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Gas measurements from the Costa Rica–Nicaragua volcanic segment suggest possible along-arc variations in volcanic gas chemistry

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ABSTRACT

Obtaining accurate estimates of the CO_2 output from arc volcanism requires a precise understanding of the potential along-arc variations in volcanic gas chemistry, and ultimately of the magmatic gas signature of each individual arc segment. In an attempt to more fully constrain the magmatic gas signature of the Central America Volcanic Arc (CAVA), we present here the results of a volcanic gas survey performed during March and April 2013 at five degassing volcanoes within the Costa Rica–Nicaragua volcanic segment (CNVS). Observations of the volcanic gas plume made with a multicomponent gas analyzer system (Multi-GAS) have allowed characterization of the CO_2/SO_2-ratio signature of the plumes at Poás (0.30 ± 0.06, mean $\pm$ SD), Rincón de la Vieja (27.0 ± 15.3), and Turrialba (2.2 ± 0.8) in Costa Rica, and at Telica (3.0 ± 0.9) and San Cristóbal (4.2 ± 1.3) in Nicaragua (all ratios on molar basis). By scaling these plume compositions to simultaneously measured SO_2 fluxes, we estimate that the CO_2 outputs at CNVS volcanoes range from low (25.5 ± 11.0 tons/day at Poás) to moderate (918 to 1270 tons/day at Turrialba). These results add a new information to the still fragmentary volcanic CO_2 output data set, and allow estimating the total CO_2 output from the CNVS at 2835 ± 1364 tons/day. Our novel results, with previously available information about gas emissions in Central America, are suggestive of distinct volcanic gas CO_2/S_T ($= SO_2 + H_2S$)-ratio signature for magmatic volatiles in Nicaragua ($\sim$3) relative to Costa Rica ($\sim$0.5–1.0). We also provide additional evidence for the earlier theory relating the CO_2-richer signature of Nicaragua volcanism to increased contributions from slab-derived fluids, relative to more-MORB-like volcanism in Costa Rica. The sizeable along-arc variations in magmatic gas chemistry that the present study has suggested indicate that additional gas observations are urgently needed to more-precisely confine the volcanic CO_2 from the CAVA, and from global arc volcanism.

1. Introduction

Characterizing the volcanic gas outputs along active volcanic-arc regions is crucial to quantifying the recycling of volatiles at subducting slabs and its consequences for arc magmatism (Hilton et al., 2002). The long-term (geological) volcanic-arc CO_2 budget (Wallace, 2005) is particularly critical to better constraining the relative C contributions from the slab, the mantle wedge, and the crust, and for predicting how arc degassing influences the atmospheric CO_2 budget and climate models (Berner and Lasaga, 1989).

In recent years a mass balance approach has been used to extensively investigate exchanges of volatiles at subduction zones (Fischer et al., 2002; Hilton et al., 2002). However, the global subaerial volcanic CO_2 flux, which is dominated by arc volcanism (Marty and Tolstikhin, 1998), remains poorly constrained, with current estimates ranging widely, from 65 to 540 Mt/yr (see review by Burton et al., 2013). CO_2 budgets for individual arc segments are also generally poorly understood (Hilton et al., 2002). In addition to estimates of the SO_2 output being incomplete and/or inaccurate, a major issue in deriving the CO_2 outputs from individual arcs is assigning a "representative" CO_2/SO_2 ratio to them. This remains problematic due to the limited data set of high-temperature volcanic gases that is available (Fischer, 2008), and the potentially

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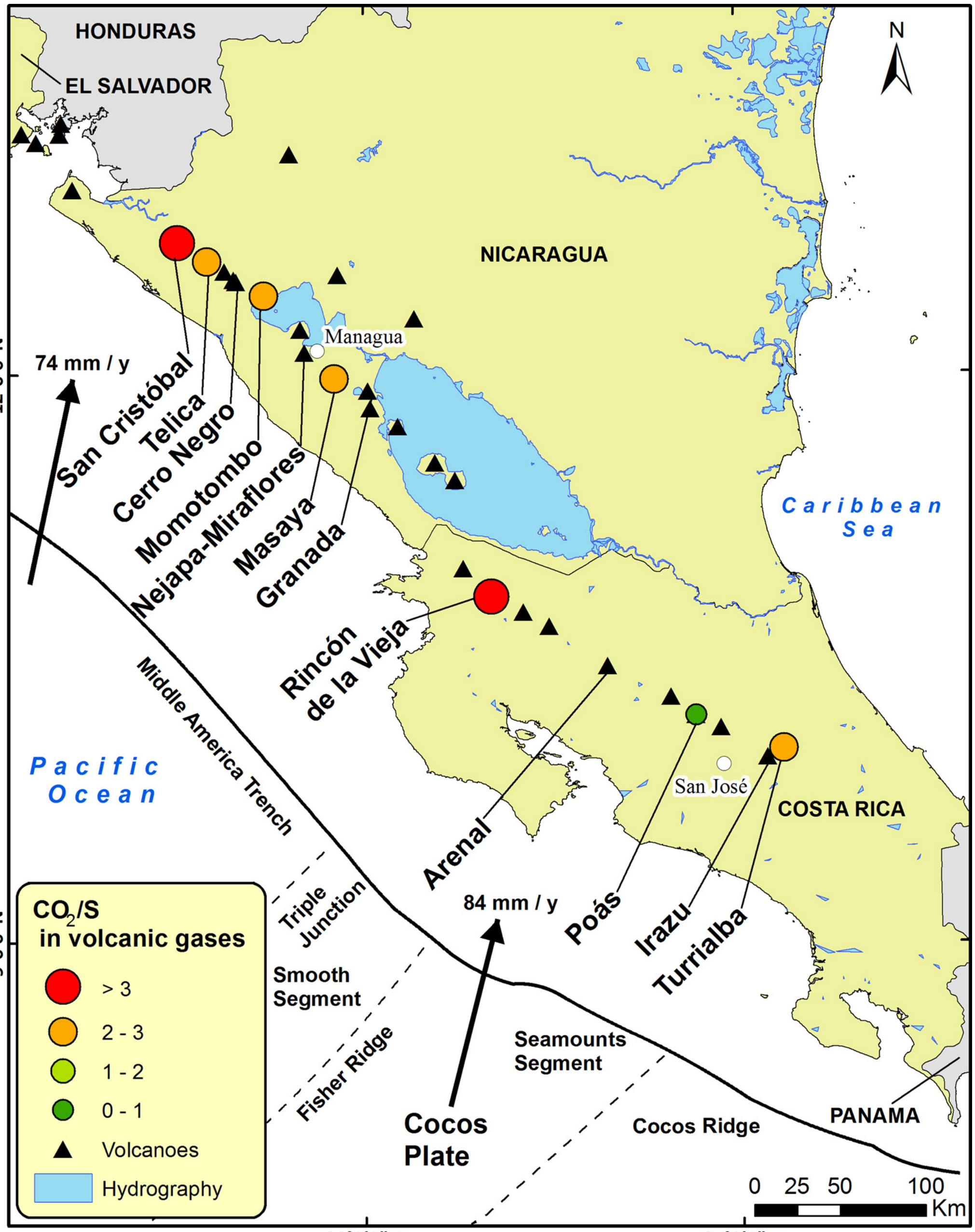

Fig. 1. Map of the subduction zone in Nicaragua and Costa Rica. Black arrows indicate the direction of motion of the Cocos Plate and the convergence velocities relative to the Caribbean Plate (in millimeters per year) after DeMets (2001). Plate segments and trench structures are interpreted from the bathymetry imagery in von Huene et al. (2000). The volcanic gas molar CO_2/S_T ratios indicated in the figure are from the present study except for Momotombo (Menyailov et al., 1986) and Masaya (Martin et al., 2010). CVS and NVS identify the Costa Rica and Nicaragua volcanic segments, respectively.

large variations in gas chemistry within a given arc segment, between different segments, and at individual volcanoes.

Herein we present experimental evidence for sizeable variations in the gas composition along the Costa Rica–Nicaragua volcanic segment (CNVS) of the CAVA (Fig. 1). Previous work in the region (Shaw et al., 2003; Zimmer et al., 2004; Elkins et al., 2006; Fischer et al., 2007) has concentrated on the chemical and isotopic systematics of poorly reactive (CO_2) or inert (N_2 and He) gases, with the majority of samples being low temperature. We concentrate here instead on determining the CO_2/SO_2 and H_2O/CO_2 ratios in the large, high-temperature emissions that generally dominate – and are therefore more appropriate to confine – the volcanic-arc CO_2 output (Shinohara, 2013). The CO_2/SO_2 signature of CAVA volcanism has been assigned constant values in previous CO_2 regional inventories (Hilton et al., 2002; Mather et al., 2006; Fischer, 2008), whereas the structural and magmatological complexities of the arc (Carr et al., 2003) make the existence of substantial along-arc variations highly plausible.

The results reported herein were obtained in the course of a gas survey conducted during March and April 2013 with the aim of characterizing the chemistry of the volcanic gas plume at five strong degassing volcanoes: Turrialba, Poás, and Rincón de la Vieja in Costa Rica, and San Cristóbal and Telica in Nicaragua. We combine our newly acquired data set with previous gas information in the region (i) to better confine the CO_2/SO_2 signature(s) of this arc segment, (ii) to derive a volcanic CO_2 budget for the region, and (iii) to infer new constraints on the (mantle vs. slab) origin of arc CO_2.