94	3.59	4.45	4.08	5.18	4.61	5.36	2.24	2.42	2.13
FeO	9.45	8.99	6.39	6.22	3.19	4.71	5.49	6.00	6.25	4.36	4.09	3.76	4.46
MnO	0.16	0.16	0.20	0.19	0.15	0.22	0.19	0.16	0.27	0.17	0.10	0.11	0.12
MgO	5.58	6.57	6.94	7.95	2.43	3.35	3.13	5.79	6.56	5.31	4.43	4.16	4.11
CaO	8.01	8.35	9.40	9.86	5.99	5.48	8.05	8.44	9.73	10.18	5.17	5.22	5.70
Na_2O	3.32	3.43	2.78	2.38	4.08	4.22	4.19	3.88	3.43	3.21	3.84	3.72	4.16
K_2O	0.11	0.31	0.64	0.59	1.21	4.19	2.82	1.98	1.75	1.33	2.58	2.04	2.70
P_2O_5	0.23	0.27	0.27	0.26	0.19	0.63	0.62	0.41	0.38	0.42	0.11	0.17	0.16
H_2O+	0.40	0.33	0.68	1.19	0.62	1.75	1.14	1.29	1.85	1.41	2.44	1.62	1.20
CO_2	0.05	0.05	0.07	0.19	0.74	0.32	0.10	0.10	0.15	0.22	0.98	0.11	0.24
Total	97.71	99.65	97.27	98.27	98.58	99.94	99.13	98.57	98.04	99.51	98.41	96.5	98.47

Appendix 2C. Analyzed volcanics from eastern Nicaragua.