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HIGH TEMPERATURE HYDROTHERMAL ALTERATION IN ACTIVE GEOTHERMAL SYSTEMS A CASE STUDY OF OLKARIA DOMES

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ABSTRACT

The Olkaria Domes Production Field (DPF) is one of the main geothermal fields within the Greater Olkaria Geothermal Area (GOGA) that is currently being developed for geothermal energy generation. DPF is approximately bound by the Hell's Gate-Ol'Njorowa gorge to the west and a ring of domes to the east and south of the area. Detailed surface investigations were conducted in the area in 1992/93; this developed a basic working model, from which exploration wells drilled. Three exploration wells were drilled in the field between September 1998 and May 1999. All these wells encountered High Temperature Hydrothermal Alteration Minerals (HTAMs). Since then more geothermal wells have been drilled at DPF. Several methods are used in advanced geothermal exploitation evaluation and understanding of the geothermal system and reservoir. The First occurrence of well-crystallized HTAMs is one of them. HTAMs are known to occur at stable pressure and temperature regimes for example epidote occurs at temperatures of over 250°C. To map the first appearance of HTAMs, Olkaria geothermal wells data was used to evaluate and understand the DPF geothermal reservoir. The depth of first occurrence of HTAMs in the DPF wells was compared with the present formation temperature at that same depth to identify the equilibrium, heating up and cooling down sections within reservoir system. This is important in determination of casing depths to be adopted of the DPF. This paper presents the finding of the HTAMs mapping, comparison of HTAMs occurrence with current formation temperature and recommends best casing depths within DPF within the Greater Olkaria Geothermal Area (GOGA).

Keywords: Epidote, High temperature alteration, geothermal reservoir/systems

1. INTRODUCTION

1.1. BACKGROUND INFORMATION

Olkaria domes production field is located within the Greater Olkaria Geothermal Area (GOGA). Situated at the south of Lake Naivasha and within the great Olkaria geothermal complex, in the Kenyan rift valley, the GOGA is partitioned into seven fields for the purposes of geothermal development. These fields include; the, Olkaria central, Olkaria east Olkaria northeast, Olkaria northwest, Olkaria southeast, Olkaria southwest and the Olkaria domes (Fig 1). The focus of this paper is the Olkaria domes production field, bound by the Ol'Njorowa gorge to the west and a ring of lava domes to the east and south. Detailed surface investigations were conducted in the area in 1992/93 (Lagat, 2004), which led to the development of a basic working model, from which recommendations for drilling of exploration wells were made (Lagat, 2004). Three exploratory wells were drilled in the field between September 1998 and May 1999. All the three wells encountered High temperature hydrothermal alteration minerals (HTAMs). Since then more wells have been drilled at Olkaria domes, and will form the basis of this paper.

According to Clarke and Woodhall (1987) described Olkaria domes as volcanic centre as a large geothermal field. A number of extrusive and intrusive domes, plugs and lavas of comenditic (soda rhyolite) composition are associated with thick pyroclastic deposits. A late stage pyroclastic cover results from not only Olkaria Complex, but also from the neighbouring Longonot complex which has a different (trachytic) composition.

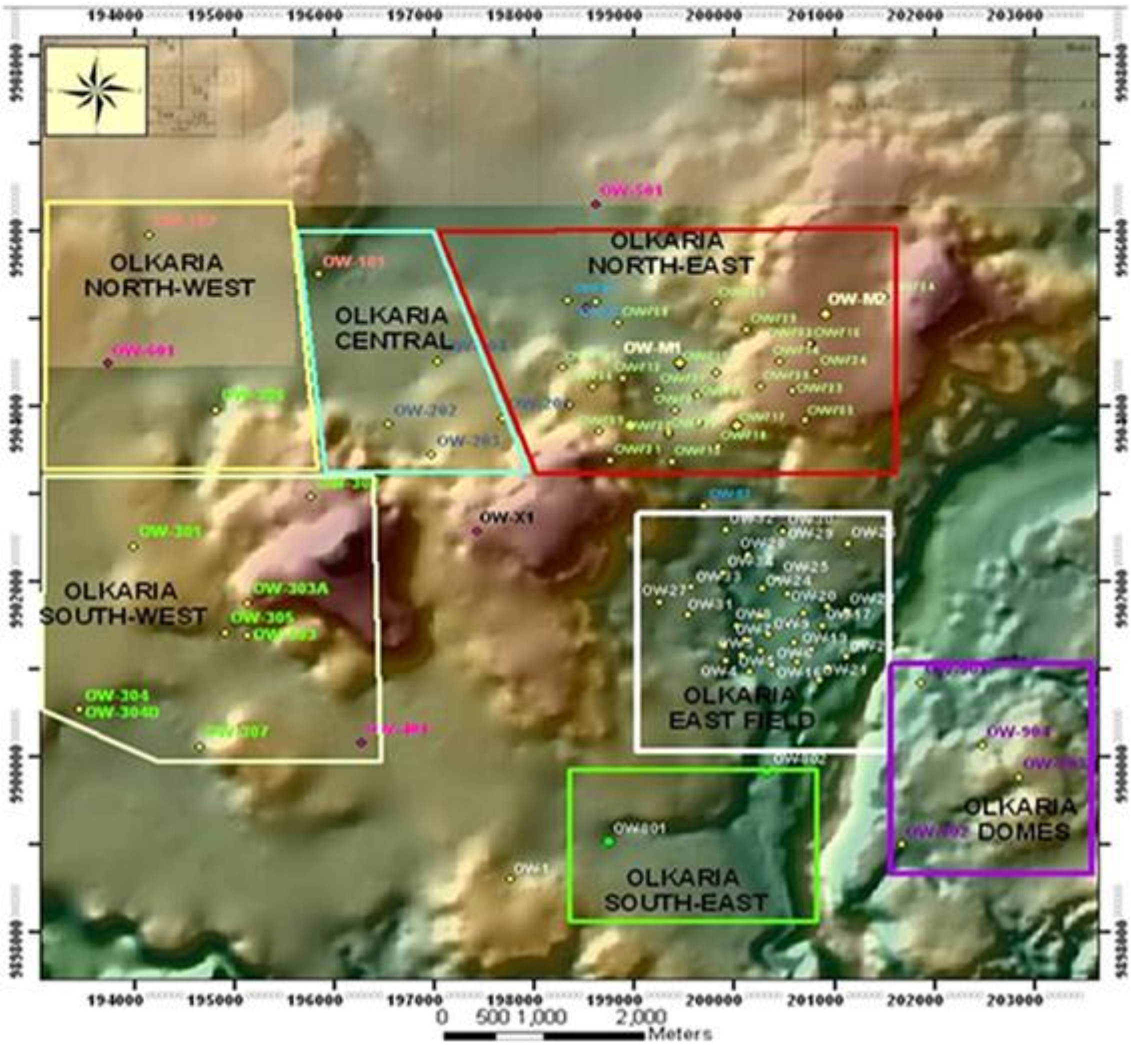

Figure 1. Map showing sectors of Olkaria Geothermal Field

The main structural features in the study area were the faults which were the NW–SW, NE-SW and N-S trending faults and fractures (Fig. 2). Some of the faults were identified from the displacement of rocks/pyroclastic while most were associated with geothermal manifestations; linear alignment of fumaroles and the geothermal grass. The general direction of the faults is N-S along the linear structure. The displacement of the faults was minor (~10 m),

1.2. PRECEDING WORK

Several researchers have carried out research in this great area of interest. Among these works are: the Geological Survey by Browne (1984). The geological mapping of the Greater Olkaria Volcanic Complex and its neighbouring areas by the British Geological Survey (BGS) revealed that the lava extrusions at the domes were of comenditic composition and these overlay the pyroclastic extrusions. In their research, the BGS under the leadership of Woodhall (1987) discovered that majority of these pyroclasts had fallen from the Longonot volcano as well as the close relationship between the continual volcanic activities and the ring fracture found at the Olkaria Domes. While studying the hydrothermal alteration mineralogy in the Olkaria geothermal fields, (Lagat, 2004) noted that understanding of the alteration mineralogy would aid in identifying the production zone.

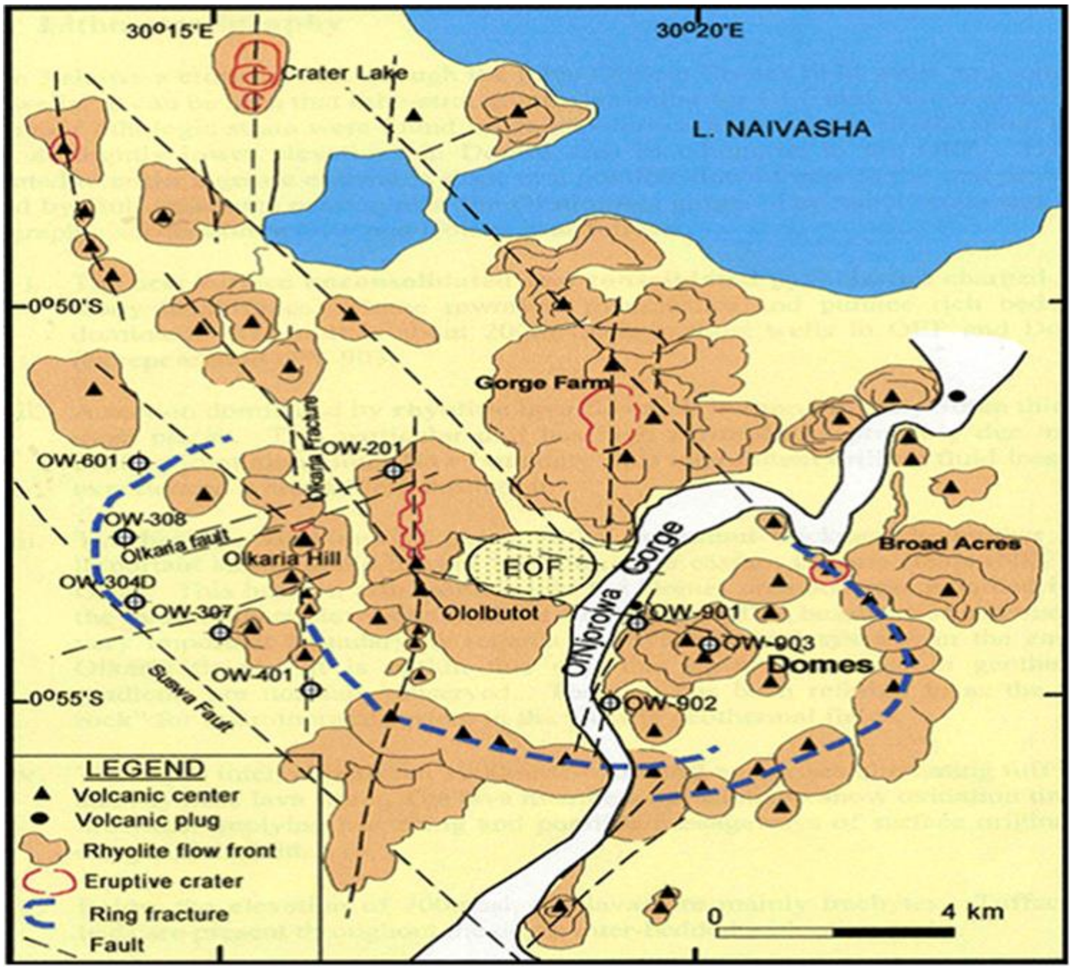

Figure 2: Structural map of Greater Olkaria Geothermal Area (KenGen, 2000)

2. OBJECTIVES

- To map the first occurrence and distribution of epidote at Domes Production Field
- To compare the first occurrence of epidote and the formation temperature at that depth
- To delineate heating up, equilibrium and cooling down areas within Domes Production Field
- To determine probable optimal casing depth within the Domes Production Field

3. HYDROTHERMAL ALTERATION MINERALS

Rock alteration simply means changing the mineralogy of the rock. The primary minerals are replaced by the secondary minerals because there has been a change in the prevailing conditions subjected to the rock. These changes could be changes in temperature, pressure, or chemical conditions or any combination of these. Hydrothermal alteration is a change in the mineralogy as a result of interaction of the rock with hot water fluids, called “hydrothermal fluids”. The fluids carry metals in solution, either from a nearby igneous source, or from leaching out of some nearby rocks. Hydrothermal fluids cause hydrothermal alteration of rocks by passing hot water fluids through the rocks and changing their composition by adding or removing or redistributing components. Temperatures can range from weakly elevated to boiling. Fluid composition is extremely variable. They may contain various types of gases, salts (brine fluids), water, and metals. The metals are carried as different complexes, thought to involve mainly sulphur and chlorine. Hydrothermal alteration minerals (HAMs) are those minerals that forms due to changes in primary mineralogy to secondary mineral.

They tend to form at specific and stable temperatures thus making them suitable for mapping of temperatures of a geothermal system and reservoir. HAM can then be classified into high temperature hydrothermal alteration minerals (HTAM) which is the basis of this paper or low temperature hydrothermal mineral. Epidote is one of the HTAM within DPF and will be used to represent other HTAM. Hydrothermal minerals can appear as either replacement of primary minerals or as in-fillings in vesicles, vugs and fractures. Some of the main hydrothermal alteration minerals encountered in the studied wells include oxides, clays, calcite, zeolites, quartz, pyrite, epidote, actinolite and adularia. While these minerals may be encountered at different depths, their presence/occurrence in a geothermal well, have specific significance. For instance; there are those minerals whose occurrence indicate low formation temperature e.g. zeolites and kaolinite, whereas minerals such as calcite, epidote, pyrite, actinolite and adularia indicate boiling conditions. Apart from being boiling indicators, adularia, pyrite and epidote signify good permeability as well. The presence of epidote and actinolite in a well indicate temperatures of over 250^{o}C and 280^{o}C respectively. Epidote is thus a good geothermometer mineral that can be used to map the temperature and pressure that existed at the time when hydrothermal alteration was occurring. A number of hydrothermal minerals are highly temperature dependant and are, thus, extensively used to map the temperature regimes of geothermal systems (Browne, 1978, 1984; Omenda, 1998). Epidote will form the basis of our discussion as this paper as noted in the Olkaria domes wells. The presence of well-crystallized epidote indicates temperatures of more than 250°C (Omenda, 1990; Gylfadóttir et al., 2011).

4. MATERIALS AND METHODS

The main material that was used is the geological logging data obtained from rock cuttings from the various geothermal wells at Olkaria domes. The other critical data is the downhole temperature logging data mainly from reservoir. Depth of the first appearance of epidote for each well was used with the surface elevation depth to find the depth above or below sea level of epidote alteration. This depth and coordinates of the well where used to generate isotherm map Fig. 3. The depth at which first appearance of crystalline epidote was encountered was compared with current formation temperature from reservoir. This difference was used to generate an isotherm map, Fig. 4. The gridding of the elevation depth of first appearance of crystalline Epidote and difference was done using ordinary kriging method. Surfer 10 program was used to generate the contours and the grids.

5. RESULTS AND INTERPRETATION

The first objective of the study was to map the first appearance of crystalline epidote at DPF through generating isotherm map. Fig. 3, shows the distribution of epidote as generated from geological well logging data. The map indicates that within the central area of the field SW-NE epidote was encountered at shallower depths of about 1000 m above sea level as opposite to the NW and SE corners with the deepest being at about 1000 m below sea level. This is interpreted to mean that the casing depth at the central part of the reservoir will be set at about 950 m with the NW and SE corner casing varying to even depths of 1200 m.

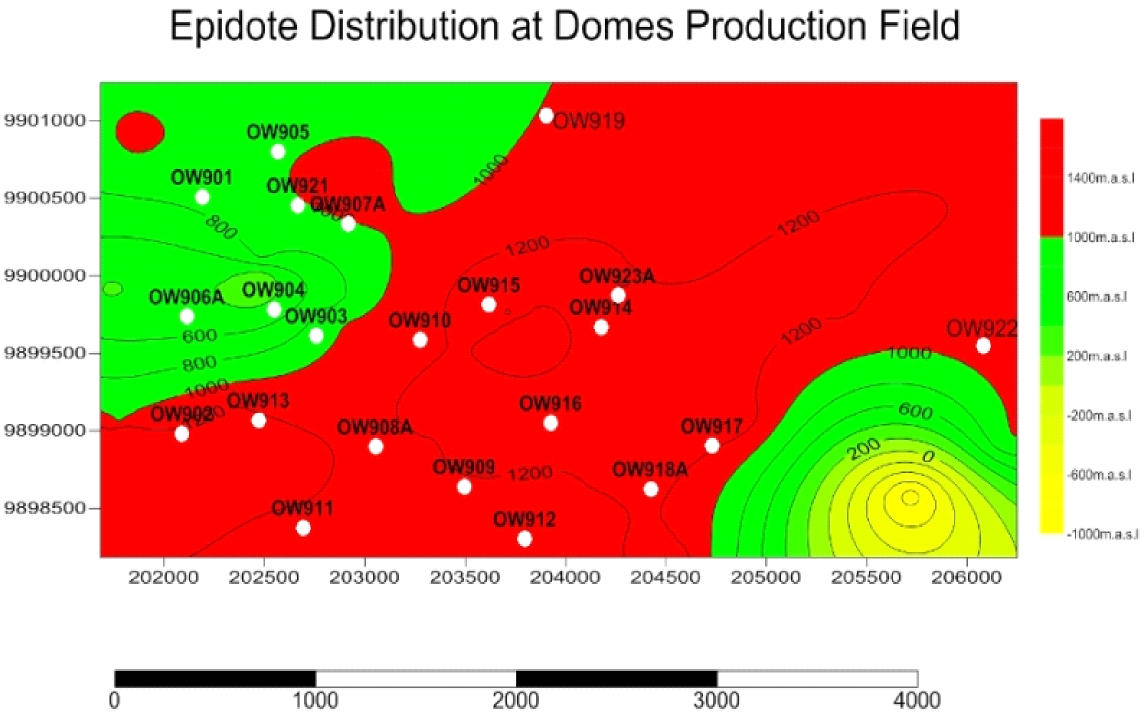

Figure 3: Epidote distribution at Olkaria domes production field

The second and third objectives of the study were to compare the formation temperature against alteration temperature and delineate areas that are heating up, at equilibrium or cooling down. This was achieved by getting the differences in temperature between the depth at which first appearance of crystalline epidote was encountered with current temperature of the same depth and then generating isotherm map Fig. 4. The map shows that areas which are Purple coloured are heating up while the Red areas show that the system is at equilibrium. Lastly areas that are yellow to dark blue indicates that there are cooling down.

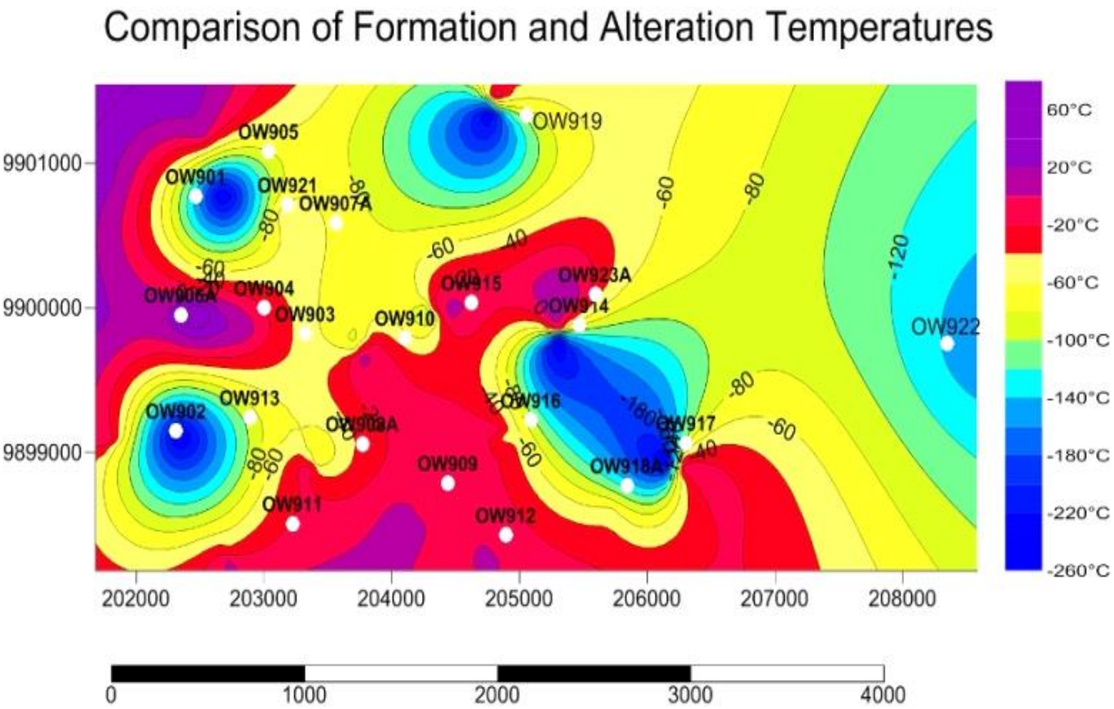

Figure 4: Comparison of formation and alteration temperatures of Olkaria domes field

6. DISCUSSION

The surface distribution of epidote (Fig. 3) shows that crystalline epidote was encountered at 950 m below the surface which is 1200 m elevation above the sea level. The figure also shows that epidote was encountered shallower at centre of Olkaria Domes running SW-NE. these areas correspond well with the SW-NE structures enhance indicating these structures are heating up zones. These are the up flow zones Olkaria domes. The figure further shows that crystalline epidote was encountered deeper at NW and SE corners of the field. This is interpreted to mean that these are the down flow zones of the reservoir system. The SE corner is outside the perceived Olkaria caldera hence maybe receiving different hydrothermal fluids; even the lithological units encountered at this well were slightly different.

The result of the comparison (Fig. 4) shows that Olkaria domes geothermal system is generally at equilibrium with some "sink holes' at OW901, OW902, OW919, OW916 and OW918 areas where the system is cooling down. This "sink holes' corresponds with the George farm fault and ring structure (OW919, OW916 and OW918) which can be interpreted as the areas which recharge the system. The heating up areas of OW923 through to OW909 area correspond well with volcanic centres with Olkaria domes. These areas are also in the trend of the NE-SW faults which have been postulated as heat up zone. This generally shows that the hydrothermal system is generally is at equilibrium but slightly cooling down. The result also shows that major structures maybe controlling the heating up and cooling down of the Domes production system.

7. CONCLUSIONS AND RECOMMENDATIONS

From this study the following conclusions can be drawn.

a. The surface distribution of epidote (Fig. 3) shows that crystalline epidote was encountered at 950 m below the surface which is 1200 m elevation above the sea level.
b. The geothermal system of Olkaria domes is generally at equilibrium and heating up at greater depth. Deeper drilling and casing is recommended at the NW and SE corners of the field. This is as seen from the Fig. 4 the geothermal system is heating up at depth and cooling down at shallow.
c. Hydrothermal alteration specifically the high temperature hydrothermal alteration is structurally controlled at Olkaria domes. This is also true for the areas that are heating up and controlling down.

This study has shown some patterns and recommend the following

a. The best recommended casing depth recommended for the Olkaria Domes is 950 m, which is in line with the current practice but pad by pad adjustments are to be made as will be advised by rig geologist. To the NW and SE corners casing of up 1200 m is recommended.
b. Further investigation of the patterns for instance why within the same structure we have sink holes and heating up areas. This is determining the extent to which structures control cooling down and heating up of the geothermal reservoir system.
c. The data had some fouls e.g. very high discrepancy of the first appearance of epidote within the same pad. This needed to be normalized and detailed more refined map of distribution and comparison can be made.
d. It’s also recommended that Fluid inclusion geothermometry study to be conducted to ascertain the above conclusions.

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