STRUCTURAL CONTROLS ON THERMAL ANOMALIES AND DIFFUSE SOIL DEGASSING AT MENENGAI GEOTHERMAL PROSPECT, THE KENYAN RIFT VALLEY

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ABSTRACT

Regional exploration for geothermal resources in Kenya indicates that the Quaternary volcanic complexes of the Kenya rift valley provide the most promising prospects for geothermal exploration. A number of geoscientific studies have been conducted to assess the geothermal potential of this area. This paper reports the results of a survey of CO_2 soil fluxes and concentrations of thoron (Rn_{220}) in soil gases. Soil CO_2 concentrations measurements were performed using an Orsat apparatus whereas Rn_{220} soil gas concentrations were measured with a portable radon detector (emanometer). A total of 275 sampling points were measured. The obtained values ranged between zero to 12% of CO_2 in total gas and zero to 6425cpm of Rn_{220}.

Peak levels of soil CO_2 concentrations and thoron concentrations were identified to be located on major faults and within the caldera floor where hydrothermal fluids are rising and the rocks are highly fractured allowing the release of CO_2 and thoron locally marked by fumaroles. Areas identified with the highest anomalies for CO_2 and thoron soil gas concentrations can be seen in the contour maps presented. The caldera, Molo TVA and also Solai graben are the important geological structures associated with these anomalies.

Keywords: geothermal resource, thoron concentrations, CO2 concentrations, TVA and faults

INTRODUCTION

The Menengai Geothermal Prospect is located in the central section of Kenyan Rift Valley, the area north of L. Nakuru and south of Lake Bogoria. The extend of the prospect covers an area of approximately 600 km^2 characterized by a complex geological setting with Menengai caldera being notably the major geological feature in the area and is also important for its geothermal potential. Most part of this area, in particular the southern section is discussed in this study.

The general exploration for geothermal resources in Kenya indicates that the Quaternary volcanic complexes of the Kenya rift valley provide the most promising prospects for geothermal exploration, and as a result, intensive exploration work has focussed on areas with volcanic centres located within the rift valley. Studies show that these volcanic centres have positive indications of geothermal resource that can be commercially exploited. Menengai geothermal area is one of the priority prospects in the current prospects ranking. Eleven locations with fumaroles have been identified in the region (Figure 1).

A number of thermal anomalies and diffuse degassing assessments have been carried out in most of geothermal prospect areas in Kenya, including Menengai. Results for CO_2 and Rn_{-220} soil diffuse concentrations have been found to discharge more in areas that coincide with faults. The purpose of this study is to establish the soil gas concentration of CO_2 and Rn_{220} and relate with known geological structures.

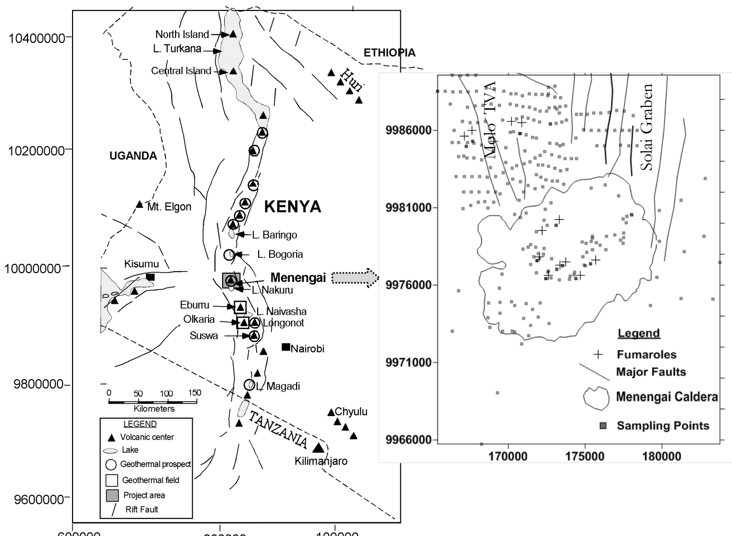

Figure 1. Location of Menengai Geothermal Prospect showing fumaroles, major faults and sampling points.

GEOLOGICAL AND STRUCTURAL PATTERN

The Kenyan Rift is characterized by extension tectonism where the E-W tensional forces resulted in block faulting (KenGen 2004). This included leant blocks as evident in both the floor and scarps of the rift. The rift trough is truncated by several normal faults, which evidently represent persistent and wide-ranging tectonism under the rift floor. Menengai Geothermal Prospect itself is located within an area characterized by a complex tectonic activity associated with the rift triple junction; the latter being a zone at which the failed rift arm of the Nyanza rift joins the main Kenya rift. Two rift floor tectono-volcanic axes (TVA) that are important in controlling the geothermal system in study area include the Molo and the Solai TVA.

Menengai has been active from about 0.4 -0.3 Ma B.P (Gislason 1989). The formation of the shield volcano began about 200,000 years ago and was followed by the eruption of two voluminous ash-flow tuffs, each preceded by major pumice falls. More than 70 post-caldera lava flows cover the caldera floor, the youngest of which may be only a few hundred years old. The caldera of Menengai volcano lies immediately north of Lake Nakuru, but ignimbrites and air-fall tuffs from the volcano cover some 1350km^2 (Leat & Macdonald 1984) extending into Molo area (Jennings 1971). The volcano is mainly composed of strongly peralkaline, Si-oversaturated trachytes and has had a complex geochemical evolution, resulting from the interplay of magma mixing, crystal fractionation and liquid state differentiation (Leat & Macdonald 1984).

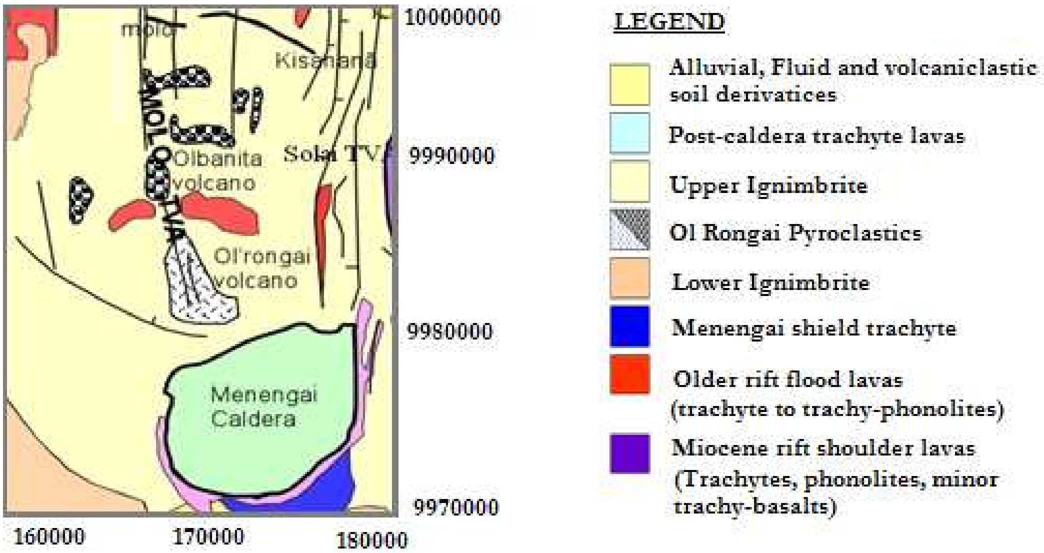

Figure 2. Geological map of Menengai Geothermal Prospect Area (after KenGen 2004)

METHODOLOGY

Early geochemical studies on diffuse soil degassing have been carried out in a number of geothermal areas. CO_2 soil gas investigations similar to the one used in this study have been conducted elsewhere in volcanic areas to examine unexpected rise in CO_2 flux (e.g. Farrar *et al.* 1995; McGee and Gerlach 1998; Gerlach *et al.* 1998), estimate total volcanic flux from volcanic vents and diffuse flank emissions (e.g. Allard *et al.* 1991; Chiodini *et al.* 1996), and to classify tectonic structures related to volcanic degassing (e.g. Giammanco *et al.* 1997; Bergfeld 1998).

The study area together with a total of 275 sampling points is presented in Figure 1. Sampling spacing relied mainly on accessibility of specific targeted points and the ease of getting samples, in particular on the rugged areas. Nonetheless, a random separation of about 300m in average was used. Areas covered by younger lava flow were almost impossible to sample and few samples thus represents such areas, as was seen with lava pond within the caldera. The survey involved measuring of CO_2 and Rn_{-220} in the soil gas. All the measurements were done at the same point. In addition, soil temperatures were taken using an infra-red thermometer at the point where the soil gas survey was undertaken.

Measurement of CO_2 gas was done by the help of an Orsat apparatus after the soil gas was hand pumped from a depth of 1m below the surface via a hole made using a steel spike with jacket. The Orsat apparatus consist of absorption vessels, which measure about 100 mls and contain a 40% KOH solution for absorbing the acidic CO_2. The corresponding volume changes in the absorption vessel represent the corresponding amounts of the gases in volumes given as percent of the total gas as a percentage.

Radon radioactivity levels were measured in the soil gas using a portable radon detector (emanometer). The soil gas was passed into the emanometer by using a hand-operated vacuum pump and Rn-$_{220}$ readings recorded in counts per minute (cpm). Three background counts were recorded at three-minute interval prior to introduction of sample into the emanometer. Upon introducing the sample, three more readings were taken at one-minute interval to give the total radon counts.

The CO_2 and Rn_{220} obtained in the survey (both 2004 and 2010 sampling programs) were corrected and used to construct concentrations contour maps (Figures 3 to 6). Natural neighbor contouring method was used because it interpolates scattered and irregularly spaced data effectively and hence produces better contours maps from irregularly spaced measurements (Ledoux & Gold 2005).

RESULTS AND DISCUSSIONS

The results of descriptive statistics of CO_2, Rn_{220} and Temperature collected are presented in Table 1. The frequency distributions are described by normal distribution. The range of values for these parameters spans several orders of magnitude.

Table 1: Descriptive statistics of CO_2, Thoron and Temperature from 275 sampling points.

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	*Statistic*	*Statistic*	*Statistic*	*Statistic*	*Statistic*	*Statistic*	*Statistic*	*Error*	*Statistic*	*Error*
Rn220	275	6427	0	6427	386	603	363391	5.14	0.15	39.49	0.29
CO2	275	12.30	0.00	12.30	1.12	1.54	2.37	5.12	0.15	30.81	0.29
Temp	275	55.90	21.20	77.10	28.70	6.99	211.52	0.05	0.15	0.62	0.29

Soil Temperature Measurements

The mapping of temperature variations at or below the earth's surface is an essential geothermal exploration instrument. The spatial variation of soil temperature is illustrated in Figure 3. Quite a number of anomalies can be identified in relation to the major structural setting. And as indicted by results, a higher temperature anomaly in the caldera is evident around the fumaroles with the highest fumaroles temperature of 88^{o}C. Similar to other soil surveys, soil temperature results in the caldera is mainly affected by the lava that covers the caldera floor and apart from the areas where the lava did not cover. The areas to the North outside the caldera gave an anomaly confirming the geothermal potential of the area coinciding with two major faults trending NW-SW.

Diffuse Degassing Measurements

The term volcanic gas defines a gas exsolved from a magmatic source of an active volcano whereas 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 magmatic and hydrothermal gases and is the most abundant gas after water vapor. The deep-seated faults in the crust tap magmatic CO_2, which is transmitted to the surface where it is naturally lost through the soil. Carbon dioxide (CO_2) of magmatic origin is normally channeled through deep-seated tectonic structures close to the surface of the earth and then seeps out of the ground through the soil. However, dealing with CO_2 anomalies especially in the Rift Valley ought to be treated with caution owing to the availability of localized sources of this gas as suggested by Darling *et al.* (1995). CO_2 may also originate from other sources like organic matter, which are likely to give false impressions of a geothermal source.

Thoron gas (Rn_{220}) is a short lived isotope of radon produced by the thorium (Th_{232}) decay series with a half-life of 55 seconds (Lopez *et al.* 2004). Due to its short half-life, thoron's transportation is limited to a few centimeters either by diffusive or convective flows, as compared to Rn_{222} ($t\ ½ = 3.8$ days) (Hutter 1993). As a result, the high concentrations of thoron are more likely to be due to convective movement of gases rather than diffusive processes and therefore 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 (Magana *et al.* 2002). High thoron values could be suggestive of enhanced permeability, as it may as well depend on other factors such as the degree of rock fracture and the ability of groundwater to circulate and remove thoron.

The CO_2 gas concentrations are plotted in Figure 4 while the results of radon emanations were recorded in counts per minute (cpm) for Rn_{-220} and plotted in Figure 5. To reduce interferences between CO_2 and Radon sources a ratio of Rn_{-220}/CO_2 have been plotted in Figure 6.

CO_2 Concentrations

The concentration of CO_2 in the soil gas in the surveyed area is given as a percentage of the total gas in the soil. The degassing of CO_2 through the soil in the prospect area is considered to be mainly supplied by two sources, the one of volcanic origin emanating from deep environment and a shallow one that result from organic activity. In this study, high CO_2 values (>2.5%) are found at a belt running in a NW-SE while other areas exhibit low values (<1 %). These areas coincide with the Molo Tectono-Volcanic Axis (Molo TVA), deep seated faults and the eruption centers in the prospect area which indicate that the source could be from a magmatic body. Highest CO_2 concentration in the soil gas was observed around Ol'Rongai Hill (located along Molo TVA) and the contiguous fumaroles with CO_2 >10% which could be indicative of good permeability in the area.

The central part of the caldera around the fumaroles, as well, displays relatively high values of CO_2 (>2.8%). There are also few highs of CO_2>5 % in the western part of the caldera. The presence of thick young lava that covers most parts of the caldera interfere with the movement of CO_2 to the surface and therefore makes sampling in these parts extremely difficult, and is also noticeable in the contouring of the CO_2 distribution as shown in Figure 4. Care ought to be taken while correlating thermal and diffuse degassing anomaly with subsurface permeability. This is because the cap of young lava that covers most part of the caldera might be directing the anomaly laterally beneath the lava bed and hence giving misleading impression as a result.

Thoron Concentrations

From the results of the absolute values of Rn_{-220}, north-western parts of the surveyed area show the highest concentrations (Figure 5). In addition, a more pronounced anomaly is evident in central part of the caldera in the areas adjoining fumaroles following similar pattern to the one revealed by CO_2 distributions. However, a mild rise in thoron values is seen in the eastern flank touching Solai Graben.

Thoron-CO_2 Ratios

The ratio of the Rn_{220}/CO_2 gases would be a good indicator of the magmatic source of the gases since the ratio is not expected to change if they are from the same source (see Figure 6). High values of these ratios are found towards the north, north-western to the north eastern parts outside of the caldera wall with two anomalous areas at the fumaroles in Ol'Rongai area. A mantle source of CO_2 as suggested by Darling et al. (1995) is a possibility of the source of this gas due to intense faulting in the area, and these faults around Ol'Rongai are of great importance in localizing degassing of CO_2 and Rn_{-220} as well thermal manifestation anomalies. If a mantle source is inferred due to intense faulting, then the faults should be deep seated. These areas apparently coincide with high CO_2 and high Rn-220 absolute values.

The western part of the surveyed area, which shows high absolute values of $CO_{2,}$ gives low value of this ratio. This is an indication of a source other than the one of magmatic origin. This coincides with an agriculture farm and consequently the CO_2 anomaly in this area is considered to emanate from organic source, as a result. Nonetheless, a higher ratio of these gases is seen within and to the east of the caldera.

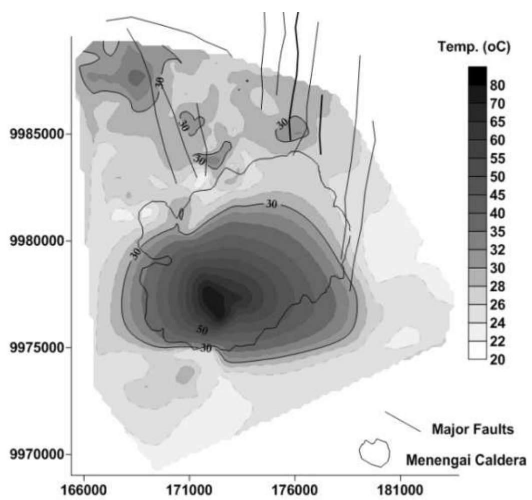

Figure 3: Temperature distribution in °C

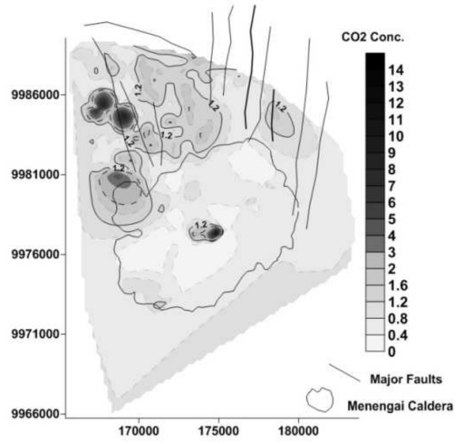

Figure 4: CO2 conc. distributions

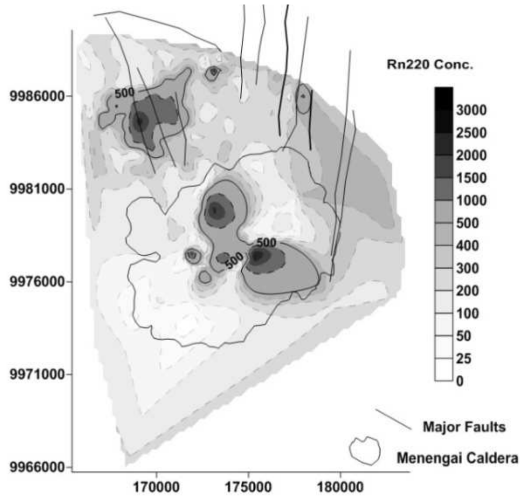

Figure 5: Rn220 conc. distributions

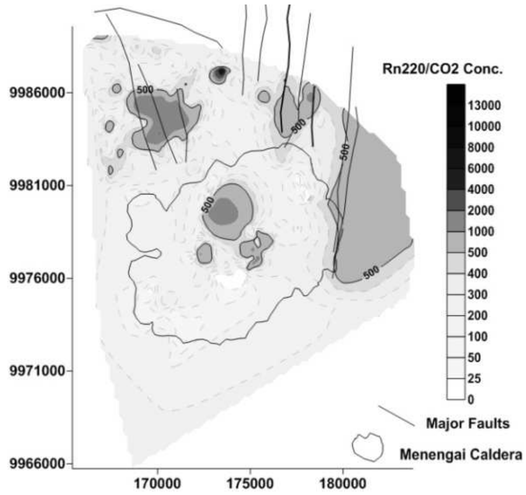

Figure 6: Rn220/CO2 conc. distributions

CONCLUSIONS

Despite the erratic distribution of sampling points, the results from acquired data can be used to make some conclusions relative to the objective. The fumaroles show close relations with geologic structures, which provides means of access for hydrothermal fluids to reach the surface. In the same way, most of the gas anomalies are located in fault zones. CO_2 and Rn_{220} emanations from the presently quiescent faults in Menengai were measured to be higher than background values.

The two fault-lines at Ol'Rongai are considered in this study to be of great importance in geothermal exploration and any future development as it reflects intensity of subsurface permeability in the area, and enhances the confidence to invest. The caldera itself as a geological structure displays a positive evidence of the existence of geothermal resource, with its thermal anomalies that coincides with CO_2 and thoron anomalies. Nonetheless, the picture portrayed by the contours within the caldera is hereby treated with caution as the pond of new lava spread across most part of the floor greatly influenced sampling spaces, and possibility of lateral flow of thermal fluids and diffuse gases at the upper zones restricted by the lava cap cannot be negated.

Generally, CO_2 concentrations are structurally controlled but may have been modified by changes in land use. As seen from the findings, the study of soil CO_2 and Rn_{220} composition as proved to be important geochemical method to identify vertical zones of high permeability. The employment of these methods in other geothermal fields could give important and relatively cheap information for field utilization and development.

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