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# DIFFUSE DEGASSING TECHNIQUES APPLIED TO GEOTHERMAL PROSPECTS DURING EXPLORATION IN EL SALVADOR

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## ABSTRACT

Geochemical surface exploration surveys are part of an interdisciplinary (geophysics and geology) approach to the exploration of geothermal resources. In El Salvador geochemical field campaigns for the exploration of geothermal resources using a diffuse degassing technique, are done with different types of equipment that involve different techniques. The soil gas surveys include different techniques such as: sampling of soil gas for analysis of different gaseous species (oxygen, carbon dioxide, nitrogen, helium, argon and methane), $^{222}$radon and $^{220}$radon emanations, carbon dioxide flux, hydrogen sulfide and mercury in soil gas. Soil gas surveys are done using various analyzers e.g. the Radon analyzer (Pylon AB-5 detector and 300A Lucas cell) for radon-222 and radon-220 determination, mercury analyzer (Jerome, model 431-X) for mercury determination, hydrogen sulfide analyzer (Jerome, model 631-X) for hydrogen sulfide determination and the Portable diffuse flux meter: Carbon dioxide & Hydrogen sulfide apparatus for carbon dioxide and hydrogen sulfide fluxes determination in soil gas. Ground temperatures are determined by the aid of a thermocouple with a temperature probe. Analyses of oil gas samples are done in the laboratory using a cuadrupolar mass spectrometer.

## 1. INTRODUCTION

The measurement of diffuse degassing is a technique that has been employed at LaGeo S.A. de C.V. since 2000 when the first study using this technique was carried out in Berlin geothermal field and was performed only on the road and marginal streets of the place.

Between 2001 and 2002 the first study was conducted in Ahuachapan geothermal field and basically was done in streams and areas close to known faults. From the year 2003, more detailed studies were performed with a regular grid E-W direction. Since then, these studies have been carried out in both geothermal fields and new areas explored: San Vicente and Chinameca.

When new areas are explored in search of a geothermal resource and areas with certain gaseous anomalies are of interest, the diffuse degassing studies are performed in conjunction with other disciplines (geophysics and geology). The studies can determine if the area is of interest for geothermal exploitation.

This technique is also used in the annual monitoring of fumaroles in both geothermal fields and geothermal well platforms; the purpose of these measurements is to determine whether the anomalies found behave the same way or if there are variations from one year to another. These results have allowed mitigation works on some geothermal well platforms (for example AH-16).

## 2. EQUIPMENT USED IN DIFFUSE DEGASSING MEASUREMENTS

When a geothermal exploration, control of degassing platforms geothermal wells and fumaroles of different geothermal areas is is carried out, the equipment described below are used:

**Radon ($^{222}$Rn) and Thoron ($^{220}$Rn).** A Pylon Model AB-5 Portable Radiation Monitor and a Pylon Model 300A Lucas Cell were used for the radon measurements. Figure 1 shows Pylon AB-5 Portable radiation Monitor set up for determination of radon in soil gas.

Gas samples at approximately 50 centimeters depth were taken at each sampling site. A vacuum pump was used to extract the gas sample through a probe into the Lucas Cell (López et al., 2004).

The radiation monitor detects the alpha particles produced during the decay process of radon and its daughter products. The number of particles or light pulses emitted per minute allows the calculation of the radon and thoron concentrations (Pylon Electronics Inc., 1993).

FIGURE 1: Pylon portable radiation monitor set up for determination of radon in soil (Grimaldi, 2010)

**$CO_2$ flux.** The $CO_2$ flux was measured directly using a closed-chamber $CO_2$ flux meter from West Systems equipment with a chamber method LICOR LI-800 an LI-820 single-path, dual wavelength, non-dispersive infrared gas analyzer (Figure 2). All flux measurements were made using a chamber with 2.756 x $10^{-3}$ $m^3$ total internal volume and 3.14 x $10^{-2}$ $m^2$ basal area. The flux measurement is based on the rate of $CO_2$ increase in the chamber (Fridriksson, 2009).


FIGURE 2: Portable diffuse flux meter (Carbon dioxide and Hydrogen sulfide) set up for determination of flux in soil (Gutiérrez, 2009)

**Mercury vapor.** Gas soil samples for determination of mercury vapor are extracted at around 50 cm depth using a stainless steel probe with a septum and a 50 cc syringe. The sample is injected in an Arizona Instruments Mercury Vapor Analyzer (Jerome 431-X), which uses a gold film sensor. It uses a pump which pumps the soil gas through a scrubber and into the flow system. The sensor absorbs the Mercury vapour.

This instrument and hydrogen sulfide analyzer determines the amount absorbed and displays the measured concentration on the digital meter in milligrams per cubic meter ($mg/m^3$) of mercury (Arizona Instruments LLC, 2004) and part per million of hydrogen sulfide (Arizona Instruments LLC, 2004).

**Hydrogen sulfide.** Gas samples for Hydrogen sulfide analysis are also extracted at around 40 cm depth using a probe with a septum and a 50 cc syringe. The sample is injected in an Arizona Instruments Hydrogen Sulfide Analyzer, which also has a gold film sensor and pump.

Figure 3 shows the Mercury vapour analyzer and Hydrogen sulfide analyzer as set up in the field.

FIGURE 3: Set up for mercury vapour and Hydrogen sulfide analyzer (Gutiérrez, 2009)

**Concentrations of gases: $O_2$, $H_2$, $N_2$, $CO_2$, He, Ar, and $CH_4$.** Gas samples for analysis of oxygen, hydrogen, nitrogen, carbon dioxide, helium, argon, and methane are extracted at around 50 cm depth using a metallic probe with a septum and a 50 cc hypodermic syringe. Samples are stored in 10 cc vacuum vacutainer. Gas samples are analyzed with a quadrupole mass spectrometer Omnistar 422, shown in Figure 4.


FIGURE 4: Cuadrupolar Mass Spectrometer and vacutainer

## 3. METHODOLOGY

The methodology and/or techniques used in diffuse degassing measurements at LaGeo for exploration of geothermal prospects, control of fumaroles, and geothermal well platforms, is as follows:

- Select a study area.
- Identify sites of interest using existing information: aerial photography, infrared,

geological mapping of faults and alteration zones.

- Establish a grid for sampling: this grid is usually done with east-west orientation; the separation of the sampling points depends on the size of the area being studied. The experience in LaGeo has been to decrease the distance from a mile between points during the first studies conducted in 2000 to 250 m during the most detailed studies in some areas investigated. If sampling is performed in a fumarole or platform wells, grids are suited to these areas.
- Perform sampling of different gases.
- Once the fieldwork is completed, the data are processed, plotted and then the results are presented in a report.

## 4. THE EXPERIENCE OF LAGEO

Since LaGeo began using this technique, it has been possible to perform many monitoring campaigns of diffuse degassing, among which may be mentioned:

- Campaigns in the Ahuachapán geothermal field (2001 and 2003) and the Berlin geothermal field (2000, 2004, 2008, and 2008);
- Exploration of new areas: San Vicente and Chinameca, with successful results at both sites;
- Studies of the fumaroles of both fields: In Ahuachapán 2006 and 2010, and in Berlin 2004 and 2009; and
- Measurements in Ahuachapán geothermal well platforms for eight consecutive years (2008-2015) and in Berlin (2012 and 2014, with monitoring to continue in 2015).

Some of the results obtained are shown in the following Figure 5 and 6.

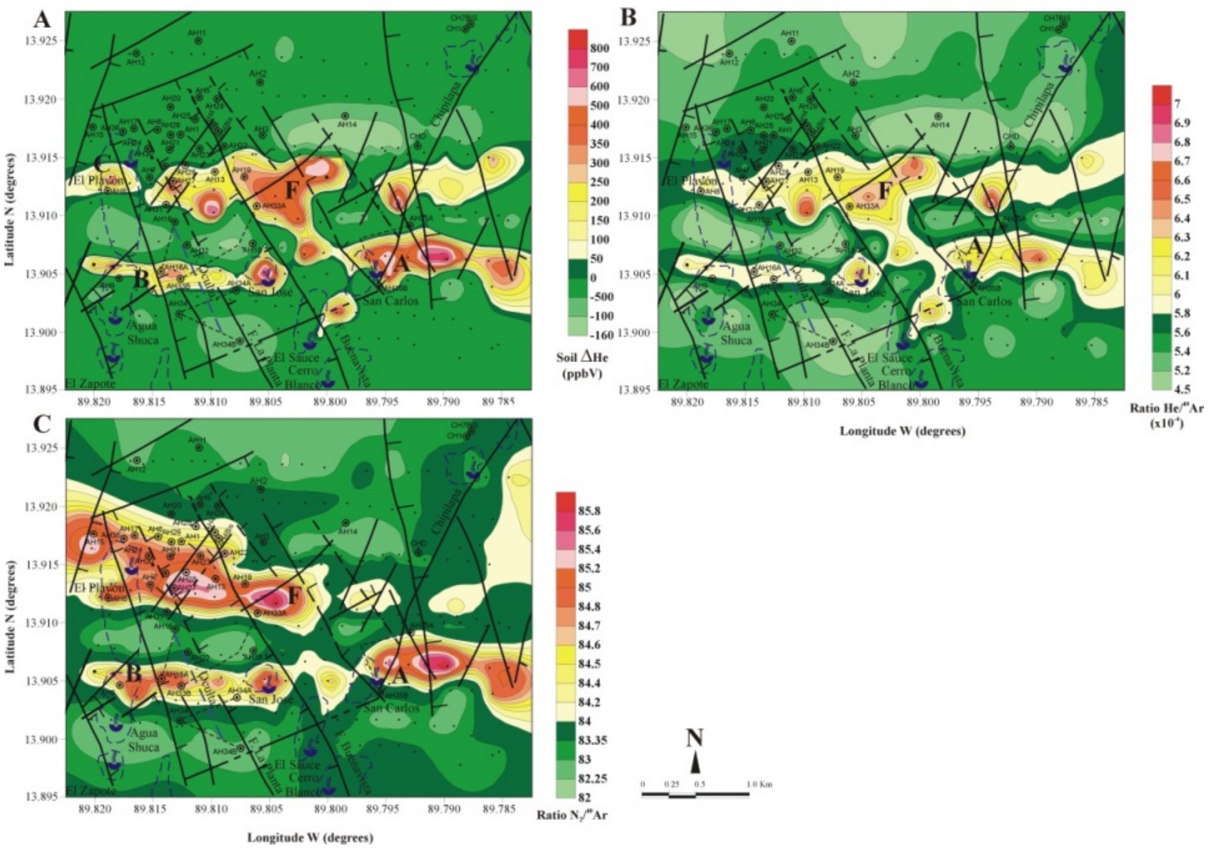

FIGURE 5: A) Delta He (He concentration at 40 cm minus atmospheric concentration), B) He/Ar ratio, and C) $N_2$/Ar in Ahuachapán geothermal field soils (Padrón et al., 2003)

Figure 5 shows the results obtained during 2003 diffuse soil degassing of $CO_2$ and radon was investigated in an area of the Ahuachapán geothermal field covering a rectangular area. The vertical permeable zones shown in the figure can be buried E-W faults that are not evident in the surface (as noted by González Padilla, 1997). The fact that noble gases can move easily throughout that zone suggests a deep source for these gases. Nobel gases are not reactive and can move faster throughout the permeable path than other gases defining more clearly the source origin (Padrón et al., 2003).

The map of the $^{220}Rn/^{222}Rn$ ratio suggests the existence of a circular high permeability structure probably buried below the more recent volcanic deposits and related to the caldera formation (López et al., 2004; Figure 6).

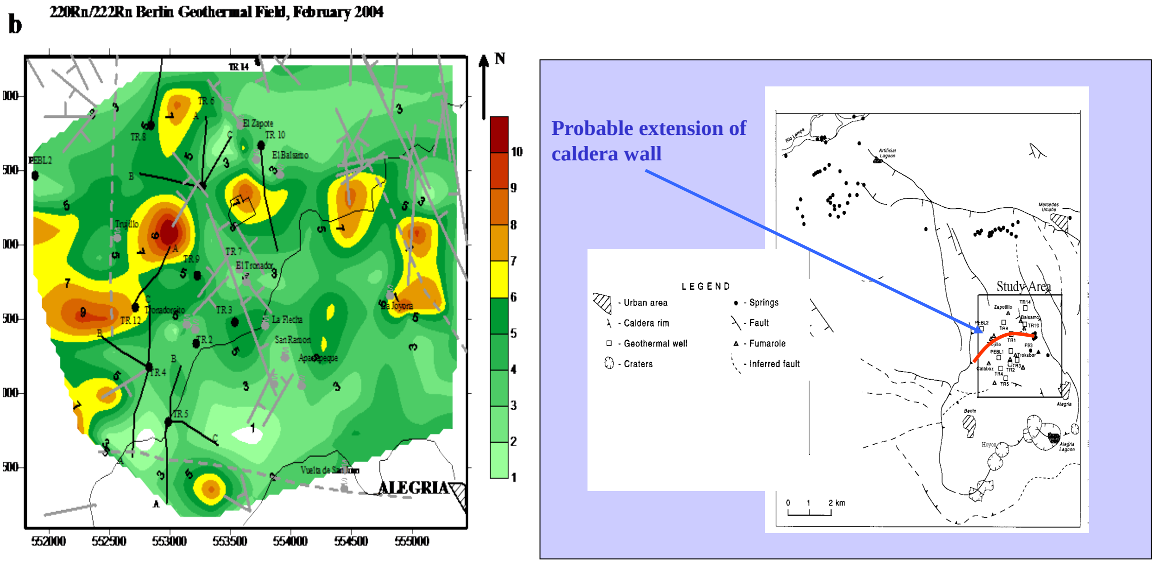


FIGURE 6: A) Spatial distribution of the $^{220}Rn/^{222}Rn$ ratio (López et al., 2004)

Figure 7 shows results of the measured temperature at 40 cm depth and $CO_2$ concentration in the fumarolic zone of TR-6-Zapotillo during the 2003 survey. It can be noted that the higher temperature

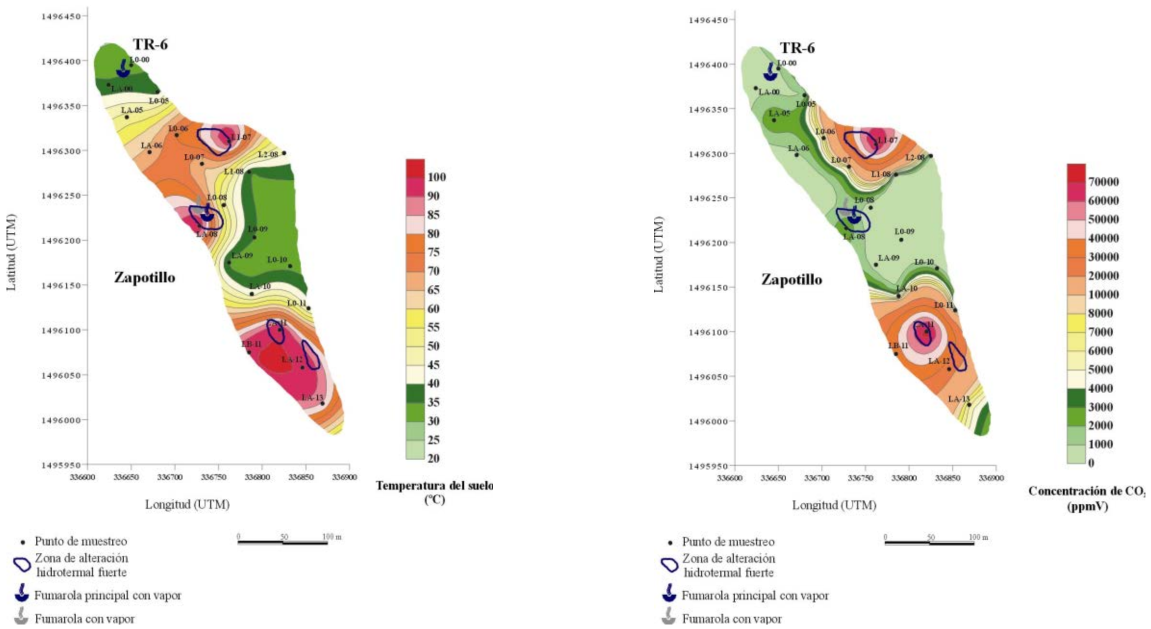


FIGURE 7: Soil temperature at 40 cm depth and $CO_2$ concentration in study area (Magaña et al., 2004)

zones correspond with the zones where the $CO_2$ concentration is greater. The contour of the area mapped in the figure corresponds with the zone of visible hydrothermal alteration. The shape of the isotherms and the $CO_2$ isoconcentration lines in this figure suggests that the alteration zones should have a wider extension (Magaña et al., 2004).

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