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Carbon dioxide diffuse emission and thermal energy release from hydrothermal systems at Copahue–Caviahue Volcanic Complex (Argentina)

Giovanni Chiodini [a], Carlo Cardellini [b], María Clara Lamberti [c,*], Mariano Agusto [c], Alberto Caselli [d], Caterina Liccioli [c], Giancarlo Tamburello [e], Franco Tassi [f,g], Orlando Vaselli [f,g], Stefano Caliro [h]

[a] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Via D. Creti 12, 40128 Bologna, Italy
[b] Università degli Studi di Perugia, Dipartimento di Fisica e Geologia, Via G. Pascoli snc, I-06123 Perugia, Italy
[c] IDEAN-GESVA, Dpto. Cs. Geológicas, FCEN, Universidad de Buenos Aires, Buenos Aires, Argentina
[d] LESVA-IIPG. Universidad Nacional de Río Negro, General Roca, Argentina
[e] Università degli Studi di Palermo, DiSTeM, Via Archirafi 36, I-90123 Palermo, Italy
[f] Università degli Studi di Firenze, Dipartimento di Scienze della Terra, Via G La Pira 4, I-50121 Firenze, Italy
[g] Istituto di Geoscience e Georisorse–Consiglio Nazionale delle Ricerche (CNR–IGG), Via La Pira, 4, I-50121, Firenze, Italy
[h] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Napoli-Osservatorio Vesuviano, Via Diocleziano 328, I-80124 Napoli, Italy

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ABSTRACT

The north-western sector of Caviahue caldera (Argentina), close to the active volcanic system of Copahue, is characterized by the presence of several hydrothermal sites that host numerous fumarolic emissions, anomalous soil diffuse degassing of CO_2 and hot soils. In March 2014, measurements of soil CO_2 fluxes in 5 of these sites (namely, Las Máquinas, Las Maquinitas I, Las Maquinitas II, Anfiteatro, and Termas de Copahue) allowed an estimation that ~165 t of deeply derived CO_2 is daily released. The gas source is likely related to a relatively shallow geothermal reservoir containing a single vapor phase as also suggested by both the geochemical data from the 3 deep wells drilled in the 1980s and gas geoindicators applied to the fumarolic discharges. Gas equilibria within the H–C–O gas system indicate the presence of a large, probably unique, single phase vapor zone at 200–210 °C feeding the hydrothermal manifestations of Las Máquinas, Las Maquinitas I and II and Termas de Copahue. A natural thermal release of 107 MW was computed by using CO_2 as a tracer of the original vapor phase. The magmatic signature of the incondensable fumarolic gases, the wide expanse of the hydrothermal areas and the remarkable high amount of gas and heat released by fluid expulsion seem to be compatible with an active magmatic intrusion beneath this portion of the Caviahue caldera.

1. Introduction

The poor knowledge of CO_2 fluxes released from natural sources, such as mantle and metamorphic reactions, is one of the most vexing problems in understanding the geological carbon cycle (Berner and Lasaga, 1989). Large uncertainties affect the estimates of global CO_2 flux from volcanoes (Burton et al., 2013 and reference therein) due to the relatively limited flux measurements of volcanic plumes from persistently degassing volcanoes. In addition, the amount of CO_2 not directly related to volcanic craters and released from hydrothermal systems associated with most active volcanic regions is poorly constrained. Recently, an international initiative to fill this gap has been promoted by the scientific community with a project named DECADE (https://deepcarbon.net/content/deep-carbon-observatory-launches-decade-initiative), which supports investigations focused on the study of CO_2 fluxes from active volcanoes. The present study is in the framework of this initiative, being aimed at mapping and quantifying deep-originated CO_2, diffusively discharged from the hydrothermal areas located few kilometers east of the active volcanic system of Copahue (Patagonia, Argentina), where fumarolic discharges and large zones of soil diffuse gas emission occur. A second goal of this study is to provide an estimation of the local geothermal potential.

The development of a quick and reliable technique for the measurements of soil CO_2 fluxes (Chiodini et al., 1998) has recently promoted applications in different fields of geological and environmental sciences. One of the most promising applications of this tool (namely, the accumulation chamber method) regards the use of soil CO_2 flux surveys for geothermal prospecting. This method allows recognizing and characterizing CO_2 flux anomalies at the surface, which are caused by the circulation of hydrothermal fluids at depth. Soil CO_2 fluxes higher than those due to biologic activity are indeed commonly associated with

* Corresponding author. Tel.: +54 114576 3400.
E-mail address: mclamberti@gl.fcen.uba.ar (M.C. Lamberti).

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the circulation of hydrothermal fluids (Chiodini et al., 1998; Cardellini et al., 2003; Lewicki and Oldenburg, 2005). In addition, recent studies have shown that CO_2 diffuse degassing can provide important and reliable constraints for a correct evaluation of the geothermal potential from hydrothermal areas (Chiodini et al. 2005; Fridriksson et al., 2006; Werner and Cardellini, 2006; Chiodini et al., 2007; Mazot and Taran, 2009; Hernández et al., 2012; Rissmann et al., 2012; Bloomberg et al., 2014; Granieri et al., 2014; Dionis et al., 2015). In particular, the total budget of hydrothermal gases released at the surface can be used for a robust estimation of the minimum amount of geothermal fluids involved at depth in the degassing process. Consequently, the accumulation chamber method represents an effective, rapid and cheap instrumentation for estimating the minimum geothermal potential of an unknown area since the thermal energy naturally transported and released by the fluids can be evaluated.

2. Geological, volcanological and hydrothermal setting

The Copahue–Caviahue Volcanic Complex (hereafter CCVC, 38°S–71°W) is located in the Neuquén Province (Patagonia, Argentina) on a segment of the Andes range, called the South Volcanic Zone (hereafter SVZ: 33.3°–46°S), 30 km east of the main Pleistocene–Holocene volcanic front (Fig. 1). Volcanism in the SVZ is related to the subduction of the Nazca Plate beneath the South American Plate, at rates as high as 10.8 cm y^{-1} (DeMets et al., 1994; Ramos and Folguera, 2000; Melnick et al., 2006).

The steepening of the oceanic plate subducted in the last 5 Ma resulted in the displacement of the asthenospheric wedge and an asthenospheric upwelling. This process favored a process of crustal thinning that caused the most recent westward migration of the volcanic arc, extensional dynamics and large effusions of basaltic–andesitic magma (Folguera et al., 2006; Yuan et al., 2006).

The CCVC includes the Caviahue Caldera (also known as Caldera del Agrio), a volcano-tectonic depression defined as an intra-arc extensional pull-apart basin (Ramos and Folguera, 2000; Bermúdez et al., 2002; Melnick et al., 2006; Rojas Vera et al., 2010). The pull-apart basin is located at the transition zone between the Liquiñe-Ofqui dextral-slip and the Antiñir-Copahue fault systems (Lavenu and Cembrano, 1999; Folguera et al., 2004). The former accommodates lateral displacements imposed by the oblique convergence between the Nazca and South American plates from ~46°S to ~38°S (Radic, 2010). The CCVC encompasses the Copahue volcano, a Pleistocene polygenic stratovolcano located in the southwestern rim of the Caviahue Caldera, whose main products are andesites and basalts (Polanco, 2003). The easternmost of the nine NE-oriented summit craters of the Copahue volcano is currently active. During the last 250 years, at least thirteen low-magnitude phreatic and phreatomagmatic eruptions occurred from this crater (Martini et al., 1997; Naranjo and Polanco, 2004). The 1992 and 1995 eruptions mostly consisted of phreatic events characterized by the emission of pyroclastic sulfur. In 2000, a phreatomagmatic eruption, mainly involving juvenile material, occurred (Delpino and Bermúdez, 1993, 2002; GVN, 2000a,2000b). Since November–December 2011, the discharge rate of fluids from the Copahue active crater increased, whereas sporadic phreatic events have been occurring since July 2012. A major phreatomagmatic–magmatic eruption was observed on December 22, 2012 and a significant degassing is still ongoing (Caselli et al., accepted for publication).

During quiescent periods, the active crater hosts a hot acidic lake (up to 63 °C and pH < 1) (Varekamp et al., 2001; Varekamp et al. 2009; Agusto, 2011; Agusto et al., 2012; 2013). Two acidic hot springs (up to 80 °C and pH = 1–2) discharge in the eastern summit flank of the cone and merge downstream to form the upper Agrio river (pH = 2–3), which flows into the acidified glacial Lake Caviahue (Martini et al., 1997; Gammoms et al. 2005; Varekamp, 2008; Caselli et al., 2005; Agusto, 2011; Agusto and Varekamp 2015).

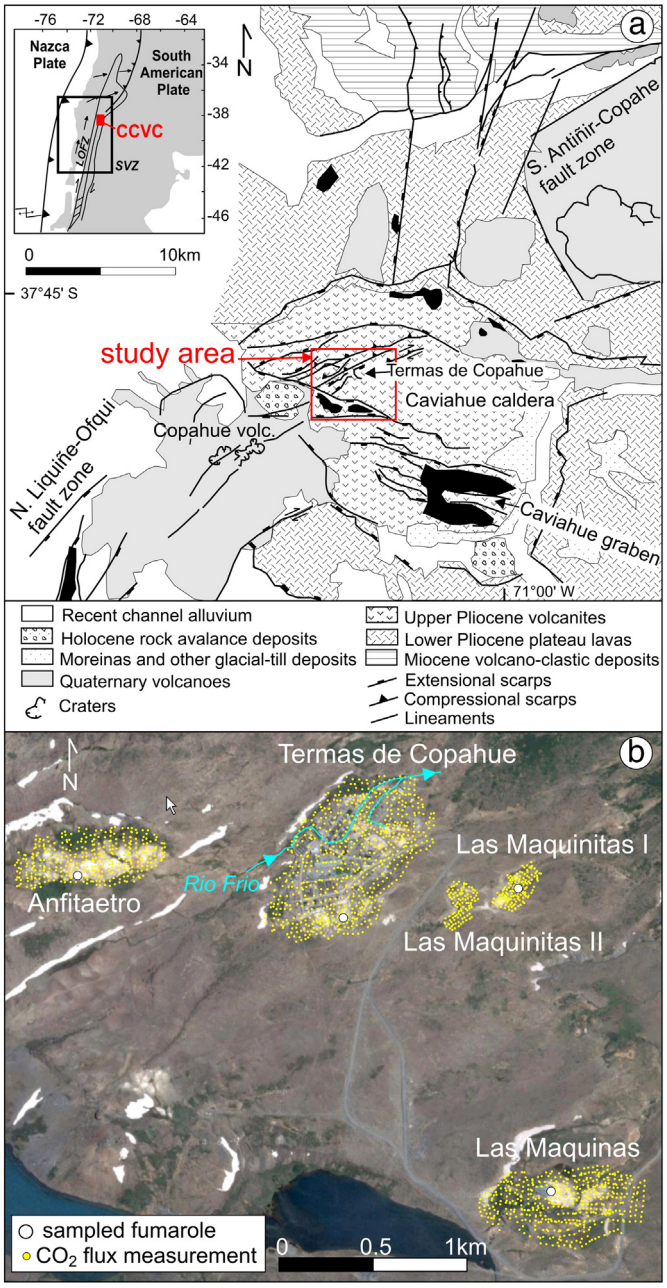

Fig. 1. a) Geological, volcanological and structural setting of the Copahue–Caviahue Volcanic Complex and location of the study area (modified from Folguera et al., 2004); b) location of the surveyed hydrothermal sites.

In March 2014, a remote sensing campaign, carried out by combining MiniDoas and Multigas techniques, revealed the presence of an important gas plume from the crater lake and allowed a rough estimation of the released SO_2 and CO_2, which resulted to be of ~960 and ~640 t d^{-1}, respectively (Tamburello et al., in press).

In the north-eastern flank of the Copahue volcanic edifice, within the Caviahue Caldera, six hydrothermal areas are recognized: Las Máquinas, Las Maquinitas I, Las Maquinitas II, Anfiteatro, Termas de Copahue and Chancho-Co (Mas et al., 1996; 2000; Fig. 1). The hydrothermal activity of some of these sites (Las Máquinas, Las Maquinitas and Termas de Copahue) is so intense that causes a background volcanic tremor as revealed by a seismic array analysis performed in the 2003–2005 period (Ibáñez et al., 2008). Fluids are discharged as boiling, bubbling and mud pools (up to temperatures of 96 °C), fumaroles (up to 130 °C at La Maquinitas I) and large areas of diffuse degassing and hot soils.