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Anomalies in the Content of Radon Gas and Presence of Hydrothermal Alteration in Chipilapa Geothermal Area

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ABSTRACT

At the Ahuachapan-Chipilapa geothermal fields in El Salvador, results of soil radon gas surveys carried out in 1984, 1991, 2002, and 2003 show anomalies that relate with structural features such as fault zones and fault zone interceptions, as well as with areas of hydrothermal manifestations in the area. These anomalies correspond with anomalies reported by other geophysical methods as well as geological studies. These results suggest that the fault systems are actively transferring fluids and heat from the deep reservoir to the near surface environment. Measurements of soil radon concentrations seem to be good indication of vertical permeability and can be used to identify faults transferring fluids in volcanic hydrothermal systems.

Introduction

The Ahuachapan Geothermal Field is located at the western part of El Salvador, 3 kms south of Ahuachapan City along the northern sector of the Apaneca cordillera. The geothermal field is related to a recent calderic structure, located at the SW boundary of the Central American Graben in El Salvador (González Partida, 1991). Adjacent to Ahuachapan Geothermal Field, to the NE, is Chipilapa Geothermal Field, near the town of Turin (Figure 1). Several geoscientific studies could not define a clear boundary between the two fields (Torres et al., 1997). In 1994, a stabilization and rehabilitation program was carried out and established the Chipilapa sector as the reinjection area of the Ahuachapan geothermal field. Figure 1 shows the geological setting of Ahuachapan and Chipilapa geothermal fields.

During the last few years, several investigations in diffuse soil gas degassing of these geothermal fields have been carried out (Padrón et al., 2003, CEL, 1984, Balcázar et al., 1993a), as well as studies of the hydrothermal alteration mineralogy of the different manifestations found in the study area. The purpose of this paper is to present a comparison between the results of soil radon studies carried out in 1984, 1991, 2002 and 2003, and the possible relationship between the transport and discharge of radon at the surface and the hydrothermal manifestations in the area.

Diffuse degassing in geothermal fields can provide important information on the vertical path of gases released from the reservoir (Padrón et al., 2003). The flow of water and gas as well as the heat transfer and the transferring of dissolved species throughout its flow path in permeable zones are usually combined processes. Geochemical techniques are helpful to identify the faults that are transferring fluids and heat towards the surface.

Figure 1. Fumaroles, hydrothermal areas and geological features in Ahuachapán-Chipilapa Geothermal Field.
Methodology

Radon measurements in the 1984 study were done using Emanometer ETR-1 (Scintrex) equipment (CEL, 1984) and in the 1991 study using Emanometer ETR-1 (Scintrex) equipment (CEL, 1991). Points sampled in these two surveys are shown in Figure 2a and 2b. In the 2002 and 2003 study 172 points and 196 were sampled (Figure 2b), respectively (Magaña et al, 2002, Padrón et al., 2003). 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 (Figure 2). 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 300A attached to a vacuum pump. The ratio of thoron to radon concentrations was obtained using the number of disintegrations (emitted alpha 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). Figures 2a and 2b presents the Radon sampling points used in 1991 and 2002-2003.

For the mineral alteration minerals, samples were collected at the fumarolic sites and analyzed using X-ray diffraction methods in a Siemens D 5000 X-ray equipment.

Geology of the Area

The Ahuachapán-Chipilapa geothermal field is associated with the southern flank of the Central American Graben in El Salvador and located at the northwestern sector of the Cerro Laguna Verde volcanic group. A complex extrusive structure was formed during the Quaternary period near the tectonic block of Tacuba-Apaneca (Pliocene age).

The regional and local structures of the field are controlled by the system of faults and fractures oriented along three main directions: a) E-W, approximately along the trend of the main graben, b) W and c) NNW which controls the hydrothermal activity of the area (Figure 1).

The stratigraphy of the Ahuachapán area is composed of the San Salvador formation which is mainly comprised of tuffs and andesites of around 200 m in thickness, young agglomerates forming the caprock of the geothermal system, the andesites of Ahuachapán with a thickness of 300 m acting as the productive reservoir and the Balsamo formation as the basement.

Results and Discussion

Radon is a naturally occurring radioactive gaseous element continually produced from the decay of radium, which is present in the earth’s crust. The extent of radon emanation in geologic formations depends on several factors, which includes the spatial distribution of radium in the formation matrix, the surface area exposed to recoil of the radon atoms formed during alpha-particle decay of the radium atoms, and the geo-fluids present in the porous formation (Stoker and Kruger, 1973). The concentration of radon in fluids released

Figure 2a. Geological features and sampling points (1991) in Ahuachapán-Chipilapa Geothermal Field.

Figure 2b. Geological features and sampling points (2003) in Ahuachapán-Chipilapa Geothermal Field.

Figure 3. Radon anomalies in Ahuachapán-Chipilapa Geothermal area, 1983.
through natural fissures depends on the emanation rate of the source rocks as well as the fluid velocity.

The gas source of radon (222Rn) in volcanic systems includes magma, volcanic rocks, and hydrothermal fluids. All contain radium (226Ra), the isotope ancestor of 222Rn (radon). Anomalous concentrations of radon in volcanic regions occur when there is a rapid movement of hydrothermal fluids, transporting the gas advectively or convectively. For these reasons, high concentrations of soil radon are related to moving hydrothermal fluids that could have also the capability of altering the rocks.

Comparing the results of radon that were obtained in 1983, 1991, 2002 and 2003, it can be concluded that:

- The results of the studies (Figure 3) undertaken in November 1983 and January 1984 reflect two zones of possible ascent of fluid, one of them associated with the Chipilapa fault and the other one with the Cuyanausul fault. Also it is possible to observe two other anomalies related with Escalante fault and El Sauce fault.

- In 1991, anomalies were found in several areas (Figure 4), some of which coincide with the anomalies identified in 1984 and with geological structures identified in the region (Escalante and Agua Shuca faults). This suggests that the identified faults in the zone serve as preferential channels for fluid transfer.

- Figure 5 represents the anomaly map for 2002 and 2003, showing areas where the anomalous values of radon exist, all coinciding with the faults or fault interceptions present in the following areas: Oriental B and San José, Southeast of AH-3 well, Escalante and Agua Shuca faults. As the fluids ascend on the faults, they bring with it radon released from the rocks or from the more distant magma source. Note that the hydrothermal manifestations coincide with areas of high soil radon concentrations. The observed hydrothermal alteration zones in the area exist due to the fluid transported throughout the faults and discharged at the surface.

Fumaroles and Hydrothermal Areas

A summary of the characteristics of some of the fumaroles in Chipilapa area is presented in Table 1, overleaf.

High content of sulphur and the presence of sulphate minerals were observed in the fumaroles of the study area: La Labor, Tanque La Labor, La Laborcita and Chipilapa, all of them located to the northeast of Ahuachapán - Chipilapa Geothermal Field (Henríquez, et al, 2003). In addition, most of the hydrothermal alteration zones of Chipilapa Geothermal Field contain minerals associated with sulphur: alunite (sodium sulphate), sphalerite (zinc sulphide) and pyrite (iron sulphide). This alteration mineralogy could be produced by interactions between gases (CO₂, H₂S, CH₄, He) and the volcanic rocks as the fluids move to the surface. Oxidation processes may have taken place as the fluids approach the surface and generate the observed sulfate minerals.

The high sulfur in the alteration minerals may be related to sulfur-rich gases that separate from the reservoir, ascend through the fault systems, specially the Agua Shuca fault, interact with the surface fluids and produce a heat anomaly.
Ground temperatures between 40–90°C are observed in the area. Alteration zones and drying of crops occur in some areas due to the gas and heat anomalies. However, in La Laborcita hydrothermal area, clay minerals (montmorillonite and nontronite) were observed which correspond to neutral alteration, probably due to evolution and neutralization of the originally sulfur-rich fluids.

It is worth mentioning in areas where clay minerals predominate, gases are usually trapped and do not reach the surface. However, conductive heat transfer still occurs producing heat anomaly in the surface (temperatures between 40-90°C).

Conclusions

The radon gas anomalies at Ahuachapán-Chipilapa geothermal fields can be related to the structural setting (faulting) of the geothermal area, and the discharge of hydrothermal fluids. Different geophysical methods have also indicated that faults in the area are responsible for the fluid conduction and zones of hydrothermal alteration (e.g. electrical resistivity, TM, TDEM) (Balcázar et al., 1991).

The results from radon studies in different years reported in this paper, suggest that the anomalous areas are more or less located in the same regions and related to faults in the area. These results indicate that the Agua Shuca, Cuyanaunasul, Oriental B, San José, Escalante, and Chipilapa faults systems are actively transferring the deep fluids to the surface. It can also be noted that in some sectors of Chipilapa area, low levels of radon are observed as well as the absence of defined anomalies. These areas occur usually at the center of fault blocks where it is known that the permeability is low (LaGeo, 2004), or in areas where it is possible that shallower aquifers are diluting the deeper ascending fluids.

Spatial correlation between the location of high radon anomalies and zones of hydrothermal manifestation indicate the role of fluid flow and transport of radon and other geothermal gases. The presence of sulphate minerals in most fumaroles and hydrothermal areas in Chipilapa may be related to ascending movement of hydrothermal and possible magmatic gases throughout faults, especially through the Agua Shuca fault. These gases interact with shallower water and rocks producing heat anomaly (ground temperatures between 40–90°C), alteration zones, and drying of crops in some areas.

Radon studies coupled with hydrothermal mineral alteration studies seem to be effective in defining faults that transfer fluid in volcanic areas. Most of the anomalous zones observed coincide with the zones of tectonic weakness, active faults or intersections between them.

References


