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Geochemical Mapping of Sulfur Within Olkaria Geothermal Field, Kenya

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ABSTRACT

This research paper focuses on the geochemical mapping of Sulfur to characterize the Olkaria geothermal field, a field associated with geothermal power generation in the northeast of Nairobi. The current geochemical methods used are CO_2 and N_2 however, a discrepancy associated with the biogenic sources of CO_2 renders it less reliable. Sulfur in geothermal systems is magmatic, hence its utilization can help solve these discrepancies. The study utilized sulfur present in the geothermal well waters to identify the main features of a magmatic hydrothermal system, their distribution within the Olkaria volcanic complex and how they relate with the Olkaria structures. Secondary data of the concentrations of H_2S and SO_4^{2-} was used for mapping using ArcMap tool within ArcGIS. The distribution of the magmatic H_2S facilitated the mapping of the possible up-flow zones and the heat sources within the study area. SO_4^{2-} was used to map possible recharge zones within the study area. The mappings, that is, the up-flow zones, the heat source and the recharge zones are important, because they increase knowledge on where exactly to drill production wells, make up wells and the reinjection wells. Geochemical mapping performed on other fluid chemical species such as CO_2, Cl^-, N_2, as well as the temperature, facilitated the correlation with the sulfur concentration variations. The distribution of various concentrations of sulfur as well as the correlation parameters were shown by different color scales on the geochemical maps. From the maps, the field-scale distributions, enabled the visualization of which faults establish the fluid ascension areas and which are more closely related to recharge zones. The findings indicate that up-flow zones were affiliated to the NW-SE trending faults as well as the Olkaria Fault while the recharge zones were associated with the Gorge farm fault, the ring structure and the Ololbutot fault. Geochemical mapping of Sulfur proved to be an effective method in the characterization of a geothermal field. Its utilization to complement conventional methods, improves precision for well siting. It should therefore, not be ignored during exploration campaign.

Keywords: *Sulfur, Up-flow, Recharge, Heat Source, Olkaria*

I. INTRODUCTION

Sulfur is important since it is one of the main components present in geothermal waters. Its source in the subsurface is believed to be the solidification of magmatic bodies resulting into the magmatic degassing of H_2S [1]. Within the hydrothermal reservoir, the Sulphur is present as H_2S [2]. This therefore implies that H_2S can be used to identify the up-flow zones as well as the heat sources in a hydrothermal system. During up-flow, in cases where the upwelling fluids undergo mixing with cold meteoric inflow, the H_2S is oxidized to form SO_4^{2-} [3]. This means that SO_4^{2-}, can facilitate the delineation of the recharge zones.

The current geochemical methods used to characterize the features of a magmatic-hydrothermal system are CO_2 and N_2 [4]. However, the biogenic source of CO_2 in such environments poses a challenge to this method [5]. This therefore, necessitates the use of Sulphur.

Olkaria is a magmatic-hydrothermal system strategically located along the East African Rift, for geothermal exploration and exploitation. The field, is the most explored and currently the most exploited, regionally [6].

Since Sulphur is magmatic, its field-scale distribution has a potential in describing the features of a geothermal field [7]. Some preliminary data sets from the results of the Clarke & coworkers [8] reveal that sulfur geochemistry portrays a variation in its distribution within Olkaria. With regard to this data, a need arises to elucidate which faults and structures closely relate to these variations and in the process, this elaboration will facilitate the characterization of the Olkaria geothermal field.

Study Area

Olkaria geothermal field is a high-temperature geothermal field with an estimated resource area of about 204 km^2 [8]. The field is divided into seven sections to facilitate easy development. These sections are: the Olkaria East, Olkaria Southwest, Olkaria Southeast, Olkaria Northeast, Olkaria Northwest, Olkaria Central and the Domes fields [8]. This study focused on four of the production fields that is, the North East, East, South East and the Domes. This is because the geochemical data available was sourced from KenGen and the four production sections are the ones being currently managed and exploited by KenGen.

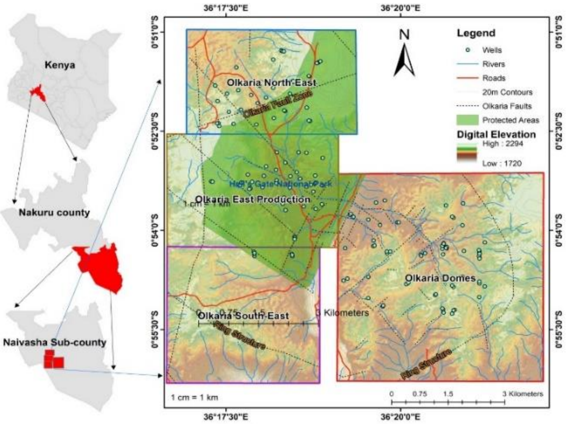

Figure 1: Location of the Study Area (KenGen, 2012)

II. METHODOLOGY

This study used secondary data obtained from KenGen, with permission, for four of the production sectors within the Olkaria volcanic complex. The geochemical data comprised of H_2S, SO_4^{2-}, temperature, CO_2 and N_2, from the production wells and the shapefile data for the Olkaria structures. The production wells furnishing the data for this research are as shown in Figure 1.

A geodatabase containing the shapefiles for the location of the wells, the chemical components under study, temperature and the Olkaria structures was created, to help in storing and managing the data for geochemical mapping as outlined by Scott [9].

These mapping was done using interpolation schemes accessible within ArcMap [9].

III. RESULTS AND DISCUSSIONS

Olkaria H_2S Distribution

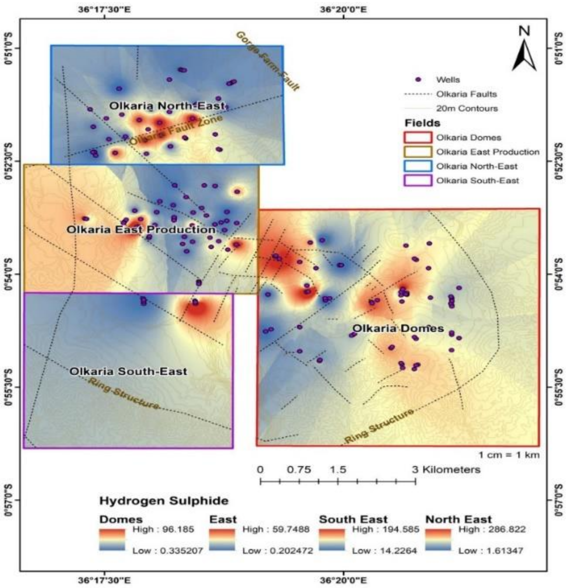

Figure 2: H_2S Distribution Map for Olkaria

The field-scale distribution of H_2S is shown on the map in Figure 2.

Six local maxima were identified in H_2S concentrations for the Olkaria geothermal field: One in the central region of the Olkaria NE production field (PF) along the famous Olkaria fault zone; one in the central region of the Olkaria E PF and another one in the Eastern region of the Olkaria E PF towards the Olkaria Domes PF. Another maxima was located in the North Eastern portion of the Olkaria SE PF while the other two were located in the central and the North western regions of the Dome PF.

Four local minima were identified in H_2S concentrations for the Olkaria geothermal field: The North Eastern and South Western parts of the Olkaria NE PF related to the Gorge Farm and the Ololbutot faults respectively. For the Olkaria E PF, there was a region in the eastern part, trending north-south. In Olkaria SE PF, the northern region was identified while for the Olkaria Domes PF, a N-S trending region between the central and the north western parts.

The field-scale distribution of H_2S infers the possible presence six regions of up-flow within the area of study in Olkaria. The regions are highlighted as areas of high H_2S concentrations.

Olkaria SO_4^{2-} Distribution

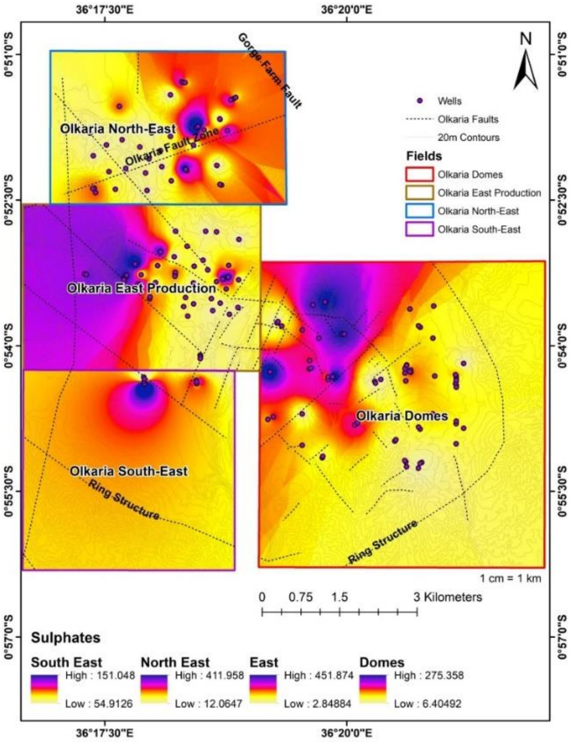

Figure 3: SO_4^{2-} Distribution Map for Olkaria

The field-scale distribution of SO_4^{2-} is displayed on the map in Figure 3.

For Olkaria NE production field (PF), the central region was identified as a minimum for SO_4^{2-} concentration. There were two regions identified as maxima in the eastern and the southeastern parts of the NE PF.

For Olkaria E PF, the western region displayed a maximum for the SO_4^{2-} concentration. On the contrary, the eastern region displayed a minimum for the same.

For Olkaria SE PF, the wells in the north region displayed a maximum for the SO_4^{2-} concentration while those in the north eastern region displayed a minimum.

For the Olkaria Domes PF, the region trending from north located between north west and central, displayed high SO_4^{2-} concentration. The northwestern and the central regions displayed low SO_4^{2-} concentration values.

High SO_4^{2-} is an indication of cold recharge along the Gorge Farm fault, the ring structure, the Ololbutot fault and the OlNjorowa gorge.

Olkaria CO_2 Distribution

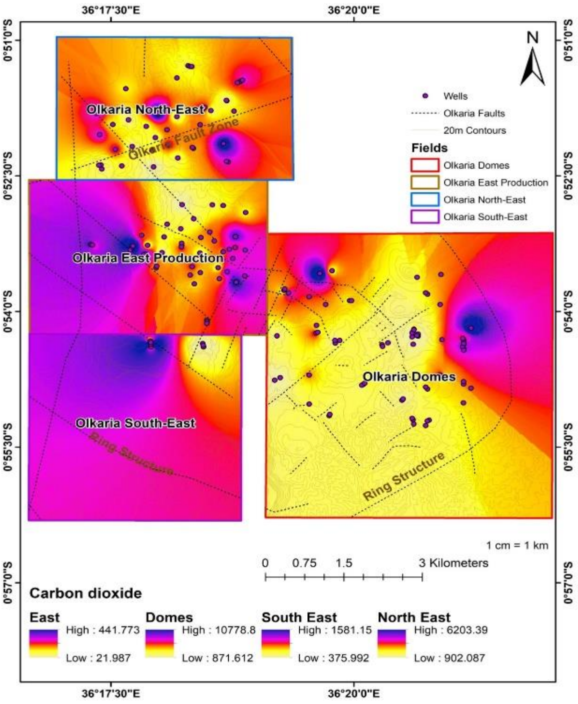

Figure 4: CO_2 Distribution Map for Olkaria

The field-scale distribution of CO_2 is given on the map in Figure 4.

For Olkaria NE production field (PF), four areas were identified as having high CO_2 concentration. That is, the northeastern region near the Gorge Farm fault, western region near the Ololbutot and a NW-SE trending fault, the southeastern, and central regions. The maximum CO_2 concentration in the central region is possibly suggestive of a magmatic origin and hence the region inferred to be an up-flow zone [10]. For the other three regions of maxima, their elevated values were linked to faults associated with cold recharge waters [11]. These areas also showed low H_2S values. This implies the occurrence of boiling processes within the reservoir, induced by depressurization as a result of cold in-flow [12]. The CO_2 could possibly be of meteoric origin from the bicarbonate recharging waters since they are in regions of recharge.

For Olkaria East production field (PF), two areas were identified as having revealed high CO_2 concentration. That is, the central region tending towards the west and region in the eastern part near the Domes field. The field-scale distribution in this portion of Olkaria showed a somewhat similarity with that for H_2S. These regions were therefore interpreted as up-flow zones.

For Olkaria SE production field (PF), the north region was identified as having shown high CO_2 concentration. Contrastingly, the northeastern region revealed low CO_2 levels. The field-scale distribution of CO_2 in this portion of Olkaria showed a sharp contrast to that of the H_2S. In the north region for instance, H_2S is low while CO_2 is high. The wells in this region lie on a NW-SE trending fault. Wells that retain high CO_2 with low H_2S suggests that there is no boiling in the formation, meaning the region is a possible recharge zone [13]. In the northeastern region, the H_2S is elevated while the CO_2 is low. The wells in this region lie on a NE-SW trending fault. This is indicative of boiling in the formation hence suggesting a possible presence of an up-flow zone.

For Olkaria Domes production field (PF), two regions showed high CO_2 concentration. One in the northwestern region near the two maxima identified in the Olkaria East production field (PF). The field-scale distribution of CO_2 and H_2S is this region is somewhat similar hence imply a possible presence of an up-flow zone. The other region with elevated CO_2 was the eastern part close to the ring structure. In this region, the field-scale distribution of H_2S was low showing a contrast to the CO_2 distribution hence suggesting that the region could possibly be a recharge zone [11].

Olkaria N_2 Distribution

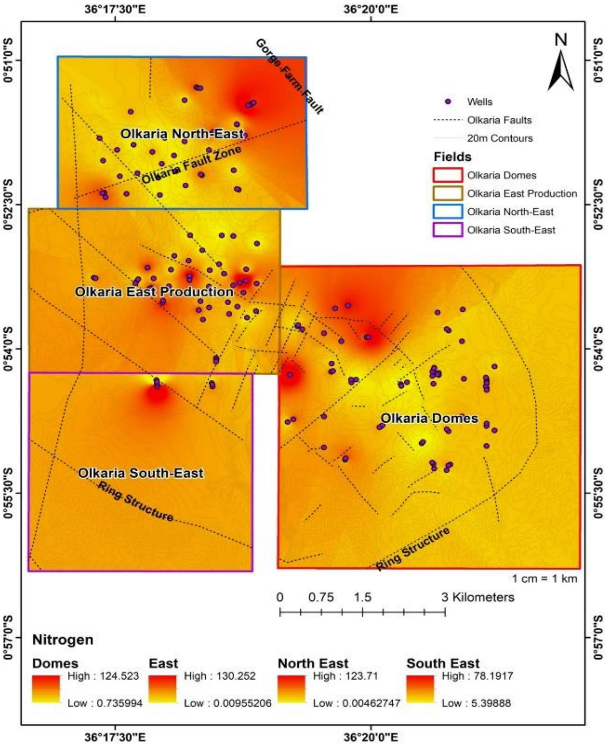

Figure 5: N_2 Distribution Map for Olkaria

The field-scale distribution of N_2 is shown on the map in Figure 5.

For Olkaria NE production field (PF), the northeastern and southwestern regions displayed high N_2 concentration. These regions were located closer to the Gorge Farm fault and the Ololbutot fault respectively. However, the central region towards the Olkaria fault zone, displayed low N_2 concentration. For Olkaria E PF, the central and eastern regions displayed high N_2 concentration. For the eastern region, the maximum was localized near the striking NE-SW trending fault.

For Olkaria SE PF, the north region displayed high N_2 concentration while the northeastern region showed a low concentration. Again, the northeastern region is localized near the striking NE-SW trending faults which are believed to transmit recharge meteoric waters. For Olkaria Domes PF, the upper and lower parts of the northwestern region displayed high N_2 concentration. The region located between these parts, trending towards the central region displayed low concentration.

The origin of N_2 in geothermal well fluids results from the meteoric recharge fluids that have equilibrated with the atmosphere or air bubbles transmission within the percolating waters. This therefore, follows that elevated N_2 concentration infers vigorous recharge zones and low levels of N_2 concentration suggest boiling hence, up-flow zones [14]. From Figure 5, N_2 concentration is maximum in the regions near the Gorge Farm fault, the ring structure in the Domes PF, the striking NE-SW trending faults and some NW-SE trending faults connected to the long N-S Ololbutot fault cutting across the NE PF, E PF and SE PF. These regions have been identified as the possible recharge zones for the Olkaria geothermal field [15].

From the analysis of the geochemical maps it is evident that sulfur is more effective compared to the conventional methods. The variation in its concentration shows a relationship with the main features relevant to a geothermal field. It can be utilized to delineate both the up-flow and recharge zones.

IV. CONCLUSION

The study identified seven major up-flow zones correlating with the possible location of the magmatic bodies. That is, one in the Olkaria North East PF, affiliated to the magmatic body beneath the Olkaria fault zone meaning this fault possibly leads directly to the magmatic chamber. The up-flow zone in the central and northeastern regions of the Olkaria East PF appears to be closely associated with heat source identified in the Olkaria North East PF. The up-flow zone feeding the eastern region of the Olkaria East PF is probably associated with the heat source in the northwestern region of the Olkaria Domes PF.

The recharge flow regime obeys notable structural trends. The cold meteoric water inflow descends via the N-S faults along the Gorge farm fault, the ring structure and the Ololbutot fault into the field.

The faults facilitating both the up-flow and the recharge for the Olkaria geothermal field are aligned in a manner providing plausible conditions for the occurrence of convection in the reservoirs.

The study demonstrated that Sulphur method can be used to map the key features of a geothermal system to complement conventional methods. When incorporated with the conventional methods, it improves the precision of well siting, for the production, make up and reinjection wells.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1]. Arnorsson, S. E. (1982). The Chemistry of Geothermal Waters in Iceland. III. Chemical Geothermometry in Geothermal Investigations. *Geochimica Cosmochimica Acta* 47:567–77.

[2]. StefAnsson, A., Arnorsson, S., & Sveinbjörnsdottir, A.E. (2005). Redox reactions and potentials in natural waters at disequilibrium.

[3]. Ramm, M. A. (1994). Porosity/Depth Trends in Reservoir Sandstones: Assessing the Quantitative Effects of Varying Pore-Pressure, Temperature History and Mineralogy Norwegian Shelf Data. *Clay Minerals*.

[4]. Arnorsson, S. A. (2007). Fluid-fluid interactions in geothermal systems. *Rev Mineral Geochem*.

[5]. Darling W.G., G. E. (1995). The origin of hydrothermal and other gases in the Kenyan Rift Valley. *Geochim. Cosmochim. Acta*.

[6]. Saitet, D. (2015). Synthesis of Well Test Data and Modelling of Olkaria South East Production Field.

[7]. Clarke, M. C. (1990). *Geological, Volcanological and hydrogeological controls of the occurrence of geothermal activity in the area surrounding Lake Naivasha.* Ministry of Energy. Nairobi.

[8]. KenGen 2012: *Stratigraphy and Hydrothermal Alteration Mineralogy of Well OW-910 and OW-917.* KenGen internal report: unpublished.

[9]. Scott, S. (2011). Gas Chemistry of the Hellisheiði geothermal field. (Master's Thesis).University of Iceland, Reykjavik.

[10]. Armannsson, H., Gislason, G., and Hauksson, T. (1982), Magmatic Gases in Well Fluids Aid the Mapping of the Flow Pattern in a Geothermal

System. *Geochimica Cosmochimica Acta*, 46, 167-177.

[11]. Opondo, K. (2008). 'The Fluid Characteristics of Three Exploration Wells Drilled at Olkaria-Domes Field, Kenya.' *Stanford, California: Geothermal Reservoir Engineering*. Stanford University.

[12]. Karingithi, C. A. (2010). Processes controlling aquifer fluid compositions in the Olkaria geothermal system. Vol.196. doc.10.1016/j.jvolgeores.2010.07.008. *Journal of Volcanology and Geothermal Research*.

[13]. Glover, R. B., Lovelock, B., and Ruaya, J. R. (1981). 'A novel way of using gas and enthalpy.' *New Zealand Geothermal Workshop*. Auckland, New Zealand.

[14]. Arnason, K., Eysteinsson, H., and Hersir, G. P. (2010). Joint 1D inversion of TEM and MT data and 3D inversion of MT data in the Hengill area, SW Iceland. *Geothermics*, 39, 13-34.

[15]. Ambunya, M. (2014). Natural-State Model Update Of Olkaria Domes Geothermal Field. Reports 2014 Number 7, UNU-GTP. Iceland.

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