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Journal of volcanology
and geothermal research

Journal of Volcanology and Geothermal Research xx (2006) xxx–xxx

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Origin of silicic magmas along the Central American volcanic front: Genetic relationship to mafic melts

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Received 24 January 2005; accepted 2 March 2006

Abstract

Silicic pyroclastic flows and related deposits are abundant along the Central American volcanic front. These silicic magmas erupted through both the non-continental Chorotega block to the southeast and the Paleozoic continental Chortis block to the northwest. The along-arc variations of the silicic deposits with respect to diagnostic trace element ratios (Ba/La, U/Th, Ce/Pb), oxygen isotopes, Nd and Sr isotope ratios mimic the along-arc variation in the basaltic and andesitic lavas. This variation in the lavas has been interpreted to indicate relative contributions from the slab and asthenosphere to the basaltic magmas [Carr, M.J., Feigenson, M.D., Bennett, E.A., 1990. Incompatible element and isotopic evidence for tectonic control of source mixing and melt extraction along the Central American arc. *Contributions to Mineralogy and Petrology*, 105, 369–380.; Patino, L.C., Carr, M.J. and Feigenson, M.D., 2000. Local and regional variations in Central American arc lavas controlled by variations in subducted sediment input. *Contributions to Mineralogy and Petrology*, 138 (3), 265–283.]. With respect to along-arc trends in basaltic lavas the largest contribution of slab fluids is in Nicaragua and the smallest input from the slab is in central Costa Rica — similar trends are observed in the silicic pyroclastic deposits. Data from melting experiments of primitive basalts and basaltic andesites demonstrate that it is difficult to produce high K₂O/Na₂O silicic magmas by fractional crystallization or partial melting of low-K₂O/Na₂O sources. However fractional crystallization or partial melting of medium- to high-K basalts can produce these silicic magmas. We interpret that the high-silica magmas associated Central America volcanic front are partial melts of penecontemporaneous, mantle-derived, evolved magmas that have ponded and crystallized in the mid-crust — or are melts extracted from these nearly completely crystallized magmas.

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Keywords: silicic magmas; Central America volcanic front; mantle-derived crustal melts

1. Introduction

This paper focuses on the geochemistry and origin of silicic pyroclastic flows and related pyroclastic deposits (>65 wt.% SiO₂), associated with the Central American

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volcanic front (Fig. 1). These deposits occur throughout the Central American volcanic front from Guatemala to Costa Rica and are principally of Miocene to recent age. In Central America, the crust in the south (southeast Nicaragua and Costa Rica) is a modified oceanic plateau (the Caribbean Oceanic Plateau), whereas in the north (northwest Nicaragua to Guatemala) it is continental crust. Geochemical data from modern lavas of the Central American volcanic front show a systematic variation in trace element ratios along the arc and these have been interpreted to indicate relative contributions from the slab and asthenosphere (Carr et al., 1990; Patino et al., 2000). Geochemical data from these lavas show an absence of arc magma interaction with the Paleozoic continental crust (Carr et al., 2003). For this reason, Carr et al. (2003) infer that a post-Paleozoic, arc-type basement underlies the modern Middle America arc and areas extending an unknown distance northeast of the modern volcanic line. This paper evaluates the relationship between the silicic pyroclastic flows and related deposits to basaltic lavas from the modern volcanic front. The compositional variation of these silicic volcanic rocks along the arc places constraints on models of the origin of silicic magmas and continental crust evolution.

Silicic magmas are common in continental convergent zones, but also are abundant in other tectonic

environments. Their origin has been attributed to a variety of processes (Cameron et al., 1980; Lipman, 1984; de Silva and Wolff, 1995; Eichelberger et al., 2000; Costa and Singer, 2002). Most models for the origin of silicic magmas in areas with continental crust involve interaction with the crust either by partial melting of crustal rocks (Cobbing and Pitcher, 1983; White and Chappell, 1983; Vielzeuf and Holloway, 1988) or by fractional crystallization along with assimilation of these crustal rocks (MASH) (DePaolo, 1981; Hildreth and Moorbath, 1988). In these models the compositions of the silicic magmas vary according to the relative contribution of evolved continental crust and mantle-derived melts. In contrast, with some exceptions (McBirney, 1969; Gill and Stork, 1979), silicic magmatism has been considered to be minor in oceanic arcs or oceanic extensional areas, where evolved continental crust is absent. However, recent work (Tamura and Tatsumi, 2002; Leat et al., 2003; Smith et al., 2003; Vogel et al., 2004) has shown that silicic magmatism can be abundant in subduction zones without evolved continental crust. These workers propose that the generation of these silicic magmas involves the partial melting, or melt extraction from, recently emplaced, mantle-derived, stalled (crystallized or partially crystallized) calc-alkaline magmas. It is clear that abundant silicic magmas can be produced both with and without the presence

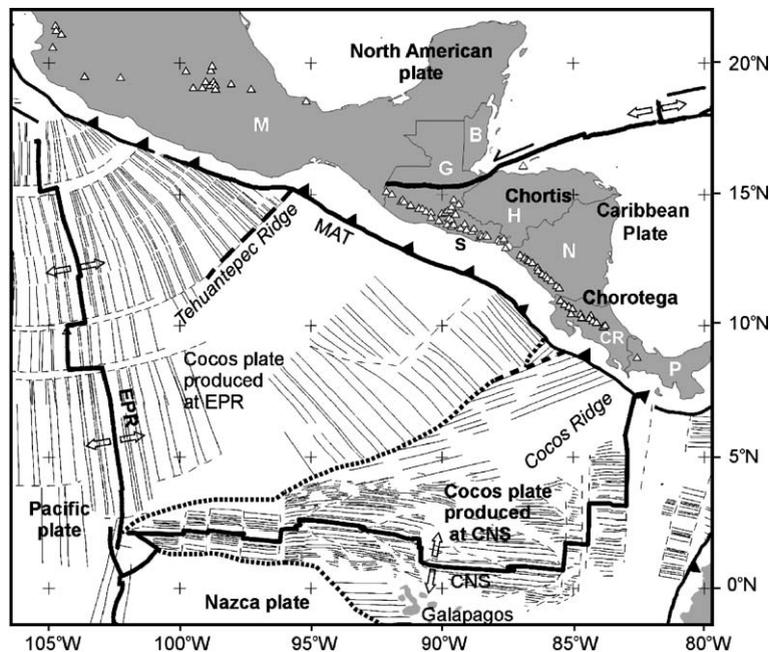


Fig. 1. Tectonic setting of northern Central America showing the Cocos–Nazca spreading center (CNS), East Pacific Rise (EPR), triple junction trace (heavy dots), volcanoes (open triangles), Middle America Trench (MAT) and the Chortis and Chorotega blocks. The boundary between these blocks is not well defined and shown by a dashed line (Rogers et al., 2002). Letters indicate respective countries in Central America.

of evolved continental crust. In areas without continental crust, the generation of silicic magmas represents the formation of continental crust.

2. Tectonic setting

Volcanism along the Central America arc (Guatemala to Costa Rica) is associated with blocks of different crustal origins: the northwestern Chortis block, and the southeastern Chorotega block (Fig. 1). An important contrast for the origin of silicic magmas is that Chortis block consists of a basement of crystalline Paleozoic rocks, whereas the Chorotega block consists of a modified, over-thickened oceanic crust with no crystalline Paleozoic basement. The Chorotega block is underlain by the Caribbean Large Igneous Province (CLIP), which was emplaced in the Cretaceous. Although there is no consensus as to the location of the boundary between the Chortis and the Chorotega blocks, the important observation is that the Chortis block is underlain by old evolved continental crust (>100 Ma), whereas the Chorotega block is not. Thus if anatexis or assimilation of continental crust is involved with the origin of the silicic magmas in the Chortis block, they should contain a chemical signature of this interaction.

Cocos plate convergence with the Caribbean plate along the Middle American Trench (MAT) (Fig. 1) pro-

duces the modern Central American volcanic front. This tectonic configuration has existed from the Early Miocene to the present and has produced large volume silicic eruptions along the volcanic front in Guatemala, El Salvador, Nicaragua and Costa Rica. Large silicic pyroclastic flows occur behind the volcanic front in Honduras (Williams and McBirney, 1969; Curran, 1981; Rogers, 2003; Jordan, 2004) and, because these are not associated with the active volcanic arc, are not part of the present study.

3. Silicic magmatism along the volcanic front in Central America

Large volume silicic pyroclastic flows and associated deposits occur along the active volcanic front from Guatemala to Costa Rica. The estimates of total volume of Pleistocene–Holocene silicic pyroclastic flows and related deposits are similar to volume estimate of lavas erupted from the volcanic front (Rose et al., 1999). The largest deposit is the Los Chocoyos Ash, which is about 280 km³ (Rose et al., 1999). No precise volume estimates have been made for the older silicic pyroclastic flows, but individual pyroclastic flows in Costa Rica have been estimated at greater than 100 km³ (Gillot et al., 1994; Villegas, 1997; Vogel et al., 2004). Most Holocene volcanism has been concentrated near the active volcanic

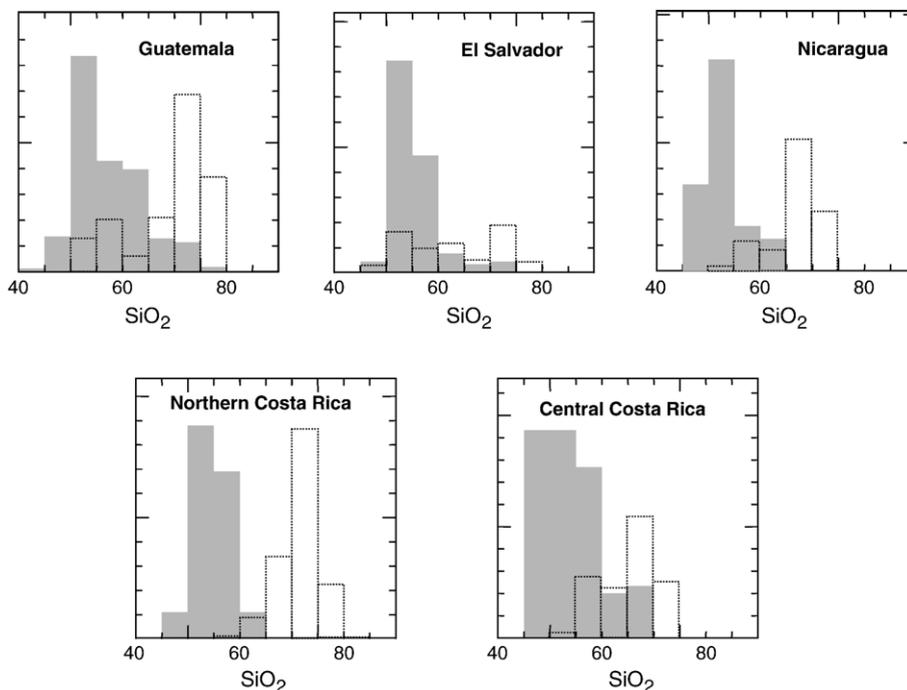


Fig. 2. Histograms of SiO₂ wt.% for lavas (shaded area) and pyroclastic flows and related deposits (open area) associated with the volcanic front in Central America. Vertical axis is relative frequency.

front and in a few areas behind the front in Guatemala, El Salvador and Honduras. There have been three periods of intensive volcanic activity in Central America due to the subduction of the Cocos Plate underneath the Caribbean Plate (Carr et al., 1982). The first period at about 14 Ma, the second between 6 and 3 Ma, and the third between 1 and 0 Ma. The composition of the volcanic products ranges from basalt to rhyolite. Miocene–Pliocene stratigraphy and geochemistry of pyroclastic flows and related deposits in Central America are poorly known (Williams and McBirney, 1969; Reynolds, 1980; Newhall, 1987; Reynolds, 1987; Alavarado et al., 1992; Gillot et al., 1994; Ehrenborg, 1996; Rogers, 2003). The age, stratigraphy and composition of the Pleistocene pyroclastic flows and related deposits are better known because most are related to obvious and restless calderas (Bice, 1985; Sussman, 1985; Newhall, 1987; Chiesa, 1991; van Wyk de Vries, 1993; Ehrenborg, 1996; Rose et al., 1999). Extensive pyroclastic flows and related deposits cover the Early Pleistocene volcanic structures

in Guatemala and El Salvador (Koch and McLean, 1975). These volcanic centers sit on top of the Los Chocoyos Ash (Hahn et al., 1979) — a silicic fall and associated hydromagmatic surge and ash flow that is a stratigraphic marker dated at 84 ka (Drexler et al., 1980). In the southern part of the volcanic front, all pyroclastic flows and related deposits underlie the Late Pleistocene–Holocene volcanoes (Carr et al., 1982).

4. Chemical variation of pyroclastic flows and related deposits

The pyroclastic flows and related deposits are dominated by silicic compositions whereas the lavas from the modern volcanic front range from mafic to intermediate compositions (Fig. 2) (chemical analyses of the pyroclastic flows and related deposits are from pumice fragments). Histograms of volcanic rocks associated with the Central American volcanic front show a mode at 55 wt.% SiO₂ for the lavas, and a mode at

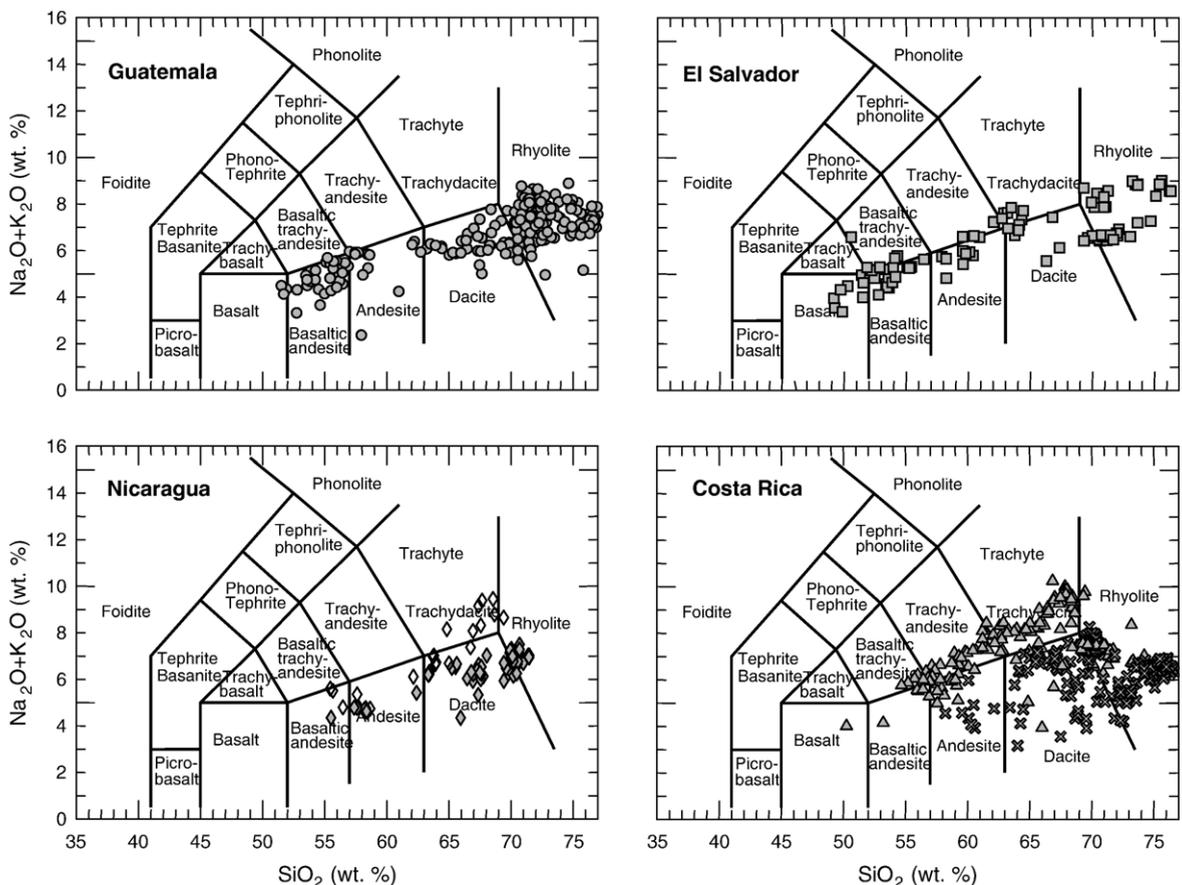


Fig. 3. Alkali–silica classification diagram (LeBas et al., 1986) for pyroclastic flows and associated deposits. Closed symbols are Pleistocene through Holocene; open symbols are Miocene and Pliocene. In Costa Rica crosses are northern Costa Rica; triangles are central Costa Rica.

69 wt.% SiO₂ for the pyroclastic flows and associated deposits. Although the high-silica compositions are dominant in all of the pyroclastic flows and associated deposits, low-silica compositions occur in these deposits in Guatemala, El Salvador, Nicaragua and central Costa Rica. However, in northern Costa Rica there are few low-silica compositions. For the volcanic front as a whole, the silicic portions of the pyroclastic flows and associated deposits (>65 wt.% silica) form a relatively tight compositional distributions and it is these compositions that we address in this paper. The general chemical classifications of the pyroclastic flows and associated deposits and related deposits based on K₂O+Na₂O versus SiO₂ plots are shown in Fig. 3.

Sources of the basaltic magmas and relative involvement of the subducting slab have been inferred from trace element ratios (Carr et al., 1990; Patino et al., 2000; Plank et al., 2002). For example in southern Nicaragua and northwestern Costa Rica the basaltic to andesitic lavas from the modern volcanic front have low Ce/Pb, and high Ba/Nb, Ba/La and U/Th ratios, indicating a large input from slab fluids. The silicic pyroclastic products follow a pattern similar to that in the basaltic volcanic products. Fig. 4A shows the variation of Ce/Pb versus Ba/La for the pyroclastic flows and associated deposits (>65 wt.% SiO₂) compared to lavas (48 to 53 wt.% SiO₂) from the volcanic front in Central America. In central Costa Rica, the basaltic samples from the modern volcanic front have the highest Ce/Pb and lowest Ba/La ratios indicating a smaller input from the slab (Fig. 4B). Ba/La variation in the modern lavas has been used to infer contribution from the slab (Carr et al., 1990) and this is shown in Fig. 4B, which shows Ba/La variation with distance along the volcanic front from Guatemala to central Costa Rica compared to the similar pattern observed in the silicic deposits.

In Nicaragua, Plank et al. (2002) interpreted the change in U/Th ratios from Miocene to recent basaltic volcanic samples as reflecting the changes in the nature of organic matter content in the sediment input due to the closing of the Isthmus of Panama. The slab contribution for the older magmas had low U content, reflecting low organic matter in the sediments (Patino et al., 2000). For the younger magmas, the U from the slab increases due to the higher organic matter content in the sediments. Sedimentary deposits that formed before the closing contain U/Th values of about 0.33, whereas deposits after the closing contain values of 1.4 (Patino et al., 2000). New U/Th data for the silicic pyroclastic flows and related deposits (Fig. 5A and B) are consistent with the conclusions of Plank et al. (2002) — the oldest silicic pyroclastic deposits have the lowest U/Th ratios

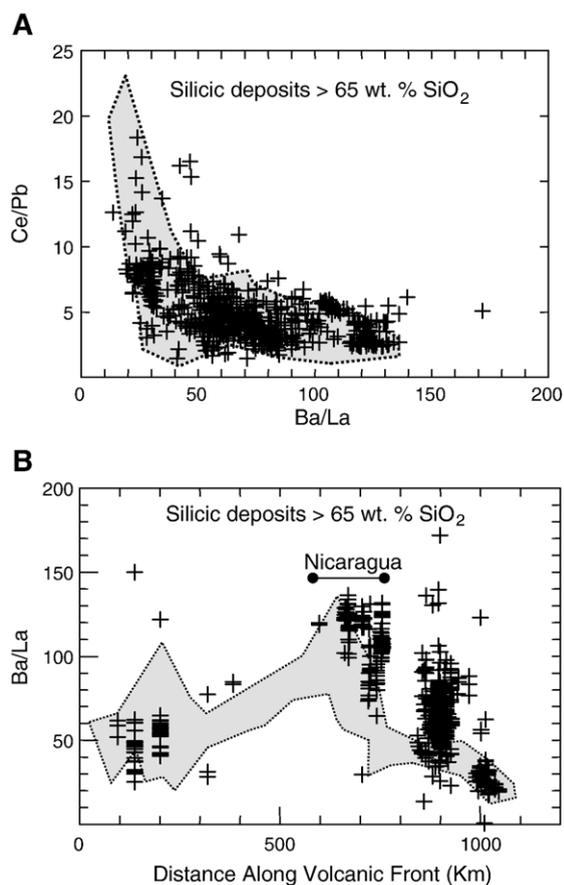


Fig. 4. (A) Ce/Pb versus Ba/La for pyroclastic flows and associated deposits (symbols) with >65 wt.% SiO₂ and for basaltic lavas with 48–53 wt.% SiO₂ (enclosed field). High Ce/Pb values indicate greater contributions from an enriched asthenosphere. (B) Ba/La variation with distance along the Central America volcanic front for pyroclastic flows and associated deposits (symbols) with >65 wt.% SiO₂ and for basaltic lavas with 48–53 wt.% SiO₂ (enclosed field). The largest input from the slab fluids is in Nicaragua — both the silicic samples and basaltic samples contain high Ba/La values in Nicaragua. Horizontal distance along the arc is from Carr et al. (2003). High Ba/La values indicate greater contributions from slab fluids (Carr et al., 1990).

(Fig. 5A) and the youngest silicic deposits mimicking the lavas from the modern volcanic front (Fig. 5B) (Viray, 2003). In Fig. 5A and B the U/Th content for the Nicaraguan lavas is shown for two time periods, Pleistocene–Holocene and Miocene–Pliocene.

Oxygen isotope variations of the pyroclastic deposits have recently been studied (Eaton, 2004). Oxygen isotopes of phenocrysts (clinopyroxene, orthopyroxene and magnetite) from Nicaraguan and Costa Rican pyroclastic deposits show an increase in $\delta^{18}\text{O}$ from northwest (600 km) to southeast (1100 km) of 1.5‰, except for a low $\delta^{18}\text{O}$ excursion in northern Costa Rica (Fig. 6A).

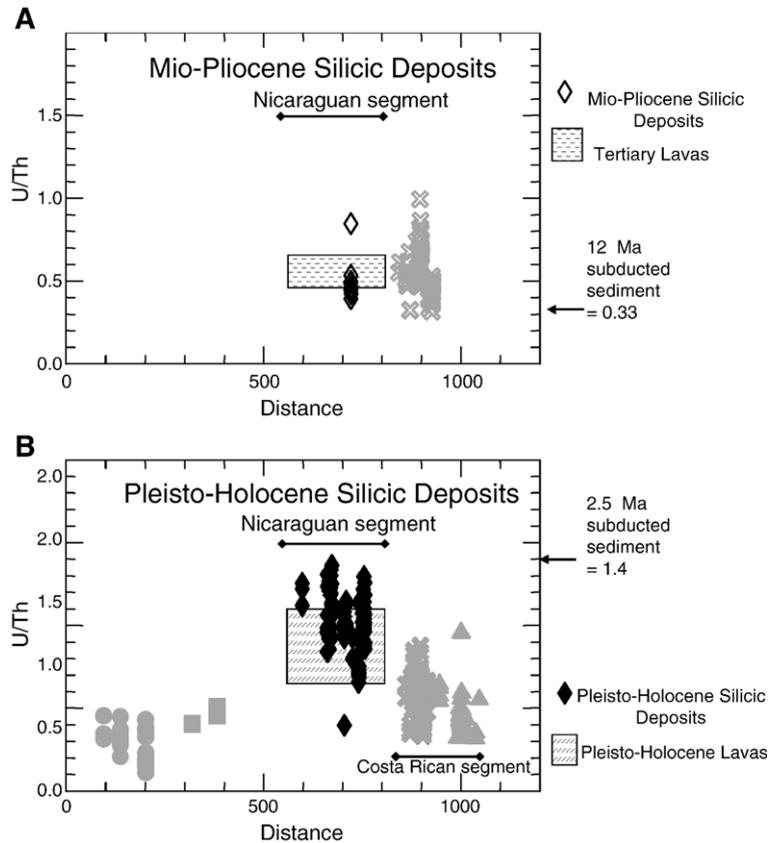


Fig. 5. U/Th values for Miocene–Pliocene (A) and Pleistocene–Holocene (B) silicic pyroclastic deposits (>65% SiO₂) compared to the basaltic lavas in Nicaragua (patterned boxes) for the same ages. Also shown are the U/Th values for 12 Ma subducted sediment in (A) and 2.5 Ma subducted sediment in (B) (Patino et al., 2000). Horizontal axis is the same as Fig. 4.

Whole rock (magma) $\delta^{18}\text{O}$ values (calculated assuming equilibrium with the phenocrysts) increase from 5.2‰ in Nicaragua to 6.7‰ in central Costa Rica (Fig. 6A). $\delta^{18}\text{O}$ values of magnetite are also shown in Fig. 6A because magnetite was present in almost all samples and represents the trends in all of the phenocrysts. In Fig. 6A the calculated whole rock $\delta^{18}\text{O}$ values are a function of assumed temperature; a decrease of 100 °C in the input temperature would shift $\delta^{18}\text{O}$ (magma) up by 0.5‰. However, this shift is systematic and does not affect the trend along the volcanic front. Thus, $\delta^{18}\text{O}$ whole rock (magma) values in Nicaragua are lower than or equal to oceanic basalt but increase to more normal or higher than oceanic basalt values in central Costa Rica. Fractionation of primitive magmas would produce a subtle increase in $\delta^{18}\text{O}$ whole rock versus SiO₂. The $\delta^{18}\text{O}$ of the whole rock would increase about 1.0‰ for a 20% increase in weight percent silica (Valley et al., 1994). In Fig. 6B we show the variation of magma (whole rock) $\delta^{18}\text{O}$ with silica concentration for three individual pyroclastic deposits, which contain a large range in SiO₂ concentra-

tions, and there is no correlation of $\delta^{18}\text{O}$ with SiO₂ variation. The $\delta^{18}\text{O}$ variation of the silicic samples may be characteristic of the source rock. Incompatible trace element ratios described above (Ba/La and U/Th), used as indicators of fluid flux from the slab, show negative correlations with $\delta^{18}\text{O}$ (Fig. 6C), whereas Ce/Pb (not shown), used as an indicator of contribution from the mantle, displays a positive correlation with $\delta^{18}\text{O}$ (Eaton, 2004). It is interesting and somewhat unexpected that $\delta^{18}\text{O}$ values decrease with increasing fluid flux.

There are few radiogenic isotope analyses of silicic samples from Central America. Detailed isotopic studies have been done by Rose et al. (1979) and Carr et al. (1990, 2003) for the Los Chacoyos Ash, and they reported both Sr and Nd isotope ratios that range from 0.70406 to 0.70407 and 0.51281 to 0.51286. Early studies reported Sr isotope values for silicic pyroclastic flows and associated deposits from Guatemala and Nicaragua of 0.7044 to 0.7070 and 0.7035 to 0.7053 (Pushkar, 1968), respectively. Recent analyses of Sr and Nd isotopes ratios for pyroclastic flows and related silicic

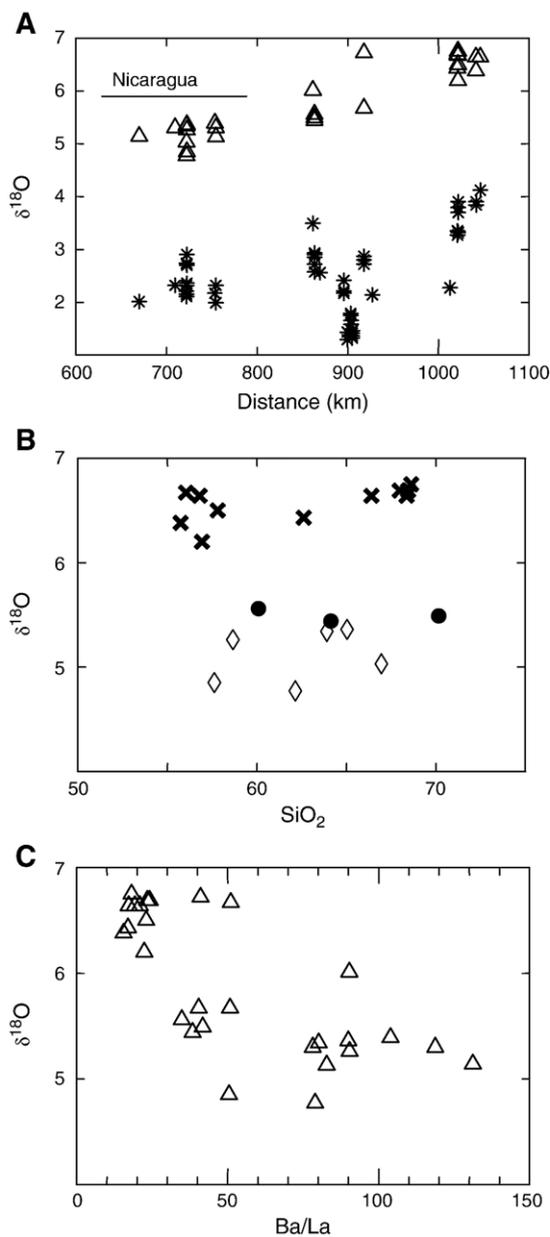


Fig. 6. $\delta^{18}\text{O}$ variation in pyroclastic flows and related deposits of Nicaragua and Costa Rica (Eaton, 2004). (A) Calculated whole rock $\delta^{18}\text{O}$ values (triangles) (calculated assuming equilibrium with the phenocrysts) and measured magnetite $\delta^{18}\text{O}$ values (asterisks) (see text for discussion) versus distance along the Central America volcanic front (Nicaraguan portion is labeled and is between 600 and 800 km). (B) Calculated whole rock $\delta^{18}\text{O}$ versus wt.% SiO_2 for three different pyroclastic deposits — each symbol represents a different pyroclastic deposit. If fractional crystallization were responsible for the increase in silica there would be a corresponding variation in $\delta^{18}\text{O}$ values. (C) Whole rock $\delta^{18}\text{O}$ versus Ba/La. The highest $\delta^{18}\text{O}$ values are associated with low Ba/La, which is somewhat unexpected because higher Ba/La values are correlated with increasing fluids from the slab.

pyroclastic deposits in Nicaragua, which range in age from Pleistocene to Miocene, vary from 0.703859 to 0.704115 and 0.512998 to 0.513043 (Farmer, personal communication 2004), respectively. Three analyses of Sr and Nd isotope ratios for pyroclastic flows and associated deposits from Guanacaste province, Costa Rica, range from 0.70386 to 0.70394, and from 0.51301 to 0.51304 ratios for Sr and Nd isotopes, respectively (Kempter, 1997). Four analyses of Sr and Nd isotope ratios of pumice fragments from the Tiribí formation, central Costa Rica range from 0.70372–0.70374, 0.512946–0.512950 (Hannah et al., 2002). The lavas and silicic samples form two trends in Sr–Nd isotope space (Fig. 7). The majority of the lava samples from the volcanic front show a positive correlation between these two isotope systems (trend 1 in Fig. 7). This has been explained (Carr et al., 1990) as the result of mantle metasomatism with fluids derived from the slab. Trend 2 in Fig. 7 is from the northwestern part of the volcanic front and displays a negative relationship between Sr and Nd isotopes, which has been interpreted as evidence of a small amount of crustal contamination (Carr et al., 1990). Because of the low $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, Vogel et al. (2004) concluded that evolved continental crust had little involvement in generation of the silicic magmas from western Nicaragua and central Costa Rica.

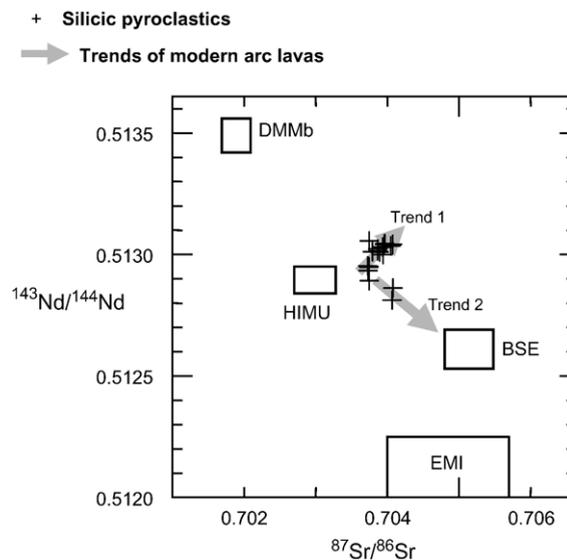


Fig. 7. $^{143}\text{Nd}/^{144}\text{Nd}$ versus $^{87}\text{Sr}/^{86}\text{Sr}$ for lavas and silicic pyroclastic flows and related deposits along the Central America volcanic front. Trends of lavas are shown by thick arrows. Silicic pumice samples are shown by pluses. Various mantle end members are also shown (DMMb = depleted MORB mantle; HIMU = high U/Pb (μ) mantle; BSE = bulk silicate Earth; EMI = enriched mantle (Zindler and Hart, 1986)).

In summary, based on key trace element ratios, oxygen isotopes and radiogenic isotopes, the silicic pyroclastic flows and related deposits associated with the volcanic front have similar trends to those of the basaltic lavas.

5. Discussion

We have demonstrated the similar chemical trends with respect to key trace element ratios and isotopes (Nd, Sr and O) in the basaltic lavas and the pumice fragments from the silicic pyroclastic deposits. This similarity is independent of the tectonic block (Chortis or Chorotega) in which they occur. These silicic magmas are produced with minimal or no interaction with an evolved, old crust.

Patiño Douce (Patiño Douce and McCarthy, 1998; Patiño Douce, 1999) recognized, based on a review of experimental studies, that the compositions of many subduction-related silicic magmas are not easy to explain without the contribution from an evolved source — the

high K_2O/Na_2O ratios observed (0.4–1.1) in calc-alkaline silicic rocks are difficult to produce by melting or fractional crystallization of low-K basaltic material without an evolved crustal assimilant. Others (Beard and Lofgren, 1991; Müntener, 2001a,b; Grove et al., 2003; Villiger et al., 2004) have shown that low-K basaltic or low-K andesitic material cannot be a source for these high K_2O/Na_2O calc-alkaline magmas. However, using more K-rich basaltic starting compositions, Sisson et al. (2005) have recently shown that partial melting or advanced fractional crystallization can produce liquids with high K_2O/Na_2O ratios similar to silicic arc magmas.

The Central American silicic deposits have high alkalis and high K_2O/Na_2O ratios (Fig. 8). In Fig. 8 we show the silicic samples (>65 wt.% SiO_2) from various areas in Central America compared to basaltic samples (48–53 wt.% SiO_2). Fig. 9A is a compilation of recent melting experiments on Mg-rich andesites and primitive basalts (Müntener, 2001a,b; Gaetani et al., 2003; Grove et al., 2003; Villiger et al., 2004). The line in Fig. 9A is

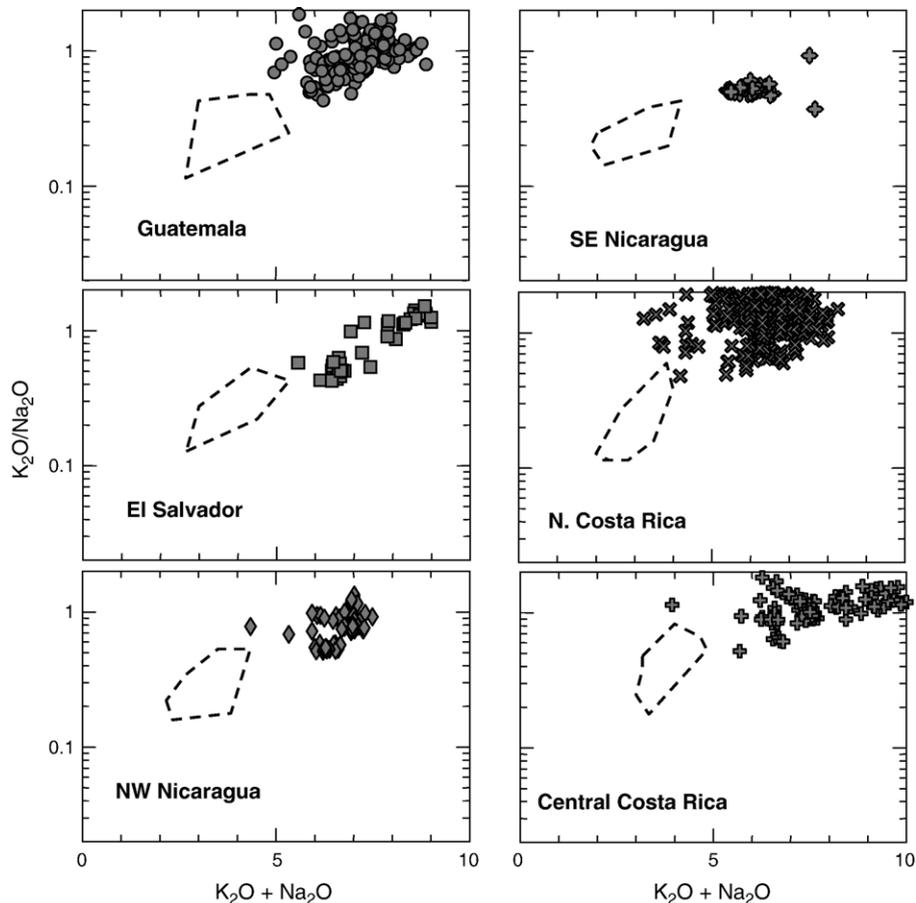


Fig. 8. K_2O/Na_2O versus $K_2O + Na_2O$ for basalts (enclosed area) and silicic (>65 wt.% SiO_2) pyroclastic flows and related deposits. Dashed area encloses lavas with 48–53 wt.% SiO_2 .

experimental data from nearly perfect fractionation (liquid is less than 3.5%) with liquids approaching dacite in composition (Villiger et al., 2004). A conclusion from these experiments is that without an evolved source, it is difficult to produce liquid with high alkalis and high K_2O/Na_2O ratios by partial melting of Mg-rich andesites or primitive basalts.

Sisson et al. (2005) using medium- to high-K, evolved basalts in melting experiments, produced melts that are very similar to the alkalis and K_2O/Na_2O values observed for the silicic rocks in Central America (Fig. 9B). Two of their samples used for starting compositions plot near or in the high-K end of the basaltic

lavas field for Central America (Fig. 9B); the other composition plots higher than any basaltic lava in Central America. These experiments demonstrate that the evolved liquids produced by partial melting of crystallized medium- to high-K basaltic magma or extreme crystal fractionation of high-K basaltic magma overlap the most abundant silicic magma types that occur in Central America. However, although the lavas from the active volcanic front are dominated by basaltic compositions, there is a large range in compositions (Fig. 2) with some consisting of high K_2O/Na_2O (Fig. 9C). Partial melts of any of these evolved rocks would be expected to form melts that occur in the silicic field of Central American silicic ignimbrites (Figs. 8 and 9B).

Our preferred model for the generation of the high-silica magmas in Central America is by partial melting of calc-alkaline, mantle-derived evolved magmas that have ponded and crystallized in the mid-crust, or by melt extraction from these nearly completely crystallized magmas. A genetic relationship between the silicic magmas and the mafic lavas is demonstrated by the similarity of key trace element ratios, oxygen isotopes, and radiogenic isotopes. Over thirty years ago, McBirney made a similar suggestion based on limited major-element and $^{87}Sr/^{86}Sr$ data (McBirney, 1969). Tamura et al. (2003) have discussed the energy problems of producing silicic melts by melting of the cold crust. Because melting or melt extraction of hot, stalled crystallized magmas is the most energy efficient process for generating silicic magmas, we prefer a process in which silicic melts form by either heat transferred from the emplacement of

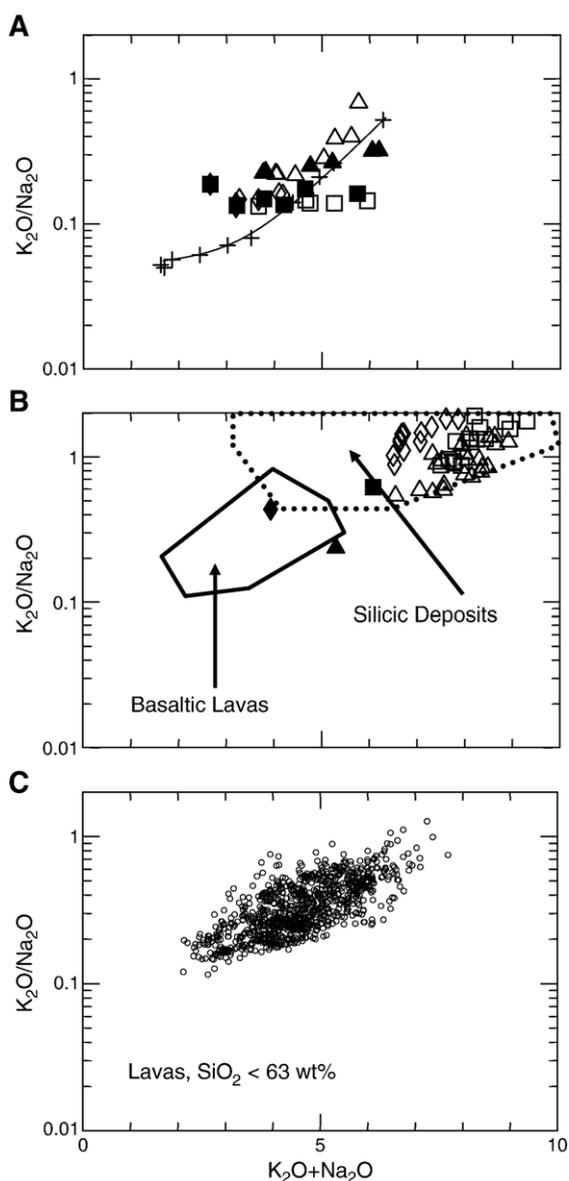


Fig. 9. (A) Experimental melt compositions for a variety of primitive basaltic and basaltic andesites starting materials. Open triangles are for Mg-rich, basaltic andesite at 0.1 MPa; closed triangles are from Mg-rich, basaltic andesite at 100 MPa; open squares are from Medicine Lake basalts at 200 MPa (Grove et al., 2003). Close squares and closed diamonds are from primitive basalts near Mt. Shasta with 3.8 and 5.0 wt.% H_2O , respectively (Müntener, 2001a,b). Pluses with solid line are fractional crystallization of tholeiitic basalt at 1.0 GPa (Villiger et al., 2004). The last value represents about 3.5% liquid remaining and has the highest K_2O/Na_2O . The conclusion is that by fractional crystallization of the investigated tholeiitic basalts or Mg-rich, basaltic andesites cannot produce the high K_2O/Na_2O ratios observed in the silicic samples. (B) Experimental compositions from Sisson and others for melting medium- to high-K basalts (Sisson et al., 2005). Solid symbols are the starting materials; open symbols are experiments liquids under various conditions and amounts of melt produced. Percent liquid in the experiments varied from 34% to 12%. The solid line encloses basaltic lava compositions that occur along the Central America volcanic front. The dotted line encloses the silicic pyroclastic compositions. (C) Compositions of lavas (less than 63 wt.% SiO_2) that occur along the Central American volcanic front. Partial melting of plutons with K_2O/Na_2O values of greater than 0.3 should yield melts that occur in the silicic field shown in B.

other mantle-derived magmas to hot plutons or by extraction of residual melt from a partially crystallized magma (Bachmann and Bergantz, 2003; Bachmann and Bergantz, 2004). Each would produce similar results.

6. Conclusions

The purpose of this study was to test if the silicic volcanic deposits and basaltic lavas are closely related and to suggest a mechanism for the origin of the silicic magmas associated with the Central America volcanic arc. Along-arc chemical variations for the silicic deposits and basaltic lavas are similar and this is particularly important for key trace element ratios such as Ba/La, Ce/Pb and U/Th, which have been used to infer magmatic contributions from the slab and mantle in arc-related magmas. The along-arc isotopic variations of Sr, Nd and oxygen are also similar in the silicic deposits and basaltic lavas. From these data we conclude that the silicic magmas are genetically related to the basaltic magmas that were produced in the mantle wedge and that there has been little or no interaction with the evolved continental crust. The isotope data do not exclude involvement of young mantle-derived rocks that intruded deep in the crust, however the oxygen isotope compositions show no evidence for hydrothermal alteration supporting the conclusion that shallowly intruded rocks can be ruled out (these would be more subjected to hydrothermal alteration and thus would be shifted in $\delta^{18}\text{O}$). Recent experimental results (Sisson et al., 2005) have shown that partial melting of medium- to high-K-rich basalts, similar to those that occur along the volcanic front in Central America, can produce the high $\text{K}_2\text{O}/\text{Na}_2\text{O}$ silicic magmas in Central America. Our conclusion is that the silicic magmas along the Central American volcanic front are produced by partial melting of mantle-derived, evolved and crystallized ponded magmas. Alternatively the silicic magmas could be produced by melt extraction of these partially crystallized magmas.

Based on the geochemical data presented above, the silicic pyroclastic rocks associated with the Central American volcanic arc have little interaction with underlying Paleozoic continental crust. This conclusion is similar to that drawn by Carr et al. (2003) from arc lavas inferring that a post-Paleozoic, arc-type basement underlies the modern Middle America active volcanic front and extends an unknown distance north of the modern volcanic line. A similar conclusion was made by Rogers based on low magnetic intensity in areas associated with the active volcanic front in Honduras, compared with other parts of the Chortis block (Rogers, 2003). He concluded that this area is underlain by accreted oceanic

terrains and is not underlain by Paleozoic crust. All of the data from the silicic pyroclastic rocks are consistent with the model that large volume silicic magmas associated with the volcanic front result from melting of evolved, mantle-derived, basaltic plutons, or melt extraction from these partially crystallized plutons.

Acknowledgements

We would like to acknowledge NSF INT-9819236 for support for some of the work in central Costa Rica. David Szymanski, Jennifer Wade and Chad Deering are thanked for their help in the field work in Costa Rica. Instituto Costarricense de Electricidad kindly provided field transportation on many field excursions. We appreciate support of individuals at the Escuela Centroamericana de Geología, University of Costa Rica and the Instituto Nicaragüense de Estudios Territoriales. Discussions with Rob Rogers and George Bergantz were very helpful in focusing our attention on some of the problems on the origin of calc-alkaline silicic magmas in Central America.

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