The exsolution of magmatic volatiles in the Los Humeros volcanic-geothermal system

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Introduction & Study Area

Magmatic volatiles can be considered as the surface fingerprint of active volcanic systems, both during periods of quiescent and eruptive volcanic activity. The spatial variability of gas emissions at Earth's surface is a proxy for structural discontinuities in the subsurface of volcanic systems. The Los Humeros geothermal reservoir is characterized by a low to medium matrix permeability where fluid flow is mainly controlled by a dense fault/fracture network. This study focuses on different soil gas surveys at different scales to identify areas of increased gas emissions, relate them to (un)known volcano-tectonic structures and determine their origin. We show that a systematic sampling approach on reservoir scale is necessary for the identification and assessment of major permeable fault segments. The combined processing of CO_2 efflux and $\delta^{13}C$-CO_2 facilitated the detection of permeable structural segments with a connection to the deep, high-temperature geothermal reservoir. Our results suggest promising areas for future exploration activities in the north- and southwestern sector of the production field.

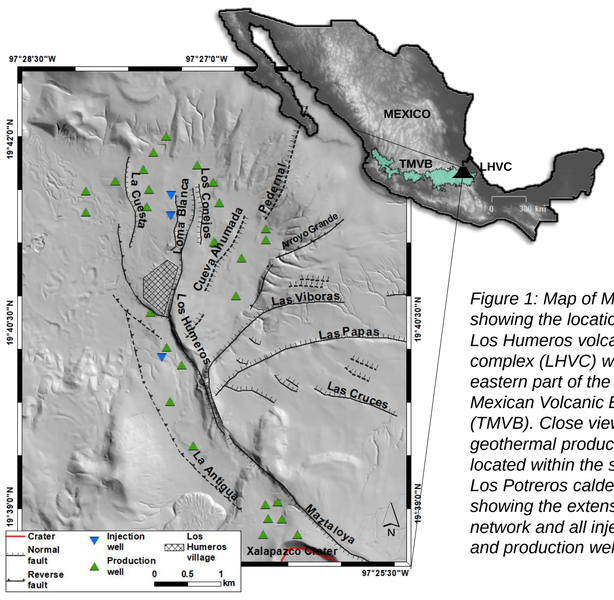

Figure 1: Map of Mexico showing the location of the Los Humeros volcanic complex (LHVC) within the eastern part of the Trans Mexican Volcanic Belt (TMVB). Close view of the geothermal production zone located within the smaller Los Potreros caldera showing the extensive fault network and all injection and production wells.

Methods & Sampling Approach

- Accumulation chamber technique for CO_2 efflux measurements
- Carbon isotopic analysis of CO_2
- Alpha-particle spectroscopy for ^{222}Rn and ^{220}Rn emissions
- Samples for high resolution mass spectrometry (SMS) for $^3He/^4He$
- Soil temperature measurements T_S (50 cm depth)
- Installation of a continuous monitoring station for CO_2 efflux

In total three soil gas sampling campaigns:

1. May 2017: CO_2 efflux scouting survey, regular spaced sampling grid 25 m x 200 m, 2700 sampling points
2. Feb. 2018: Four small-scale, domain-based CO_2 efflux surveys, 25 m x 100 m grid, 715 sampling points
3. April 2018: ^{222}Rn /^{220}Rn survey and T_S measurements, 50 m x 200 m grid, 880 sampling points

Results

CO_2 efflux large- and small-scale surveys

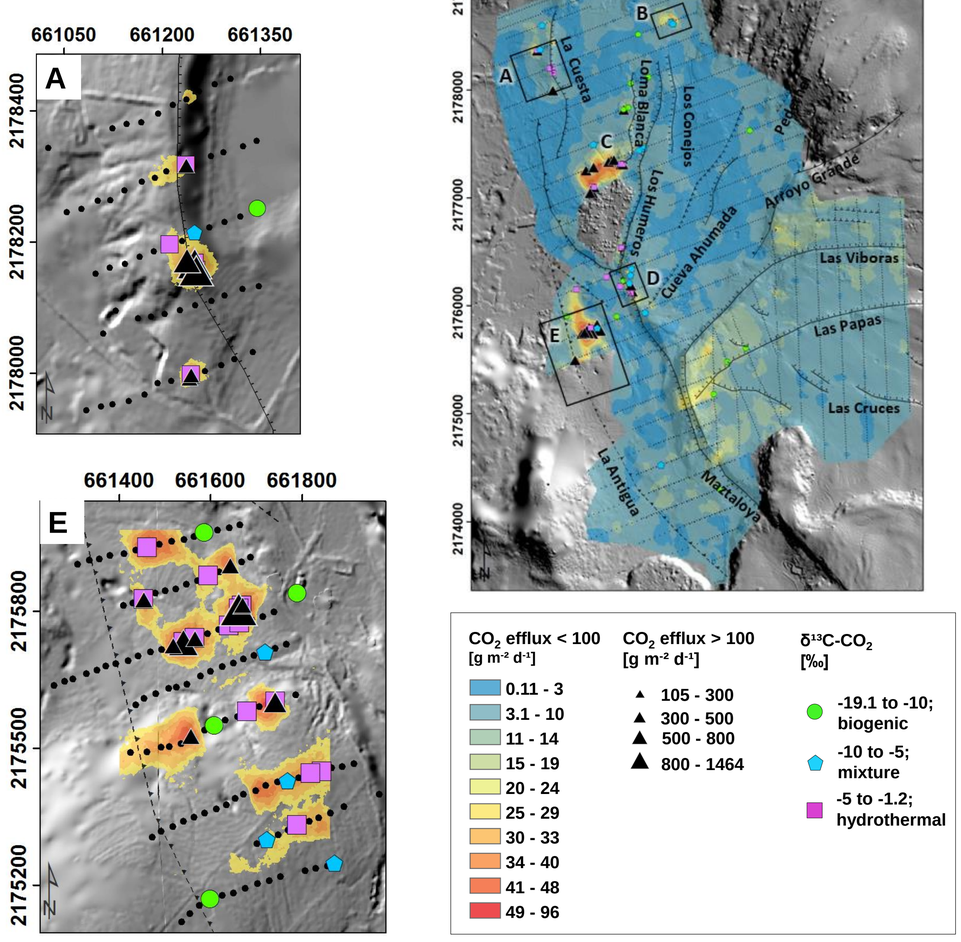

Figure 2: Results of sequential Gaussian simulation for the CO_2 efflux scouting survey in 2017 (middle) showing the distribution of low, intermediate and elevated degassing sites up to 97 g m^{-2} d^{-1}. Black squares (A, B, D, E) show the location and size of the domain-based surveys performed in 2018. Values lower than 29 g m^{-2} d^{-1} are masked. Values > 100 g m^{-2} d^{-1} are illustrated as graduated black triangles. Carbon isotopes are classified in three groups (biogenic, mixed, hydrothermal). Small black dots represent CO_2 efflux sampling sites. Solid and dashed black lines illustrate known and inferred faults. The grey cutout between Area C and D shows Humeros village where no measurements were performed due to expected anthropogenic disturbances.

Soil temperature

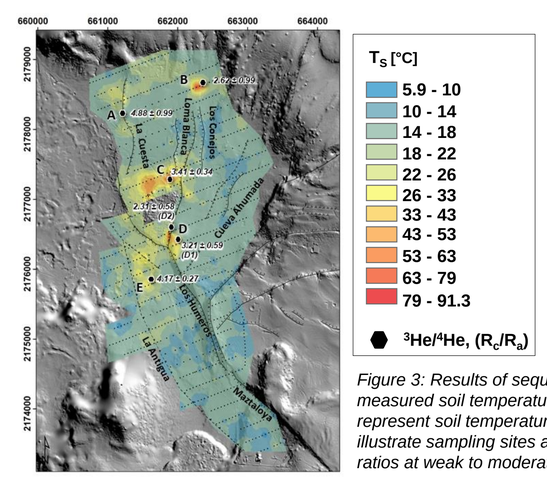

Figure 3: Results of sequential Gaussian simulation for all measured soil temperatures in 2017. Black small dots represent soil temperature sampling sites. Black hexagons illustrate sampling sites and results for air-corrected helium ratios at weak to moderate steam vents..

Radon activity concentration

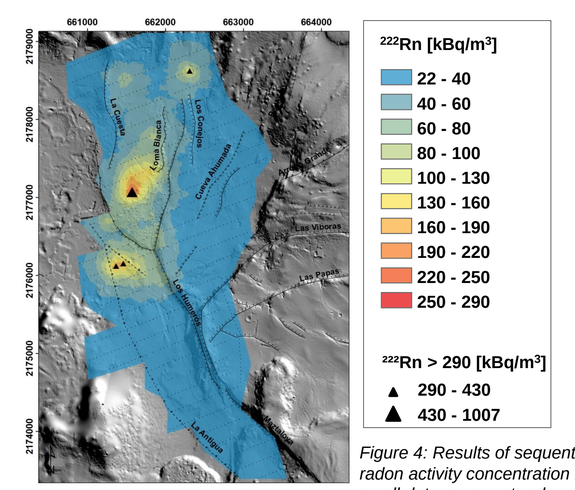

Figure 4: Results of sequential Gaussian simulation for radon activity concentration measured in 1 m depth. Black small dots represent radon sampling sites.

Discussion

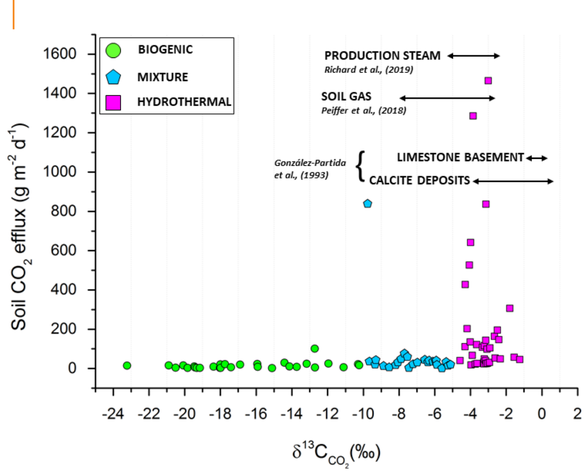

Figure 5: Plot illustrating soil CO_2 efflux versus carbon isotopic composition of soil CO_2. Their spatial distribution can be seen in Fig. 2. We illustrate the range of measured carbon isotopes from various studies at Los Humeros for comparison. $\delta^{13}CCO_2$ values from increased soil gas emissions and production steam are in accordance with our values from the hydrothermal and mixed groups.

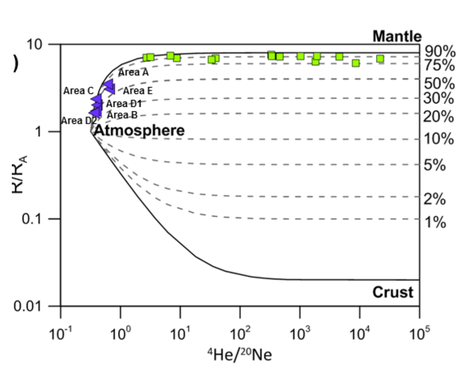

Figure 6: a) Binary plot of R/R_A vs. $^4He/^{20}Ne$ of samples from steam vents (purple triangles, this study) and geothermal production steam (green squares from Pinti et al., 2017). Results show a mixing between atmosphere and up to 65% mantle (Area A and E).

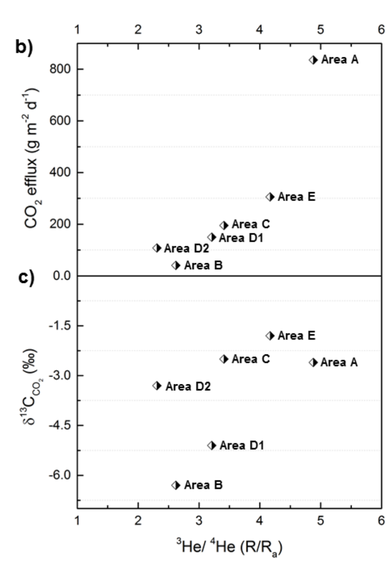

Figure 6: b) $^3He/^4He$ (R/R_A) ratios versus CO_2 efflux; R = 0.89.
c) $^3He/^4He$ (R/R_A) ratios versus carbon isotopic composition of soil CO_2; R = 0.6. There is a significant positive correlation between all three parameters.

Conclusion

- Appearance of increased gas emissions indicate presence of a fault-controlled fluid migration
- Increased CO_2 emissions hydrothermal/mantle derived
- Combined analysis of CO_2 efflux and $\delta^{13}CCO_2$ is a powerful approach to estimate the actual extent of geothermally active areas
- $^3He/^4He$ (R/R_A) ratios prove existence of deep-rooted faults down to the high-temperature geothermal reservoir
- Soil temperature and radon activity concentration measurements can give further information about migration pathways of hydrothermal fluids in the subsurface
- Large-scale survey successful approach for geothermal exploration. Domain-based surveys improve the assessment of spatial variability of gas emissions along specific faults
- Results indicate that future exploration should focus on the NW (Area A) and SW (Area E) part of the geothermal field since it shows the most evident relation to the superhot geothermal reservoir

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 727550.

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