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Delineation of upflow areas through the measurement of diffuse gas emissions and noble gas isotopes in the Cerritos Colorados Geothermal System, Mexico.

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INTRODUCTION

The identification of upflow zones of thermal fluids is crucial in geothermal exploration because it helps to identify promising areas for energy extraction. Therefore, the study of main geothermal gases (e.g., CO_2) and noble gases (e.g., He and Rn) in soils and surface thermal manifestations facilitates the delineation of these preferential flow zones .

Noble gases such as helium and radon, being rare, are transport in the system by more abundant gas species, such as CO_2 or CH_4, toward the surface through of areas of high permeability, which play a dominant role in controlling the transport and redistribution of trace gases (Rn and He), provide information on vertical fluid migration (Etiope and Martinelli, 2002; Hernández et al., 2015). As a result, both gases are key elements in the study of geothermal systems to track fluid and heat sources, understand interactions with the reservoir and between fluids, estimate residence times, and ultimately determine the useful life of the reservoir for the sustainable exploitation of this resource (Pinti et al., 2019). The objective of this work is to quantify the diffuse gas emissions in soil (CO_2 and Rn) and correlate them with noble gas isotopes measured in surface thermal manifestations (spring and fumaroles) to identify vertical gas upflow zones in the Cerritos Colorados Geothermal Field (CCGF) located near Guadalajara, central Mexico (figure 1). As a strategy of re-exploring the geothermal field.

METHODS

Sampling campaigns were carried out to measure CO_2 and Rn fluxes, and to collect gas samples for the analysis of noble gas isotopes (figure 1c), in 2023 and 2024. A West System fluxmeter with an accumulation chamber was used to measure the CO_2 flow (West System, 2019).

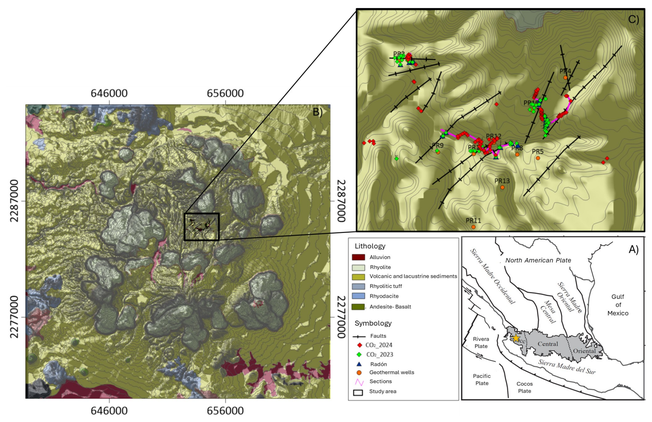


Figure 1 A) Location map of the CCGF, B) Location map of the study area, C) Location of sampling points for diffuse gases and noble gases.

The DURRIDGE RAD 7 Electronic Radon Detector 2684™ was used to measure ^{222}Rn and ^{220}Rn gas. The measurement method used in the present study was the protocol for thoron (^{220}Rn; DURRIDGE, 2019).

Noble gas isotope samples were collected in copper tubes and analysed at the GEOTOP noble gas isotope laboratory (UQAM, Canada) using a HELIX MC spectrometer.

RESULTS

The CO_2 flux measurements in soils revealed: low fluxes associated with background degassing values, intermediate or mixed fluxes, and high or anomalous fluxes associated with the vertical ascent of thermal fluids through faults (figure 2).

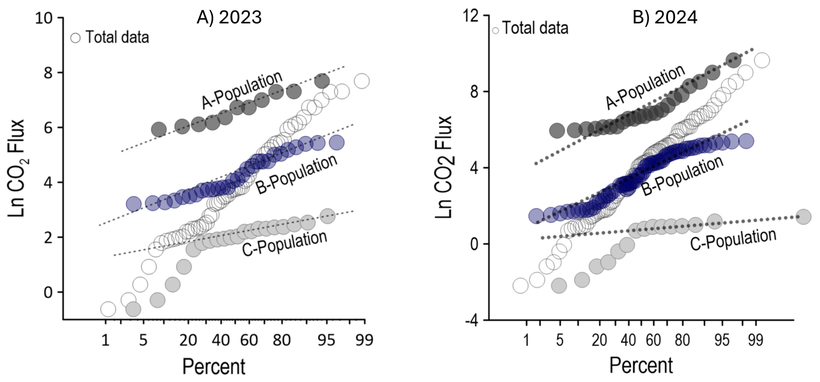


Figure 2 Cumulative percentage diagram of Ln CO2 flux (A) June 2023and (B) July 2024.

The ^{222}Rn and the ^{220}Rn concentrations indicating a spectrum from high rates of deep degassing, intermediate deep flows, and low flows of shallow provenance (figure 3). The R/Ra isotopic ratios measured in this study and those reported by Han et al., 2022 (7, 8, 9) and Pinti (10, 11 unpublished), show that the gases originate from magmatic sources. The highest CO_2 fluxes, and the highest concentrations of ^{222}Rn and ^{220}Rn, associated with high fluxes, were found in areas near SW-NE and E-W oriented faults with in the central and NW parts of the field; as well as high values of the R/Ra isotopic ratio located in fumaroles zones associated with the faults mentioned above (figure 5).

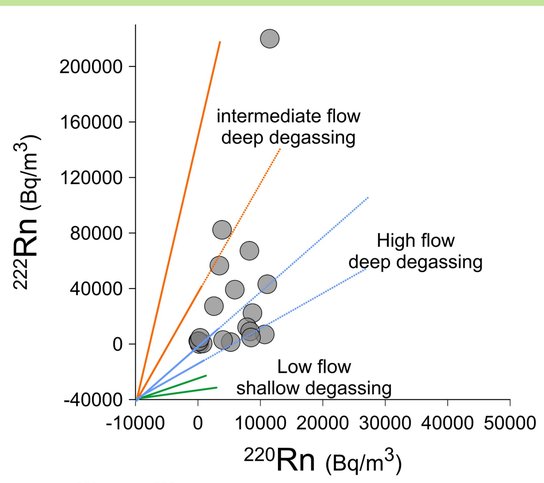
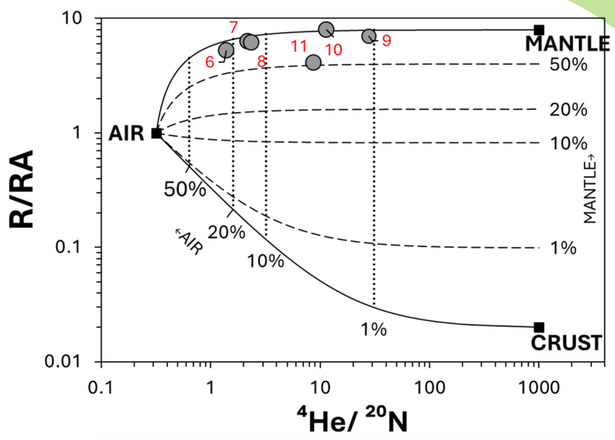


Figure 3 ^{222}Rn & ^{220}Rn diagram shows different degrees of degassing.



Name	Mantle %	Air %	Crust %
6	62.56	23.07	14.37
10	97.25	2.75	0.00
11	50.68	3.64	45.68
7	77.27	14.65	8.08
8	75.53	13.53	10.94
9	88.21	1.12	10.67

Figure 4 $^{3}He/^{4}He$ & $^{4}He/^{20}Ne$ diagram of Cerritos Colorados fumaroles and their end-member proportions according to their origin.

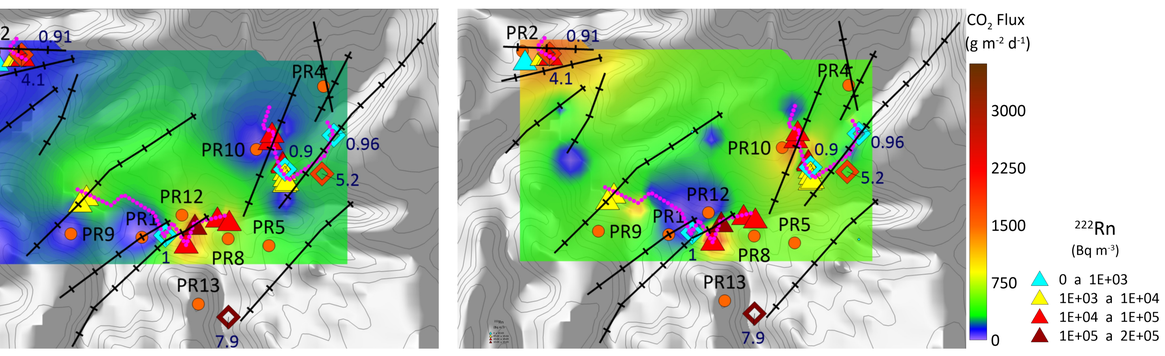


Figure 5 Map showing CO_2 flux distribution for the years:(A) 2023 and (B) 2024. Values of ^{222}Rn and R/Ra isotopic ratio at the sampled sites. The dotted pink lines show the three sections made (west, center and east).

Figure 6 shows three sections where the blue areas show the correlation of degassing of the different gases measured associated with the main faults, but also areas where there is no evidence of them on the surface.

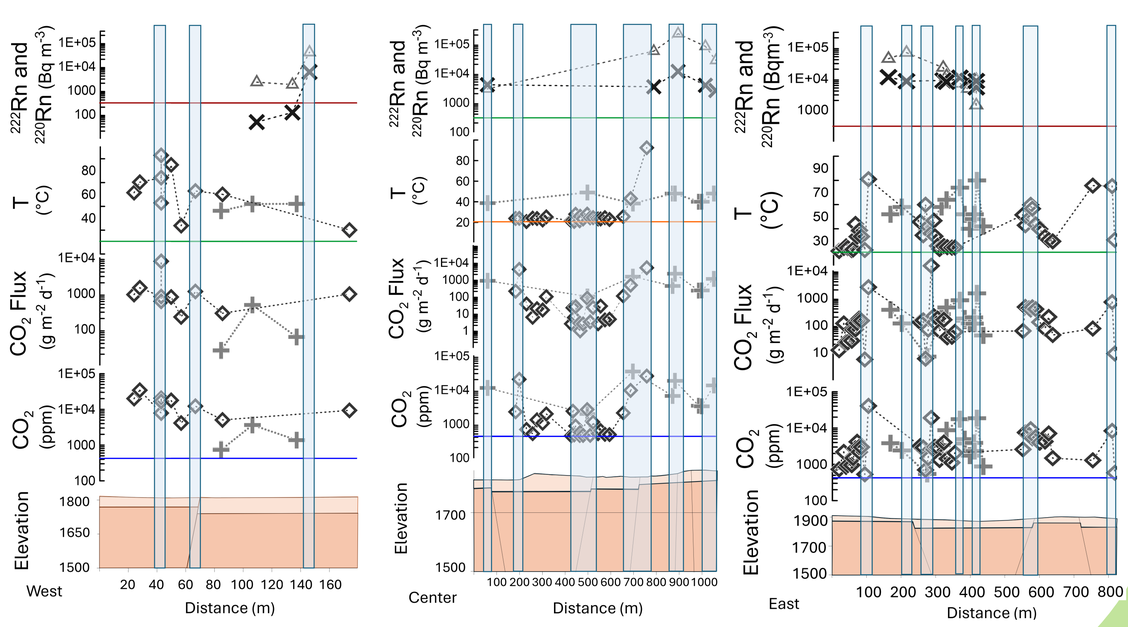


Figure 6 Diffuse gas profiles (CO_2 and Rn) ,soil temperature and main geological structures (zones of higher permeability).

DISCUSSION

Anomalous CO_2 and ^{222}Rn fluxes associated with fumarole areas mainly near the main faults of the system. The presence of He and Ne isotopes in some fumarolic areas suggest a mantle-derived gas component. These noble gas anomalies show spatial correlation with anomalies of CO_2 and Rn fluxes, indicating possible zones of vertical ascent of gases (upflow zones), which evidence the extent of the reservoir.

In upflow areas, CO_2 acts as a carrier gas for trace gases (Rn and probably He). Through the study of gases, areas of vertical gas ascent were identified, such as those near wells PR-12, PR-10, and PR-9.Which could represent new areas of interest for the re-exploration of the geothermal system.

CONCLUSION

In the Cerritos Colorados geothermal system, anomalous CO_2 and Rn degassing flows were observed, associated with the main faults that cross the system, and also observed in areas where no faults are present, suggesting these structures are located at depth. Analysis of gas emissions and isotopes shows that the areas south of well PR-12 and east of well PR-10 are important zones of vertical gas rise. These are two possible areas for re-exploration of the site.

This work demonstrates the usefulness of diffuse gas measurement and noble gas isotope analysis as a tool for delineating possible deep structures and locating areas of interest for exploration.

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