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Radon and Soil Gas Surveys in Paka Geothermal Prospect, Kenya

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ABSTRACT

Radon and soil gas surveys involved measuring of carbon dioxide gas using an Orsat apparatus and radon gas using an Emanometer. The Paka geothermal prospect has sparse groundwater boreholes and almost non existent hot springs. Radon soil gas was conducted as part of the sampling programme in Paka. The radon soil gas were conducted to determine the greatest extend to which high radon counts could be determined. The lowest radon counts from the radon surveys were observed to the south, west, the northern and eastern parts of the Paka geothermal prospect. Most of these parts were covered by alluvial deposits. This restricts the paths for radon as it ascends to the surface and thus lowers the counts. In the central parts of Paka Volcano, high radon counts were encountered in the vicinity of the summit and areas of high fumarolic activity. This could be associated with possibly a highly fractured area and high heat flux. High carbon dioxide gas (CO_2) concentrations in the soil gas was observed close to central parts of Paka on the summit volcano. In an east-west trend on the western of the summit volcano, the amount of CO_2 in soil gas values increased. In a north-south trend along the summit volcano, the amount of CO_2 in soil gas values increased. In a north south pattern on the summit volcano, high CO_2 concentrations were observed. This could be associated with proximity to a magma source and deep seated faults.

1. INTRODUCTION

The Paka geothermal prospect is located within the Gregory Rift of the East African Rift valley that extends from the Afar triple junction in the Red Sea to Mozambique, Figure 1.

It is a well defined volcano situated 25km north of Lake Baringo and 15 km east of Nginyang. It rises 600-700 m above the rift floor to reach a maximum altitude of 1697m and in plan view has an irregular outline covering an area of ~ 280 km^2. Paka Volcano lies between Korosi and Silali Volcanic centres. Paka is a small shield volcano constructed largely of trachyte lavas and pyroclastic deposits. Basalt, hawaiite and mugearite lavas were erupted from a series of fissure and fault zones located on the north east and the southern flanks. Trachyte lavas were erupted from numerous domes and cones located along N-trending and NNE-trending fissures on the upper flanks and the summit area. Further faulting and fracturing across the shield led to the formation of an axial rift zone defined by two important faults, the Eastern and Western boundary faults.

Few surface manifestations occur in the Paka geothermal prospect making the use of classical geochemical exploration techniques difficult. Boreholes are sparse and few in this prospect.

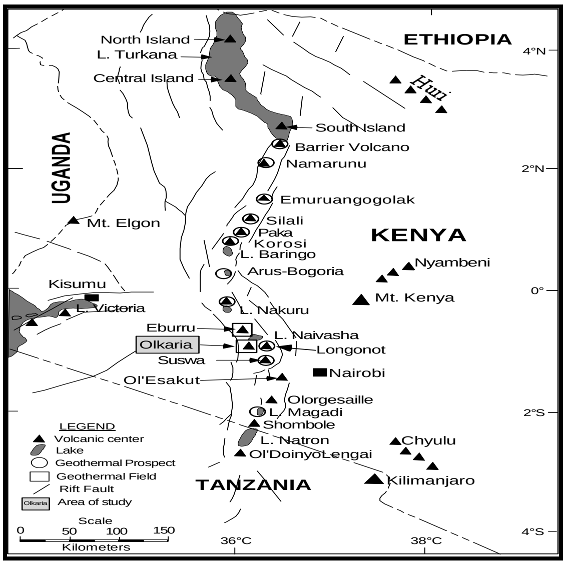

Figure 1: Map of the Kenya rift showing the location of Paka geothermal field and other quaternary volcanoes along the rift axis

However, geothermal activity manifested in the form of hot ground, steaming ground and fumaroles associated with hydrothermal alteration, is widely developed on Paka within the summit craters and upon the northern flanks.

Geothermal activity on Paka is dispersed over a broad NNE-trending zone covering an area of ~ 32 km^2 extending from high on the southern flanks northwards across the summit area and down the northern flanks.

Radon soil gas surveys has been used with variable success in geothermal exploration (Cox, 1980; Dyck, 1968; Nielson,1978; Whitehead et al., 1983 and Wollenberg, 1974). Geothermal fluids and hydrothermal mineralisation are possible sources of for anomalous radon emanations (Andrews, 1983; Belin, 1959; and Wollenberg, 1976). Regions of high permeability such as faults, provide avenues for rapid advective transport of radon before significant radioactive decay. One goal for geothermal exploration is to locate zones of high permeability and rapid upward movement of fluids, radon soil- gas surveys may provide useful information to site wells and other surveys.

1.2 Previous work

Previous work on the geochemical aspects of the geothermal prospects to the north of Lake Baringo up to Lake Turkana was conducted by the British Geological Survey (BGS) under the auspices of the Overseas Development Administration (ODA) of the British Government and the Ministry of Energy of the Government of Kenya in the year 1985 through 1990. The initial project was to undertake preliminary geothermal reconnaissance studies of the northern part of the Rift, between Lake Baringo and Emuruangogolak volcano, with particular emphasis on several volcanic centres (Allen and Darling, 1992). Paka geothermal prospect was included in this work. In their work they used the chemistry of thermal boreholes and surface waters from rivers and streams to describe the water composition in the Paka geothermal prospect. Their work also included the chemistry of condensates and gases composition from fumaroles and altered grounds. Radon and soil gas surveys were not included in their work.

1.3 Objective

The main objective of the study was to locate a potentially attractive heat source (geothermal reservoir), which could be economically exploited for geothermal power generation through interdisciplinary geoscientific disciplines (Geology, Geochemistry and Geophysics). Radon and soil gas surveys were used, especially since surface features such as hot springs and surface waters are absent in the greater part of the Paka prospect.

2. GEOLOGICAL SETTING

Paka is composed of different rock types that consist of trachytes , basalt lavas and pyroclastic deposits. These were erupted at two different periods through geological history and are broadly separated into trahytic volcanism and basaltic activity. Older shield-forming lavas are mantled by trachytic pyroclastic deposits which cover much of the northern, western and southern flanks of the volcano. The summit and flanks of Paka are characterised by short trachytic flows that can be discerned beneath the mantle of pyroclastic deposits. Basalt features were erupted from fissures and cones located along N-trending fractures on the northern and southern flanks, and normal faulting led to the formation of a N-trending linear zone of rifting which extends down the northern flanks. Paka is surrounded by a number of smaller satellite volcanic centres, which are linked to the main volcano by linear zones of basalt and trachyte cones and eruptive fissures. Paka volcano is dominated by a zone of intense normal faulting and fissuring located on the eastern and north-eastern flanks and to the southern part of the volcano.

3. METHODOLOGY

The geochemical surface exploration programme was involved sampling of boreholes and springs, fumaroles and steaming grounds, soil gas and radon surveys. The Paka geothermal prospect has very few boreholes drilled in the area. The boreholes were sampled simultaneously with steaming grounds and fumaroles. Fumaroles sampling for gas and condensates was done for those that could be accessed. Fumarole sampling, steam condensates and soil gas plus radon -222, were determined where possible for steaming and altered grounds. This was for the purposes of establishing anomalous temperatures and gaseous emissions. Soil gas and radon surveys around the Paka geothermal prospect were first conducted randomly to determine anomalous areas and also because of the nature of the terrain. Radon concentrations were obtained taking a soil gas sample from about 70 centimeters depth with a probe using a portable monitor Pylon Model AB-5 and a Lucas cell Model 110B attached to a vacuum pump.

3.1 Fumarole gas and radon-222 sampling.

Close to the fumarole on solid ground, a spike with an outer steel jacket was used to penetrate the ground to desired depth. The outer jacket was left inside the hoe to allow for the sampling after the spike was removed. A stopper attached to a flexible tube was fixed on to the mouth of the outer jacket and by using a hand operated vacuum pump, soil gas was driven into a radon emanometer (radon detector) by using the hand pump. Three radon counts read out from the LED display and recorded at three-minute intervals. After the radon-222 sampling the flexible tube was connected to the Orsat apparatus for the determination of CO2 in the soil gas.

3.2 Fumarole gas and radon-222 sampling.

Traverse lines running east-west were done to cover most of the prospect. Due to difficult terrain especially on the eastern and north eastern parts of the prospect, the traverses were conducted along foot paths for ease of access. The spacing between the lines varied from 1 to 5km while the distance between sampling stations was also very spread out, between 2 to 5 kms to cover most of the prospect. This was necessary to identify areas where radon emanations were highest and which could be associated with an anomaly. This was done in order to optimise the available time since this phase was undertaken within a very limited time coinstraint. The survey carried out involved measuring CO_2, Radon-222 & Radon – 220. A spike with an outer steel jacket was used to penetrate the ground to desired depth of ~ 0.7m. The outer jacket was left inside the hole to allow for the sampling after the spike was removed. A stopper attached to a flexible tube was fixed on to the mouth of the outer jacket and by using a hand operated sunction pump, soil gas was driven into the radon emanometer (radon detector) using the suction pump. Three radon counts were read out from the LED display and recorded at three-minute intervals. The soil gas sample containing radon was forced into the decay chamber of the emanometer consisting of a cylindrical copper can, whose walls are coated with zinc sulphide where the radon decays into other radionuclides by emitting alpha particles. The alpha emissions are detected by a photomultiplier attached to the detector and a rate meter displays the signals. Three background counts were recorded at three -minute intervals prior to introduction of the sample into the emanometer. After introducing the sample, three readings were taken at three minute intervals to give the total radon counts. Both the Rn-222 and Rn -220 (Thoron (Tn)) are detected by the emanometer but since they have different half-lives, it is possible to differentiate between the two. After the radon -222 sampling the flexible tube was connected to the Orsat apparatus, for the determination of % CO_2 in the soil gas. Using suitable pumps, the pathways were purged and the samples of soil gas transferred into the burette of an ORSAT analysis apparatus for the determination of carbon dioxide. A known volume of soil gas is pumped into the burette and subsequently transferred to the absorption vessels for the selective removal of CO_2 and O_2 which are determined by the changes shown in the gas burette.

4. RADON AND SOIL GAS SURVEYS

Radon has been used in the exploration for geothermal areas with little or no surface expressions and is adopted from mineral exploration techniques which have included the exploration for uranium. Uranium-238 is the parent source of Radon-222 and it is highly mobile and tends to concentrate in the late phases during crystallization. Radon has a very short half life and its mobility is not as great as that from its noble gas properties. Radon is a product of the radioactive decay chain of Uranium-238 and Thorium-232 respectively. The Uranium-238 produces a number of daughter products before decaying to the stable Pb-206 isotope. The decay chain may be divided into two sections separated by Ra-226 which has a half life of 1600 years. Rn has a half life of 3.82 days. The shorter-lived daughter products are produced by alpha decay (especially Po-218 with a half life of 3.05 mins) usually exist in the form of aerosols which may plate out on the walls of the counting chamber. Thorium (Tn) decay series is much shorter. The half-life of Tn is only 54.7 secs so that by repeating counts after some time interval e.g 3 minute intervals the presence of Tn may be identified easily. Problems may arise where both Rn and Tn occur and in this case corrections have to be applied. The immediate daughter product of Rn is Po-218 which has a half-life of 3.05 mins. For the first few minutes after a sample of Rn has been obtained the count rate increases as the Po-218 isotope breeds into equilibrium. Tn has a half-life of only 54.7 seconds. Its immediate daughter is Po-216 which has a half life of only 0.16 seconds. This means that the count rate contribution from Tn is amplified by equivalent counts from Po-216.

Where both Rn and Tn occur the relative proportions contributing to the alpha activity can be calculated. Caliberation with a pure Rn source enables corrections to be made for the contribution from Tn and Rn to the total alpha activity of the soil gas. A total count after one minute is recorded and then sequentially at minute intervals. If the count rates at minutes one to three are given as C1, C2 and C3 then cpm due to Rn can be calculated s 0.87*C3 + 0.32*C2 – 0.34*C1 (Clarke et al, 1990). The chain series of Uranium-238 decay, starting with the loss of an alpha particle (^4_2He) is shown below.

$^{238}U \rightarrow$ $^{234}U \rightarrow$ $^{230}Th \rightarrow$ ^{226}Ra $^{222}Rn \rightarrow$

$\rightarrow$ ^{218}Po $^{214}Pb \rightarrow$ $^{214}Bi \rightarrow$ ^{214}Po $\rightarrow$

$\rightarrow$ ^{210}Pb $^{206}Pb \rightarrow$

Radon is a naturally occurring radioactive noble gas, which decays radioactively by emitting alpha particles. There are two isotopes of radon, radon-222 derived from Uranium – 238 decay series and radon-220 (Thoron) from Thorium – 232 decay series. The two isotopes are easily distinguished by their different half-lives, which is 3.82 days for Rn –220 and 55 seconds for Rn 222 respectively. Radon-222 was chosen as an exploration tool mainly due to it's short half-life (55 seconds) and due to it's source which is mainly magmatic U-238. Since it is a noble gas and soluble in water, Radon-222, could be used to infer areas of high permeability and also areas of high heat flow. High values of the total radon counts at the surface would be taken to indicate a fracture or a fissure zone where both isotopes can migrate to the surface rather quickly. High temperature fluids carry the radon–222 through convection to the surface through fissures and cracked rock zones along faults which act as conduits for the fluids. Radon in the geothermal fluids is a function of porosity and fracture distribution in the geothermal reservoir (Stoker et al 1975). Where radon reaches the surface quickest, this could be an indication of areas with the highest permeability or upflow zones of the geothermal system.

^{222}Rn (t ½=3.8d), ^{220}Rn (t ½= 55 s) and ^{219} Rn (t ½ = 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 a short half life of (t ½= 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 fumaroles are used to identify convective flow areas and to monitor degassing changes trough time. These gases can show changes of the hydrothermal volcanic system due to magmatic activity and/or seismic movement e.g , Izu-Oshima Volcano (Notsu et al., 1991) and Mt Etna (Giammanco et al,1995)

Due to half life of radon, in areas where slow diffusive flow exists, the average depth 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.

Other factors that affect radon counts are distance traveled between the source and the detection point, temperature, and the mineralogy of the reservoir rocks. The short half-life and physical characteristics of the host rock limit the mobility of radon.

4.1 Radon radioactivity in soil gas

Radon surveys were carried out in this prospect to determine the greatest extent to which high radon counts could be obtained. Initially the traverses were random. Results obtained from the radon soil surveys are presented in figures 3a and b respectively. The counts due to radon (Rn) were corrected according to the descriptions given above to determine the effects from radon counts only.

The distribution of radon in soil gas and the sampling locations indicate some interesting patterns. The lowest radon counts were observed to the south west, the northern and eastern parts of the Paka prospect (Figure 3 a). In these parts the areas are mostly covered with alluvial deposits. It is probable this restricts the paths for radon as it ascends to the surface and thus lowers the counts. Radon counts increase towards the central parts of the prospect, in the vicinity of the summit volcano where the highest counts were observed. In areas where high radon counts were observed this was close in some parts to where there is high fumarolic activity. The high radon counts close to the central parts of the Paka volcano are associated with a possible highly fractured area and a high heat flux. Radon is easily transported in steam. From the summit of the Paka volcano, to the NE the radon counts decrease progressively. This is along a NE-SW trending. This could suggest structurally controlled trends and the existence of a buried structure. To the east a zone of low radon counts was observed.

Figure 3 b depicts radon patterns when the highest values are removed. The trends change since the areas with high values appear to be localised to the northeast and southeast of the summit volcano. To the northwest there exists a localised spot where the counts are greater than 1500. The spots with high radon counts trend in a north-south pattern. This could suggest the existence of a lineament.

4.2 Carbon dioxide distribution in the soil gas

In an area like Paka geothermal prospect with few surface features, carbon dioxide in the soil gas could be a very useful tool in the search for buried sources of heat and the determination of structures. This could confirm the presence of a potential source of an area where geothermal activity could be concentrated when other evidence lacks (e.g hot springs, fumaroles and altered grounds). Other sources of CO_2 if not magmatic could easily be from biological decay of organic material. This could also determine the concentration of the soil gas in the samples. Figure 4 a and b shows the carbon dioxide distribution in soil gas in the Paka geothermal prospect.

The traverse for CO_2 and Radon were done along footpaths in most cases because of the nature of the terrain. Very steep vertical down faulted scarps are prominent in this prospect, especially on the Eastern part that make it difficult to carry out these surveys by crossing the features targeted. It is evident from the plots made in Figure 4 a and b, high CO_2 concentrations in the soil gas was observed close to the central parts of Paka on the summit of the volcano. Close to the summit crater CO_2 values close to ~ 4.4 % were measured. This value was determined where there was some fumarolic activity. Such high values could be associated with a link to a high temperature magmatic source. Some interesting trends were observed with the soil gas values. In a West- East trend on the western part of the summit volcano, the amount of CO_2 in soil gas increases. This could be associated with an increase in magmatic activity as the summit of Paka volcano is approached. On the eastern part of the prospect in areas associated with the top of the fault scarps, the concentration of CO_2 is low, close to those of normal levels. This could be caused by some thick alluvial deposits on these scarps which seal openings where CO_2 could issue from to the surface. This could interfere with the movement of CO_2 to the surface. The high CO_2 concentration could also appear to be trending in a N-S pattern along the summit volcano, suggesting the presence of high CO_2 concentration close to the summit. It is probable the high CO_2 concentrations close to the summit are associated with deep seated faults or fractures. Localized spots of relatively high CO_2 concentration exist to the southeast and the northwest of the summit crater.

4.3 Radon-222/CO_2 ratios in soil gas

The determination of the absolute values of CO_2 and radon (Rn) are often not significant. Correction for atmospheric dilution has to be considered. This has been allowed for assuming the CO_2 present represents the geothermal gas, by considering the ratios of Rn to CO_2 rather than their absolute amounts as determined in the field.

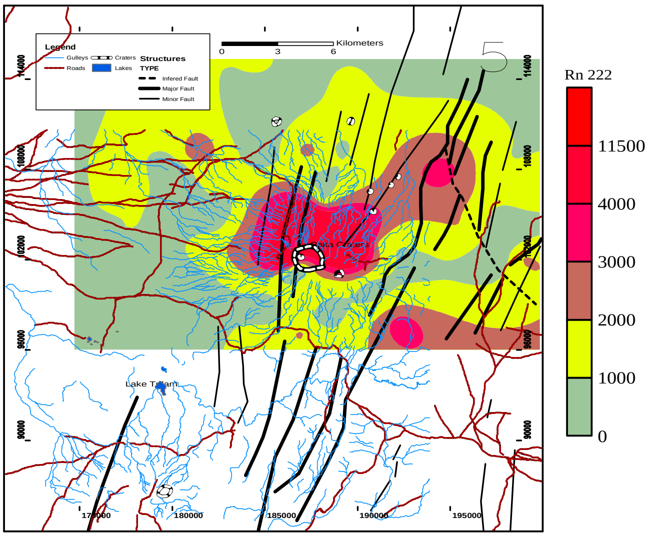

Figure 3 a: Radon -222 in soil gas in Paka geothermal prospect

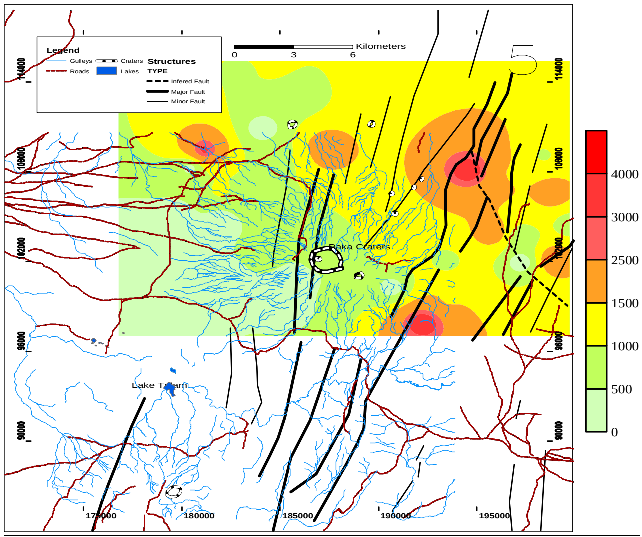

Figure 3 b: Radon-222 in soil gas in Paka geothermlal prospect (excluding the highest values)

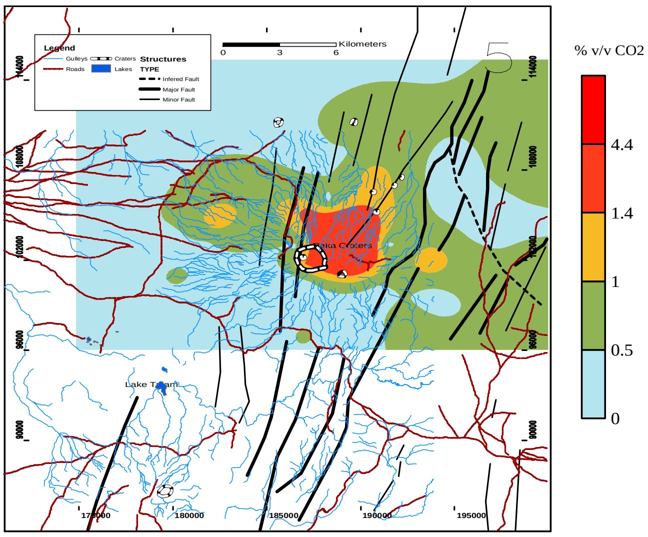

Figure 4a: Carbon dioxide in soil gas in Paka geothermal prospect.

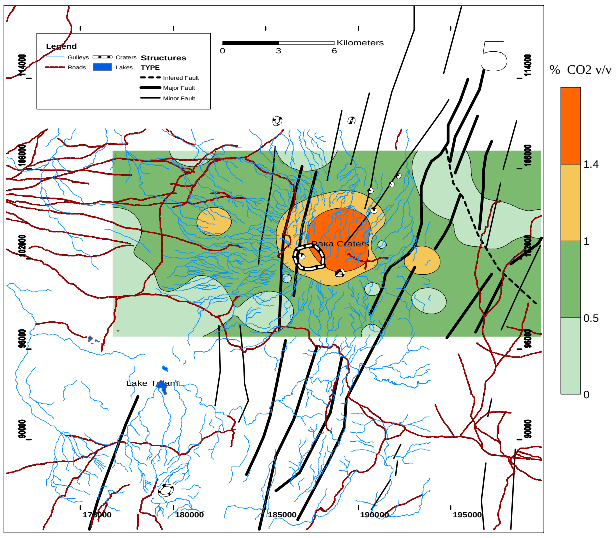

Figure 4a: Carbon dioxide in soil gas in Paka geothermal prospect (excluding the highest values).

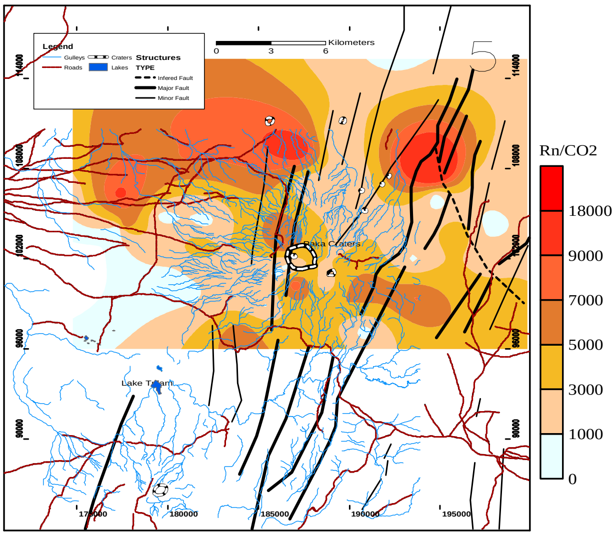

Figure 5a: Radon-222/CO_2 ratio in soil gas in Paka geothermal prospect.

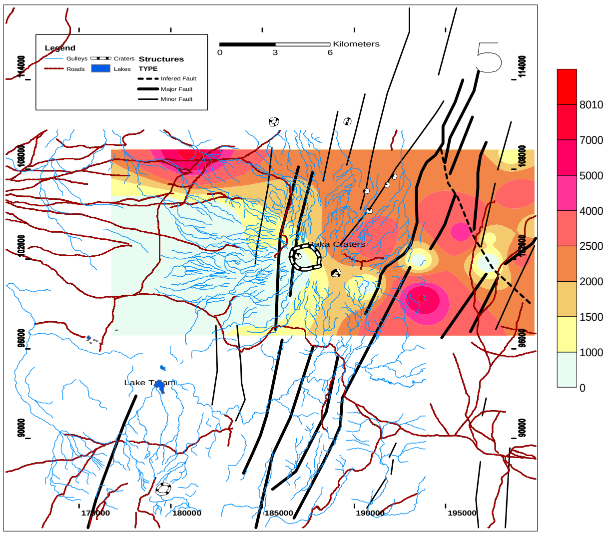

Figure 5b: Radon-222/CO_2 ratio in soil gas in Paka geothermal prospect (excludes the highest values)

Interferences due to different sources of radon-222 and carbon dioxide can be reduced or eliminated by evaluating the Radon-222/CO_2 ratio in the soil gas. High radon counts and high CO_2 in soil gas, would often suggest the existence of a direct pathway from magmatic heat sources. Radon is transported in steam as well as CO_2 if they are not coming form other sources. As they ascend to the surface, they become diluted as they travel through permeable zones. The Radon-222/CO_2 ratio distribution in the soil gas is presented in Figure 5 a and b.

Sectors of the prospect that had high absolute counts for radon-222 had much higher ratios of Rn-222/CO_2. In areas associated with fumarolic activity the Rn/CO_2 ratios are very high. The increase in the ratio of Rn/CO_2 trends almost in a NE-SW pattern with a peak after the summit of Paka volcano. The high Rn-222/CO_2 ratios are almost in samples collected in the summit crater. This is indicative of the possibility of a more direct route from the heat source to the surface. It could also be associated with enhanced permeability due to fractured zones. The sampling stations were sparse for establishing a better interpretation of the Rn-222/CO_2 trends.

CONCLUSIONS

- High CO_2 concentrations in the soil gas was observed close to the central parts of Paka on the
- summit of the volcano. This occurred in areas of high fumarolic activity .
- The CO_2 in soil gas increases in a West –East trend on the western part of the summit volcano.
- A thick layer of alluvial deposits exist which mask actual CO_2 concentration in eastern part of Paka on the fault scarps
- High CO_2 concentrations also trend in a N-S pattern along the summit volcano which could be associated with deep seated faults
- The lowest radon counts were observed to the southwest, the northern and eastern parts of the Paka prospect which are mostly covered with alluvial deposits.
- Radon counts increase towards the central parts of the prospect, in the vicinity of the summit volcano where the highest counts are close to fumarolic activity.
- The high radon counts could be closely associated with highly fractured area and a high heat flux
- On the summit of the Paka volcano, to the NE the radon counts decrease progressively along a NE-SW trending. This could suggest structurally controlled trends and the existence of a buried structure.

REFERENCES

Allen, D.J., and Darling, W.G., 1992; Geothermics and Hydrogeology of the Kenya Rift Valley between Lake Baringo and Lake Turkana. *British Geological Survey Research Report SD/92/1*

Andrews, J.N., 1983; Dissolved radiaoelements and inert gases in geothermal investigations. *Geothermics, 12,67-83*

Belin, R.E., 1959; Radon in New Zealand Geothermal Regions. *Geochemica et Cosmochimica Acta,16, 181-191.*

Clarke, M.C.G., Woodhall, D.G., Allen, D., and Darling, G.,1990: Geological, Volcanological and Hydrogeological controls on the occurrence of geothermal activity in the area surrounding Lake Naivasha, Kenya. *British Geological Survey(BGS) Research Report No SD/90/1 p292*

Cox, M.E., 1980; Ground Radon Survey of a Geothermal area in Hawaii: *Geophysical Research Letters, 7, 283-286.*

Connor, C., Hill, B., La Feniwa, P., Navaro, M., and Conway, C., 1996; Soil ^{222}Rn pulse the during the initial phase of the June-August 1995 eruption of Cerro Negro, Nicaragua. *Journal of Volcanology and Geothermal Research,73, 119-227*

Dyck, W; 1968, Radon-222 emanations from a Uranium deposit; *Economic Geology,63, No.3*

Gaimmanco,S., Gurrieri, S., Valenza, M., 1995; Soil CO2 degassing on Mt.Etna (Sicily) during the period 1989-

1993; Discrimination between Climatic and Volcanic Influences. *Bull. Volcanology. 57, 52-60*

Mania, J., Chauve, P., Klein, D., and Chambaudet, A., 1995; The radon anomalies into the Karstic System of the Haut-Doubs-County (Franche-Conte,France). *In: Gas Geochemistry, Editor Calude Dubois, Science Reviews, Northwood, 305-315*

Nielson, D.L; 1978; Radon emanometry as a geothermal exploration technique. Theory and an example from Roosevelt Hot Springs KGRA, Utah. *University of Utah, Research Institute Report ESL-14, 31 p*

Notsu, K., Wakinta, H., Igarash, G., 1991; Precusroy change in fumarolic gas temperatures associated with recent submarine eruption near Izu-Oshina Volcano, Japan. *Geophysics Research Letters, 18, 191-193*

Whitehead, N.E., Gingrich, J.E., and Fischer, J.L., 1983; A New Zealand test of the Track-Etch Method of Prospecting for Geothermal Steam: *Journal of Volcanology and Geothermal Research,15,339-354*

Wollenberg, H.A., 1974; Radon alpha-track survey of a potential geothermal resource area*; Lawrence Berkley Laboratory Report, LBL- 3225 P14*

Wollenberg, H.A., 1976: Radioactivity of Geothermal Systems; *In Proceedings Second United Nations Symposium on the Development of and Use of Geothermal Resources, San Francisco CA: U.S. Govenrment Printing Office, 2, 1283-1292*