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Soil CO_2 Diffuse Degassing at Chachimbiro Volcano, Ecuador

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ABSTRACT:

Soil CO_2 diffuse degassing is often a prominent feature of geothermal systems associated with volcanic regions. Studies have shown that identifying the spatial distribution of these emissions improves understanding of the systems, helps identify up-flow paths and, ultimately, quantifies thermal energy released. This study presents the first CO_2 diffuse degassing analysis ever carried out at Chachimbiro volcano, situated at the north of Ecuador's Andean Cordillera; the location of the most advanced geothermal project in the country. This investigation aims to better understand the heat and permeability distribution to identify future targets for geothermal exploration/exploitation. The survey covered an area of 3.6 km^2 with 642 points measured and 18 samples collected for carbon isotopic analysis. Results show two CO_2 sources contributing to the system: biogenic and magmatic, supported by the Graphical Statistical Approach (GSA) and carbon isotopic analysis. Sequential Gaussian Simulation (SGS) was used to model the spatial distribution of CO_2 flux to preserve spatial variability and quantify uncertainty. The study concludes that several high-flux areas support the Chachimbiro geothermal conceptual model, indicating both promising and less favorable targets for future drilling.

Introduction

Over the past decade an increasing number of studies have begun to use CO_2 diffuse soil emissions as a method for characterizing geothermal resources by revealing zones of high permeability where highest hydrothermal flows occur (where deep-derived gases are escaping) [1]. In geothermal exploration, this is

vital information for locating productive and cost-effective drilling sites. Unquestionably, geochemical and geophysical methods are useful in assessing geothermal resources. However, they can fail to indicate the current permeability status of the system [2], making CO_2 degassing a complementary exploration tool.

In Ecuador, the Chachimbiro geothermal project, located on a dormant volcano with evolved volcanic compositions, represents the country's most advanced geothermal initiative, with an estimated 50 MW potential. In 2017, the first exploration well was drilled. Fortunately, it showed satisfactory results, confirming a high-temperature reservoir of 235° C at depth [3]. This study aims to enhance understanding of Chachimbiro's geothermal potential by using CO_2 degassing measurements to obtain insights into the structural permeability and heat source distribution that might serve as potential targets for geothermal drilling exploration/exploitation.

Methodology

Data collection lasted over a month during November of 2020. We sampled 642 points (Figure 1) to collect CO_2 flux (ppm/sec) along with other environmental parameters known to influence degassing dynamics, like soil and air temperature, among others. The samples were collected on relatively dry days to keep weather conditions moderately consistent. CO_2 flux was measured following the accumulation chamber method as detailed in Chiodini et al. (1998). We also collected 18 gas samples for carbon isotopic analysis following the procedure proposed by Chiodini et al. (2008) and established a control point that was monitored twice per day to normalize for diurnal variability. Data analysis involved unit conversion (from ppm/s to g/m²/day), followed by the creation of a cumulative probability plot to distinguish individual populations using the Statistical Graphical Approach (SGA) ([4]).This was complemented by analyzing the carbon isotopic signature of the collected samples. The spatial distribution of CO_2 flux was modeled by the Sequential Gaussian Simulation (SGS) using R programming language, where 400 simulations were generated for uncertainty quantification.

Results and discussion

The SGA revealed three distinct populations of CO_2 origin—interpreted as biogenic, magmatic, and a mix of both—with statistical tests confirming significant differences among them. Although 44 g m² day^{-1} day was tentatively proposed as the threshold separating biogenic from magmatic fluxes, carbon isotopic analysis and theoretical mixing curves suggest that biogenic CO_2 flux likely ranges from 1 to 15 g m² day^{-1}, indicating that the 44 g m² day^{-1} threshold is an overestimation.

The ensemble map of CO_2 flux (Figure 2), generated from 400 SGS simulation, shows areas of high flux concentrated in the southern and southeastern sectors, particularly near and within the dome structures. Additional high-flux anomalies occur along a broad NE-SW corridor that broadly follows the orientation of mapped faults which suggests a structural control on permeability. These faults are likely acting as conduits for deep-seated CO_2-rich fluids rising toward the surface. Fault intersections or areas where faults bend or splay could create enhanced permeability zones, explaining some of the more localized flux anomalies (e.g., center-south). The southeastern dome complex coincides with a notable cluster of high flux which might represent an area of residual magmatic heat or shallow hydrothermal upflow, contributing to higher degassing. On the other hand, the low flux zones at the central-western side of the map could be associated with less fractured, more impermeable lithology which in turn might suggest the heterogeneity of the clay cap and thick difference in both areas central-western vs SE and SW.

In terms of targets for future drilling southeastern dome area shows the highest CO_2 flux, indicating strong upflow, heat presence, and good permeability, making this section the top drilling target. Central-southern zones along NE-SW faults also suggest structurally controlled upflow and could be promising for exploration. In contrast, the northwestern and central zones showing low CO_2 flux likely correspond to cooler, less permeable areas without active fluid migration so these should be deprioritized.

Conclusion

CO_2 diffuse degassing is a valuable tool for identifying zones of high permeability and potential heat sources within the Chachimbiro geothermal system. The spatial distribution of CO_2 flux, supported by isotopic analysis, reveals that the southeastern dome area and NE-SW fault-controlled zones are key targets for future drilling due to their high fluxes and likely structural upflow. These findings highlight the role of faulting and dome-related fracturing in enhancing permeability, while low-flux zones mark areas of limited geothermal potential and should be deprioritized in exploration strategies.

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Figure 1. Chachimbiro volcano and data points collected during field work. Faults, caldera rim and domes mapped by CELEC 2016.

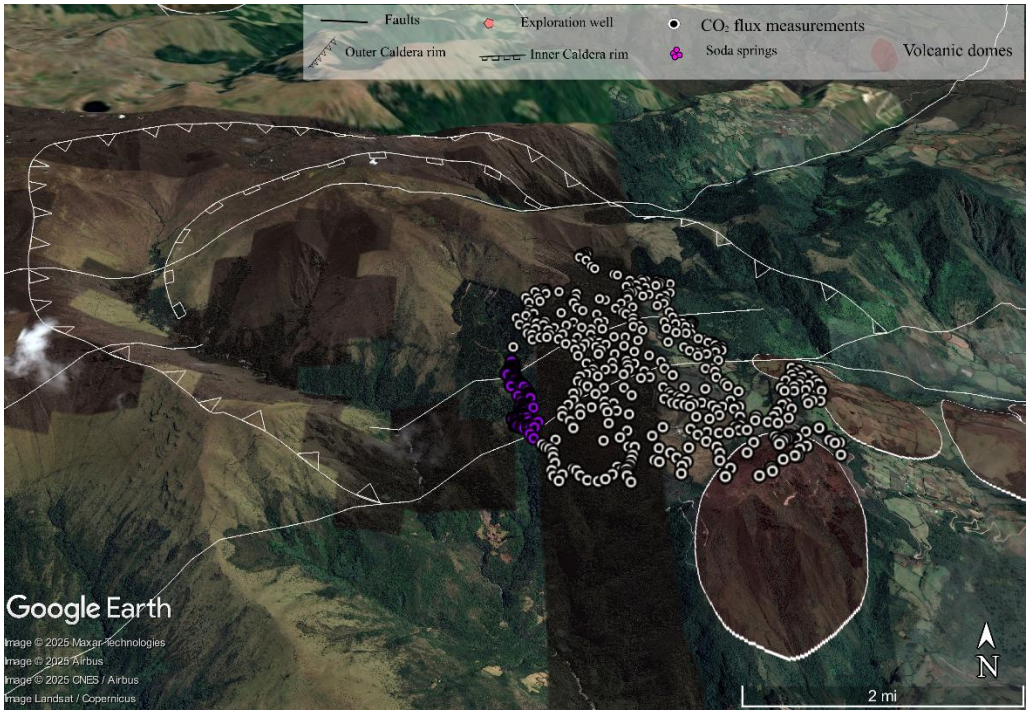
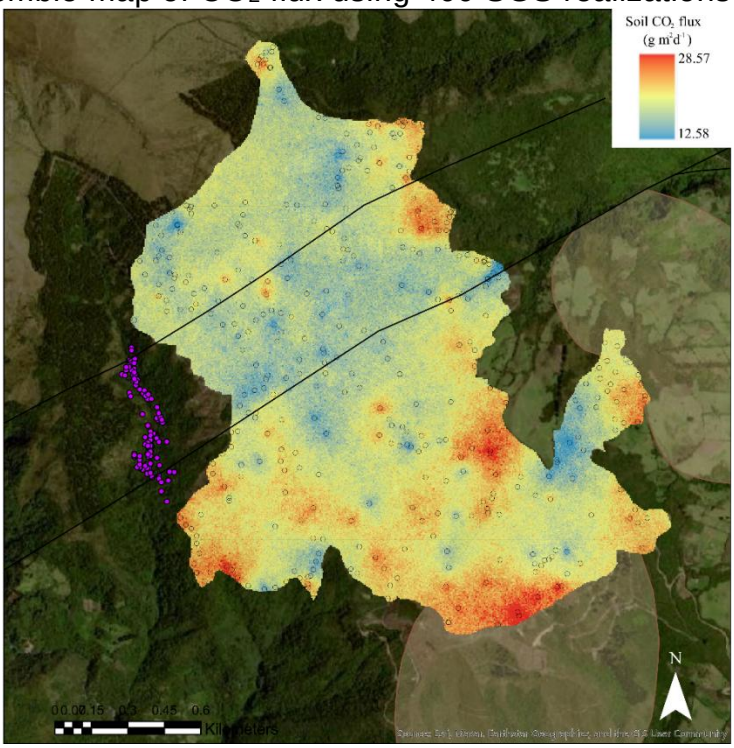


Figure 2. Ensemble map of CO_2 flux using 400 SGS realizations



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