Radon and Carbon Dioxide Diffuse Soil Degassing At Ahuachapan Geothermal Field, El Salvador

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ABSTRACT

The Ahuachapan Geothermal Field in El Salvador, Central America, has been in exploitation since 1975. Future expansion of the exploitation area towards the south and east is being considered. Several geoscientific studies have been conducted to evaluate the geothermal potential of this area. This paper reports the results of a survey of carbon dioxide soil fluxes and concentrations of radon in soil gases. Soil CO_2 flux measurements were performed using the accumulation chamber method and a LICOR LI-800 CO_2 Analyzer. ^{220}Rn and ^{222}Rn soil gas concentrations were measured with a portable radiation monitor Pylon Model AB-5 and a 110A Lucas Cell. 172 sampling points were measured. The obtained values ranged from 6 to 406 $g.m^{-2}.d^{-1}$ for CO_2 flux with a background mean of 20 $g.m^{-2}.d^{-1}$, from 2 to 132 pCi/l and 10 to 935 pCi/l for radon and thoron, respectively. Peak levels of soil CO_2 flux, radon, and thoron concentrations were identified at the intersection of faults where hydrothermal fluids are rising and the rocks are highly fractured allowing the release of radon. Two areas were identified with the highest anomalies for CO_2 flux and radon and thoron soil gas concentrations. These areas are located between the Oriental (B) and San Jose Faults, and the zone between Los Amates, Oriental (B) Faults and a fault that is found close to the AH-35 well. These areas are proposed as good geothermal drilling targets.

Introduction

The Ahuchapan Geothermal Field, El Salvador, has been in exploitation since 1975. This geothermal field is one of the main sources of electrical energy for El Salvador during its twenty-seven years of energy production. At the present time, research efforts are oriented to expand the exploitation area in order to extend the life of the geothermal field and improve the production of electrical energy. For that reason, the southern and eastern region of the geothermal field is investigated. A survey of radon concentrations in soils and fluxes of CO_2 from soils was carried out during January-February, 2002. This paper reports the main findings of these investigations.

^{222}Rn ($t^1/2$=3.8 d), ^{220}Rn ($t^1/2$=55 s) and ^{219}Rn ($t^1/2$=3 s) form the isotopic group which decay from radioactive natural elements such as ^{235}U and ^{238}Th. ^{222}Rn is an inert radioactive gas with short half life ($t^1/2$=3.8 d). ^{222}Rn is soluble in water and its solubility increases with decreasing temperature (Mania, *et. al.*, 1995). Radon gases in soils and in fumaroles are used to identify convective flow areas and to monitor degassing changes through time. These gases can show changes of the hydrothermal volcanic system due to magmatic activity and/or seismic movement, for example Cerro Negro Volcano (Connor, *et. al.*, 1996), Izu-Oshima Volcano (Notsu, *et. al.*, 1991), and Mt. Etna Volcano (Giammanco, *et. al.*, 1995).

Due to the half-life of radon, in areas where slow diffusive flow exists, the average depth of origin is approximately 2 m (Connor, *et. al.*, 1996). Therefore the high concentrations of radon are more likely to be due to convective movement of gases rather than diffusive processes.

Thoron gas (the isotope ^{220}Rn) disintegrates quickly, it is present only during few minutes after the collection of the sample. Its half-life is 55 seconds (Hutter, 1995). It is difficult to achieve an exact quantitative measurement of its concentration. If we measure the disintegration of thoron, it shows a decrease during the first three minutes after collection of the sample, as opposed to the radon that presents a half-life of almost 4 days.

The term volcanic gas defines a gas exsolved from a magmatic source of an active volcano. The term hydrothermal gas defines a gas exsolved from the envelope of hot water that surrounds the magmatic environment. Volcanic gases have composition different from the hydrothermal gases, the first is richest in SO_2 and the second in H_2S (Giggenbach, 1996). CO_2 occurs in both and is the most abundant gas after water vapor. The composition of hydrothermal gases is dominantly H_2O (usually higher than 90%) and CO_2 (Nicholson, 1990). For this reason, emissions of CO_2 are considered very useful to monitor volcanic activity. Changes in CO_2 emissions can indicate magma movements and possible eruptions (e.g. Hernandez, *et. al.*, 2001). Carbon dioxide emissions are also related to permeable zones in volcanic geothermal fields. A correlation between high CO_2 fluxes and fault zones has been found (e.g. Ustica Island, Etiope, *et. al.*, 999).

High fluxes of hydrothermal gases are usually discharged at the end of faults or where multiple faults are encountered intercept. These areas of fault propagation and interaction are characterized by high stresses that produce breaking or hydro-fracturing. These stresses provide active fracturing with continuous opening and sealing of fractures by deposition of minerals. These fractures are the conduits for fluid flow (Chiodinni, G., *et. al.*, 1994). The objectives of this work are to identify areas of higher fluxes of soil CO_2 and radon and to correlate contour maps of CO_2 flux and radon concentrations in soil gases with existing faults and with the results of other geophysical and geological surveys in the area being studied.

Study Area

The Ahuachapan Geothermal Field is located in western El Salvador (Figure 1). The 240° C hot fluids discharged from this field are related to the hydrothermal envelope that surrounds the andesitic vents Laguna de las Ninfas and Laguna Verde. The volcanism in this region is related to the subduction of the Pacific Plate below the Caribbean Plate. The Ahuachapan Geothermal Field is located to the north of these volcanoes in an area intensively faulted and within the Central American graben, which southern fault is defined by the volcanic chain in this region.

Methodology

The study area and the sampling stations are shown in Figure 2. 172 points were sampled. The average distance between sampling points was about 200 m. The sampling points were oriented more or less perpendicular to faults present in the study area.

The soil CO_2 flux measurements were performed using the accumulation chamber method (Baubron, *et. al.*, 1991) and a LICOR LI-800 CO_2 Analyzer. Radon and thoron concentrations were obtained taking a soil gas sample from 40 cm of depth with a probe and using a portable monitor Pylon Model AB-5 and a Lucas cell Model 110A attached to a vacuum pump. The ratio of thoron to radon concentrations was obtained using the number of disintegrations (emited alfa particles) during minutes 1,2, and 3 and the radon concentration was obtained using the number of disintegrations during minutes 10,11, and 12 as described in the Pylon manuals (Pylon Electronics Incorporated, 1989).

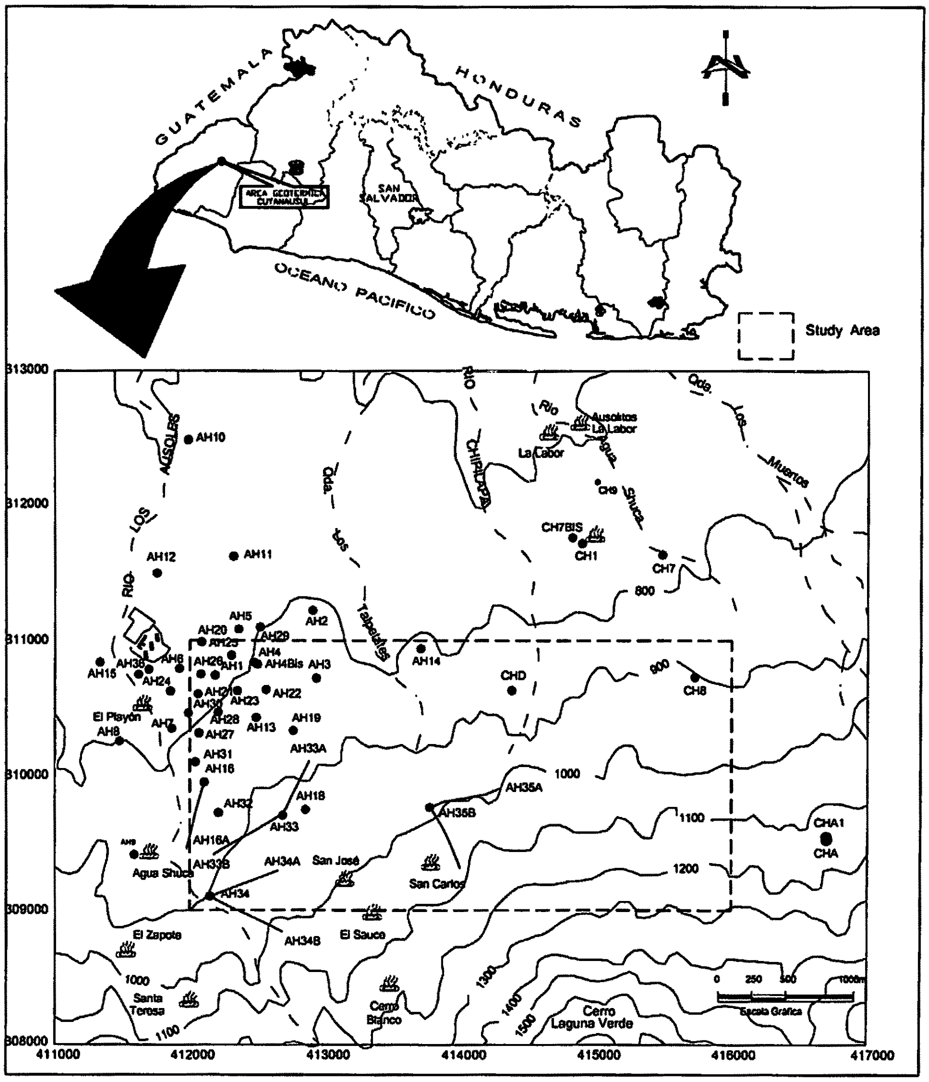

Figure 1. An overview of the Ahuachapan Chipilapa geothermal system.

Results

The results of the measurements of CO_2 flux are shown in Figure 3. Several high flux anomalies can be recognized. One of these anomalies is located where three faults converge: Fault Oriental (B), Fault Los Amates and the extension of Fault 35. The other region with high CO_2 flux is located at the intersection of the extension of Chipilapa Fault, Fault Oriental (A) and a fault with NE-SW direction, near the San Carlos fumarole (Figure 1).

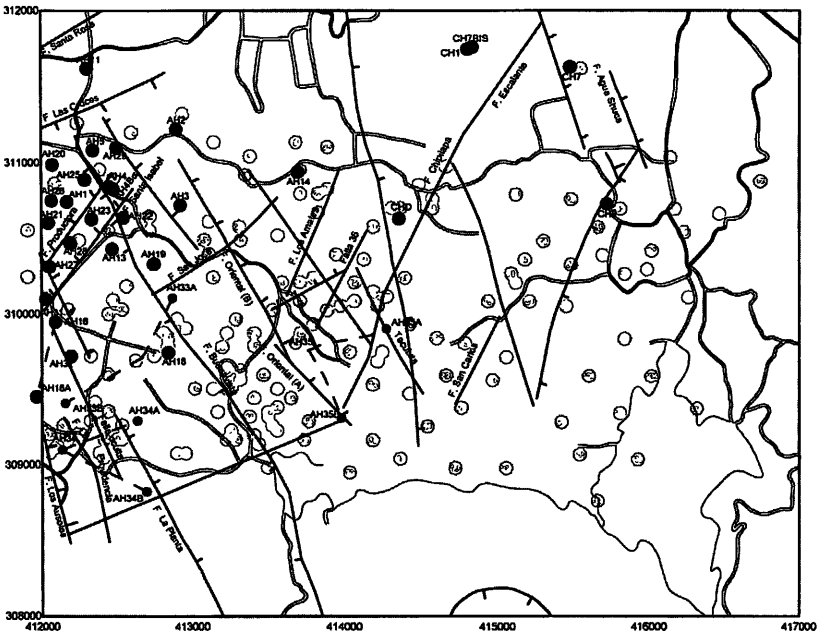

Figure 2. Study area showing the Ahuachapan-Chipilapa Geothermal Fields. 172 sampling points were included in this study.

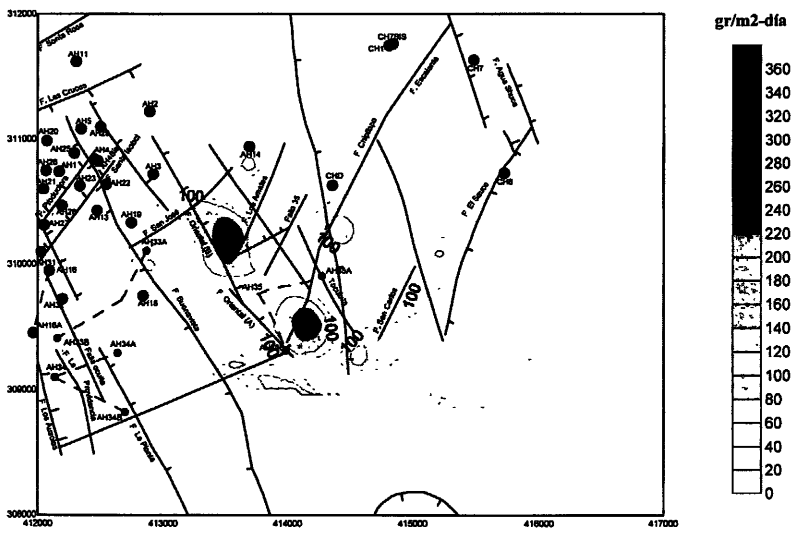

Figure 3. CO_2 flux contour map of Ahuachapan Geothermal Field.

The two previously mentioned areas present the highest values of CO_2 flux. However, a third high flux area can be observed. It is located at the intersection of the Chipilapa fault and a fault that runs NNW. There are also high flux anomalies at the intersection of The San Carlos Fault, Tacubita Fault and Chipilapa Fault. There are high fluxes in the proximity of the AH-14 well and another close to well AH-33A. It is important to note that the areas with high emissions of CO_2 correspond to areas that have perceptible hydrothermal discharges (fumaroles) and/or are located at the intersection of fault systems.

Figure 4, overleaf, shows the results for radon soil gas concentrations. Several high radon concentration anomalies are observed in this area. Again, they correspond to intersection of faults, end of faults or sectors among several faults. First, the area of convergence of the Oriental (B) Fault and San José Fault can be mentioned. This area also presents a high CO_2 flux anomaly, which is not always the case. CO_2 anomaly depends on the existing faults and upward movement of magma that results to the liberation of CO_2 gas. Another region of high radon concentration is the area to the NW of the AH-14 well, at the end of the fault. Other high radon zones are located at the south and southwest of the AH-14 well (between Faults 35 and Oriental (B) and other between Faults Buenavista and Oriental (A), respectively).

Figure No. 5, overleaf, shows the results of thoron gas concentrations. The occurrence of this isotope requires a quick ascent of fluid. Again, the high thoron concentrations are associated with faults. High concentrations are observed at San José and Oriental (B) Faults, similar to the previous gases (CO_2 and radon). These results support that this area is a good area for emission of gases. In this zone, several mineral sulfates are observed, such as alunite and natroalunite, and in some occasions anhydrite (García and Henríquez, 2001).

Changes in porosity and density of the rocks due to deposition or dissolution of minerals are observed during water-rock interactions in geothermal fields. In the area between Oriental (B) Fault, Los Amates Fault, 35 Fault and San José Fault, an anomalous flux of carbon dioxide, radon and thoron exists. This zone presents hydrothermal alteration that correlates with the existence of a hydrothermal bicarbonate-sulfate fluid type where anhydrite ($CaSO_4$) is present in this area (Garcia and Henriquez, 2001). These acid sulfate waters are probably brought about by a channel or fracture zone (fault system) in the area and mix with bicarbonate waters at shallow levels. The deep penetration of these fluids may have occurred down the fracture zones, which are being continually reopened through fault movement.

This distribution of anhydrite suggests high sulfate activity and fluid acidity from acid fluid channels. Faults and fracture zones when anhydrite is abundant coincide with the emission of CO_2 and radon gases. The presence of this mineral associated with the emission of CO_2 and radon gases suggests that this area has good permeability and is transferring hydrothermal fluids easily, making this area a good target for exploitation.

At Buenavista Fault, an acid type of alteration exists (Garcia and Henriquez, 2001). In this area, the presence of some minerals of the silica group, sulfur, iron oxides group, titanium and clay minerals have been identified (García and Henríquez, 2001). These minerals suggest that carbon dioxide is probably consumed in the generation of clay minerals, sealing the fault, and explaining the low fluxes of CO_2 at this fault.

Also some weaker soil gas emission anomalies are located to the East, such as close to the Escalante Fault and other in the

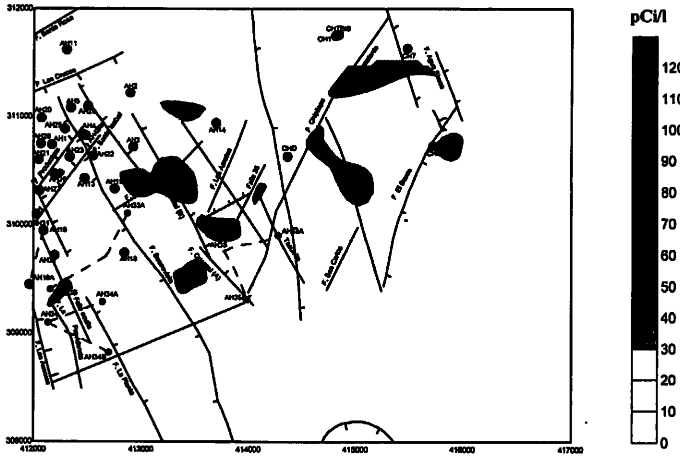

Figure 4. Soil radon concentration contour map of study area.

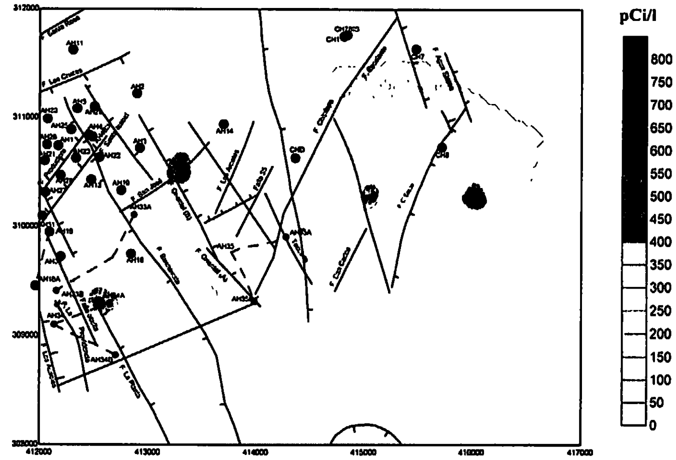

Figure 5. Soil thoron concentration contour map of study area.

extension of El Sauce Fault and at the fault close to the CH-8 well. These two anomalies are associated with the Chipilapa geothermal system to the East of the Ahuachapan Geothermal Field. The region of the AH-33B well presents a small anomaly for CO_2 flux, radon, and thoron. The emission of these gases at this site is congruent with the identification of anhydrite in the cores of this well (Garcia and Henriquez, 2001).

These two surveys have found some anomalies that have been already identified by other geophysical methods (DiPippo, *et. al.,* 1999), as well as some new anomalies that should be considered for more detailed work.

Conclusions

The results of this work allow the following conclusions:

1) The zones with the highest CO_2 flux, radon, and thoron soil concentrations is found between the Oriental (B) Fault and San Jose Fault, and the zone between Los Amates Fault, Oriental (B) Fault and the fault that is found close to the AH-35 well. These areas should be considered as good geothermal targets for future exploitation.
2) Mineralogical studies indicate that the presence of anhydrite correspond to areas with high CO_2 fluxes, radon, and thoron soil gas concentrations suggesting high permeability and fast fluid transfer.
3) In the producing well area, to the NW of the study area, high fluxes of CO_2 or radon soil concentrations are not observed. This behavior is probably due to the extraction of the hydrothermal fluids throughout the wells that offers faster conduits for the movement of gases and prevents the release of gases throughout the overlying soils.

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