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GEOCHEMICAL SAMPLING METHODS APPLIED TO KENYAN GEOTHERMAL PROSPECTS DURING EXPLORATION

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ABSTRACT

Geochemical surface exploration surveys are part of an interdisciplinary approach to the exploration of geothermal resources. In Kenya geochemical field campaigns for the exploration of geothermal resources are done in several phases that involve different techniques. The different phases include hot and cold springs and borehole sampling, condensate and gas in steam sampling and analysis and soil gas surveys. The soil gas surveys include radon-222 and radon-220 emanations, carbon dioxide and mercury in soil gas. Soil gas surveys are done using various analysers e.g. the Radon analyzer (RAD7) detector for radon-222 and radon-220 determination, mercury analyzer (Jerome, model 431-X) for mercury determination and the Orsat apparatus for carbon dioxide determination in soil gas. Ground temperatures are determined by the aid of infrared thermometers or a thermocouple with a temperature probe. Analyses of samples for condensates, hot and cold springs and boreholes are partly done on site and partly in the laboratory.

1. INTRODUCTION

Geochemical surface exploration surveys conducted in the Kenyan Geothermal Prospects involve the determination of radon, carbon dioxide and mercury in soil gas surveys. In these surveys sampling stations are targeted to map faults in the study areas. Most of the geothermal prospects in Kenya are found in the Kenya Rift, in areas where there is a paucity of surface waters and hot springs (Figure 1).

The methods applied during the exploration of geothermal prospects in Kenya involve several phases i.e. sampling of hot and cold springs, ground water boreholes (surface water) where these are found, sampling of fumaroles and hot grounds for both condensate and gas in steam and the determination of radon, carbon dioxide and mercury in the soil gas. The later technique of the determination of radon, carbon dioxide and mercury are more extensively applied since most prospects are in water deficit areas. Active geothermal features in most of the prospects manifest as hot grounds, fumaroles and on some occasions hot springs as those observed in the Bogoria, Lake Baringo and Silali prospects. The hot springs may deposit minerals e.g. carbonates or silica sinter. Observation carbonate deposition is made of hot spring waters from Lake Bogoria. In rare cases elemental sulfur deposition is observed on the surface (e.g. some parts of Paka).

Traverse lines of the soil gas surveys (radon, carbon dioxide, and mercury) are deployed in away that they target structures in most of the prospects. In some instances due to difficult terrain in some prospects, traverses are conducted along areas where access exists. The distance between sampling stations is often spread at ~ 0.5 km, but this could vary depending on the ease of access, size, challenges in terrain and the duration of the survey. The soil gas surveys aid in delineating permeable structures and lineaments and patterns in fluid flow. Soil gas surveys involve measuring carbon dioxide (CO_2) in soil gas using an Orsat apparatus (CO_2 flux meter being adapted), Radon (Rn) using a Durridge RAD7 solid state alpha particle detector (or any radon detector) and Mercury (Hg) using a Jerome Mercury (Hg) detector. Ground temperatures are determined using infrared thermometers or a thermocouple with a probe.

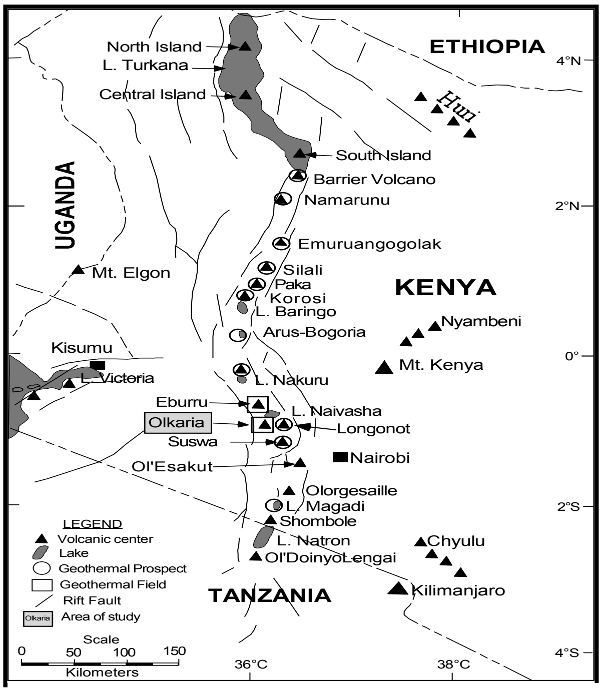

FIGURE 1: Map of the Kenya rift showing the geothermal prospects and other Quaternary volcanoes along the rift axis

1.1 Radon determinations using RAD7 radon monitor

A spike with an outer steel jacket is used to penetrate the ground to a desired depth of ~ 0.7 m. The outer jacket is left inside the hole to allow for sampling after the spike is removed. A stopper attached to a flexible tube is fixed on to the mouth of the outer jacket which is connected to a tube with a small drying unit attached to a filter connected to the RAD7 radon monitor. This uses an automatic pump which drives the soil gas sample into the RAD7 detector (radon detector). Three radon counts are read out from the LCD display and recorded at three-minute intervals. The alpha emissions are detected by a photomultiplier attached to the detector and a rate meter displays the signals (RAD7 User Manual, 2009). The setup for radon determination is shown in Figure 2.

FIGURE 2: RAD7 set up for determination of radon in soil gas

Three background counts were recorded at three -minute intervals prior to introduction of the soil gas sample into the RAD7 radon monitor. After introducing the sample, three readings were taken at three minute intervals to give the total radon counts. After moving to a new location the instrument is purged to remove the radon and thoron count rate that normally build up on the RAD7's solid state alpha detector and for count rate and reach equilibrium. The lingering daughter's can greatly confuse the result when you try to measure a low radon sample immediately after a high radon count. Both the radon-222 and radon-220 (Thoron, Th) are detected by the RAD7 radon monitor but since they have different half-lives, the two can be differentiated (RAD7 User Manual, 2009).

1.2 Carbon dioxide (CO_2) sampling using Orsat Apparatus

After the radon sampling the flexible tube is connected to the Orsat apparatus, for the determination of carbon dioxide (% CO_2) in the soil gas. Using suitable pumps, the pathways are purged and the samples of soil gas transferred into the burette of an Orsat analysis apparatus for the determination of carbon dioxide. A stopper and hose pipe are fixed onto the mouth of the jacket and using a hand operated pump, the soil air is driven into the analytical apparatus. A known volume of soil gas is pumped into the burette and subsequently transferred to the absorption vessels which measure about 100 mls. The vessel contains 40% potassium hydroxide (KOH) solution for the selective removal of CO_2 which is determined by the changes in volume in the gas burette, which correspond to changes in volumes given as % total gas. The set up for CO_2 determination using the Orsat apparatus is shown in Figure 3.

FIGURE 3: Set up of the Orsat apparatus for carbon dioxide determination

1.3 Mercury determinations with the Mercury Vapour Analyser

The concentration of mercury in the vapour in soil gas can be determined by connecting the flexi tubing to a Jerome (Model 431-X) Mercury vapour analyser which uses a gold film sensor. It uses a pump which pumps the air through a scrubber and into the flow system. The sensor absorbs the Mercury vapour. The instrument determines the amount absorbed and displays the measured concentration on the digital meter in milligrams per cubic meter (mg/m^3) of mercury (Jerome 431-X manual, 2000). Figure 4 shows the Mercury vapour analyser as set up in the field.

FIGURE 4: Set up for Mercury vapour analyser

2. GROUND TEMPERATURE DERTERMINATION

Ground temperature distribution in an area is controlled by various factors in the proximity of the heat source to the surface which could be a magma chamber, granitic rock or an intrusive body, depth at which the readings are taken and the kind of formation encountered, consolidated or loosely held and the weather conditions prevailing at the time of measurement. Measured ground temperature determinations are often carried out at a depth of about 0.7 meters. An infrared thermometer or a thermocouple with a probe is often used. Ground temperatures may delineate areas of localized heat sources but could serve as a guide of possible anomalous temperatures in a thermal area especially where ambient conditions are close to room temperatures. The technique can be applied cautiously especially in areas with very hot temperatures e.g. desert environments. Figure 5 shows a thermal infrared thermometer that is used in this technique.

FIGURE 5: An infrared thermometer used for the determination of ground temperatures

3. SPRING, BOREHOLE AND FUMAROLE SAMPLING

Borehole sampling would involve flowing boreholes fitted with manual pumps. The pumps are driven manually and samples collected at the surface. Exceptions are boreholes that are fitted with solar electric pumps. On occasions water has to be drawn manually from hand dug water wells. Where hand dug water wells are encountered sampling of the water is done lowering a clean sampling jug and drawing the water. For boreholes use of a clean jug is used to scoop the water. The jug has to be severally rinsed with de-ionised water before sampling is done. The sample was drawn while the wells flowed and divided into several portions after filtration. Spring sampling has to done for both cold and hot springs in the prospects. In prospects where hot and cold springs are found the method adopted from (Arnorsson, 2006) are adopted. Sampling from hot springs in shown in Figure 6.

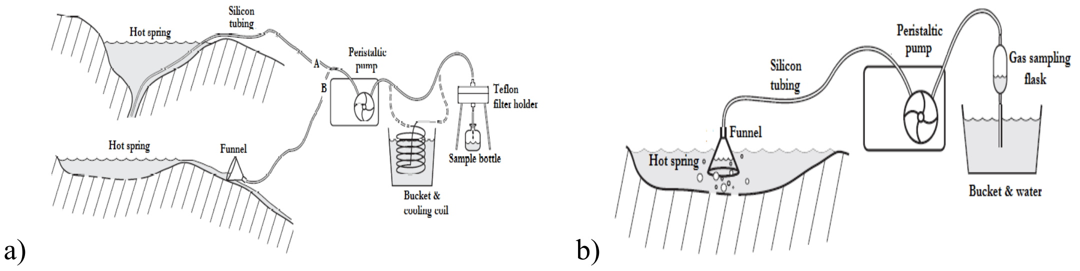

FIGURE 6: Sampling springs for a) water b) gaseous emissions in geothermal prospects (modified, Arnorsson, 2006)

Hot springs, springs with high flow rates and high temperatures (e.g. springs at Lake Bogoria) are best to sample though the sampling campaign should be done for all springs both hot and cold (Figure 7).

For condensate and gas sampling a large funnel is used to cover the mouth of the fumarole and after ensuring thorough sealing is achieved, a flexible tubing is fixed to the narrow outlet of the funnel (Figure 8).

FIGURE 7: Sampling of hand dug water well

FIGURE 8: Set up for sampling of condensate and gas in steam from fumaroles and hot ground (Sampling in the Crater in Paka)

The fumarole gases are sampled by directing the steam into two evacuated gas sampling flasks containing 50 ml of 40% sodium hydroxide solution and with continuous cooling using cold water being poured on the flask. Carbon dioxide and hydrogen sulphide gases are absorbed by the sodium hydroxide solution and hence create space for the residual gases such as, hydrogen, nitrogen, methane, argon etc. One flask is used for the analysis of carbon dioxide and hydrogen sulphide, while the other flask is used for the analysis of hydrogen, nitrogen and methane using a gas chromatograph.

After the gas sampling is completed, the flexible tubing is connected to a cooling coil, submerged in cooling water. The coil is then connected to a flask attached to a hand pump or a field pump. Through pumping, the condensate from the steam issuing from the fumarole is collected (Arnorsson, 1991). The collected condensate is divided into five portions as described in the part below and immediate analysis done.

The first portion is for immediate analysis for hydrogen sulphide (H_2S), carbon dioxide (CO_2), pH, Conductivity, and total dissolved solids (TDS). A measured amount of 5% zinc acetate solution is added to another portion of the sample for the preservation of sulphates. To samples that are to be used for metal analysis 1 ml of concentrated nitric acid is added to preserve the metal ions. To a portion of the sample for silica analysis, a neat sample is taken for condensate while for hot springs and boreholes these are acidified to avoid polymerisation of monomeric silica. Samples for silica analysis from boreholes and hot springs can also be diluted taking into account that the dilution factor has to be approximately ten times that of the sample.

The last portion of the sample is not treated in anyway. It is reserved for the analysis of chloride, fluoride, and boron. For condensate, spring and borehole water samples hydrogen sulphide is analysed at the sampling site, while carbon dioxide, conductivity, total dissolved solids and pH are done at the end of each sampling day in the field laboratory. Analysis of hydrogen sulphide is done by use of the mercuric acetate technique while total carbonate carbon is determined by titrating with 0.1 N HCl. Conductivity and TDS are measured using conductivity and TDS meters respectively while the pH is measured using a pH meter. Chloride and fluoride are determined using the Mohr titration method and ion selective electrode method respectively. Low chloride of condensates are determined using the UV-VIS Spectrophotometer at a wavelength of 460 nm. Metal analysis is determined using the Atomic Absorption Spectrophotometer (AAS) method.

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