

## Rock Types and Alteration Mineralogy Occurring In Olkaria Geothermal Field, Kenya

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**Abstract:** *Olkaria Geothermal Field is a high temperature geothermal system; the system is characterized by Quaternary volcanic centers in the central Kenya Rift Valley. The surface geology of Olkaria Geothermal Field is mainly dominated by commenditic lavas and pyroclastic. The subsurface geology is mainly characterized by basalt, tuffs, rhyolite, trachyte and intrusion. The aim of this study was to describe the lithology and alteration mineralogy of OW 924A, OW 923A, 917A, OW917A, OW914B, OW731C, OW710C and OW39B wells. The lithology and alteration mineralogy in geothermal system is used to solve the following; 1) Trachyte formation and epidote mineral are indicators of entry into the reservoir and hence must be considered when setting up production casing during drilling. 2) It also helps in understanding the reservoir by modelling the inflow, up-flow and outflow of geothermal systems. 3) The fluid chemistry can be studied so as to predict future problems in the fields. For example, mineral sequence can indicate cold-water incursions into the well while abundant calcite and quartz in a well may suggest casing corrosion problems in the future. Drill cuttings were collected at a two meter intervals at the rigs site and analyzed in preparing lithological and alteration logs by KenGen rig geologists. We obtained permission from KenGen management to use the analyzed data. The data was analyzed using computer software LogPlot 8 to interpret the lithology, alteration mineralogy and temperatures heat up profiles.*

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### I. Introduction

Rock type or lithology in geothermal field simply is the different kinds of solid mass consisting of at least two minerals (Lagat, 2009). Rock alteration mineralogy on the other hand is the changing of mineralogy of the rock. This happens when primary minerals are replaced by secondary minerals due to changes in chemical conditions, temperature and pressure. Hydrothermal alteration mineralogy is a change in the mineralogy as a result of interaction of the rock with hot water fluids called hydrothermal fluids.

Geological studies which was carried out in Olkaria defined the eastern scarp of Olkaria as a complex system of down faulted blocks that are variably tilted (Thomson, 1964). Lithology and alteration mineralogy are significant in exploration and development of geothermal system of new geothermal fields. This study focusses on describing the lithology and alteration mineralogy occurring on selected wells in Olkaria geothermal system. In exploring new geothermal fields and siting next appraisal or production wells, understanding lithology and alteration mineralogy can help in setting the production casing of wells, predict corrosion and scaling tendencies, indicate whether the well is permeable and understand the nature of the reservoir by knowing whether there is temporal changes that have occurred in the well.

### Field development

In Kenya geothermal exploration started in 1950's with main focus on geological investigation in the region between Olkaria and Lake Bogoria in the North Rift (Mariita, 2009). In the year 1970's exploration of geothermal energy was concentrated in Olkaria and by 1976, six wells had been drilled and the evaluation of these wells, indicated that development of geothermal in Olkaria is feasible. Subsequent years saw numerous expansions with additional power plant being installed in Olkaria. These include Olkaria III in the year 2000, with capacity of 110 MWe, Olkaria II in the year 2003 with capacity of 105 MWe (Wamalwa et al., 2016). Olkaria I additional unit 4 and 5 and Olkaria IV, with capacity of 280 MWe in 2014 and several well heads have been installed to the power grid. Plans are underway to construct Olkaria V and Olkaria I additional unit 6 with a capacity of 140 and 70 MWe respectively. Geology in such setting is vital. Through understanding the lithology and alteration mineralogy more geothermal fields can be developed within the country.

The Government of Kenya through the Ministry of Energy (MOE) in collaboration with the British Geological Survey (BGS) carried out a study in 1990 on regional exploration of geothermal energy in the Kenyan rift. The study entailed, geological mapping of Longonot Volcano, Olkaria Volcanic Complex and the

adjacent areas. The study concluded that the extrusion of the lava domes which were of comendite composition, in the Olkaria Volcanic Complex was preceded by the extrusion of pyroclastic. The pyroclastic rocks were predominantly of fall origin and could have erupted from Mt. Longonot volcano (Woodhall, 1987)

### **Geology of Olkaria Volcanic Complex**

The recent information on the geology of Olkaria Volcanic Complex and its surrounding offered hereafter emanates from the comprehensive pioneering efforts of various scholars (Clarke et al., 1990; Marshall et al., 2009; Omenda, 1998). Their work has provided the basis upon which extra current work has sustained to build and has been advanced through successive field development. The Olkaria Volcanic Complex constitutes portion of the central Kenya peralkaline province which agrees with the Kenya Dome (Macdonald & Scaillet, 2006).

### **Surface Geology**

The surface Lithology units of Olkaria Volcanic Complex are dominated by commenditic lavas, pumice fall and pyroclastic. A big portion of the pumice fall and pyroclastic deposits have originated from Longonot and Suswa volcanoes. Six phases in the development of the complex were listed based on geological work (Clarke et al., 1990). According to Clarke et al., (1990) the first stage is Pre-caldera trachytic magmatism then followed by collapse of caldera forming a depression. The third stage is the eruption of lower commendite then development of ring structure which is the middle commendite member extrusion period. The fifth stage involves resurgence of caldera floor collapse. And finally the last stage is the eruption of very thick lava flows which is believed to be the youngest geologically.

### **Subsurface Geology**

Samples from drilling cuttings from several geothermal wells have added valuable information to the understanding of the subsurface lithology of the Olkaria Geothermal Field (Otieno, 2016). Penetrating to depths above 2500 m has provided new understandings into the deep subsurface lithology of the Olkaria Geothermal Field.

The litho-stratigraphic units of the Olkaria Geothermal area, have been classified in six distinct groups (Omenda, 1998). Pyroclastic and commendites are predominant within this minor interbed of trachyte and basalt.

The upper Olkaria volcanic formation is underlain by Olkaria basalt. Basaltic lavas are predominant, though alternating with thin horizons of tuffs, minor trachyte and sporadic rhyolites. The formation has been intersected by wells at the depth between 1900 and 2500 m.a.s.l and forms the cap rock (Okoo, 2013)

The Olkaria geothermal system after the Olkaria basalt is then followed by trachyte of Pleistocene age. The trachyte form portion of the Kenya rift floor fissures flows which are visible to the South and North of Olkaria Volcanic Complex. Plateau trachyte is the reservoir for the Olkaria Geothermal Field. It's width has been projected to be greater than 1.5 km (Mwangi, 2012; Okoo, 2013).

## **II. Problem statement**

Kenya's electricity demand is constantly increasing as many activities are fast-tracked and the targeted vision 2030, resulting on pressure on conventional methods of energy such as hydropower, wind and solar which is affected by weather/climate changes. Dependable, reliable, sustainable and environmentally friendly form of energy is vital. Kenya is a developing country and as a result geothermal energy seems to be the best way of providing energy. When developing geothermal resources in any new field, understanding the geological setting of the area is key. As a result it is important to study the lithology or rock type and alteration mineralogy as it assists in exploring and developing new fields. Rock-type and alteration mineralogy incorporated with other fields like geophysical techniques, geochemistry and reservoir information assist in understanding the nature of geothermal systems and develop conceptual models.

## **III. Methodology**

In Olkaria Geothermal Field wells are drilled to a maximum depth of 3000 m with supervision of specialist groups of geologists, logging engineers and drilling engineers. Drill cuttings are collected at a two meter intervals and analyzed in preparing lithological and alteration logs. To analyze the drill cuttings the instrument used is a binocular microscope and further analysis by use of petrographic microscope and for clays analysis XRD machine is required but for this studies clay analysis was not done due default in the XRD machines. For this study data was analyzed by KenGen rig geologist and permission was obtained from KenGen management to use the analyzed data. The data was analyzed using computer software LogPlot 8 to interpret the lithology, alteration mineralogy and temperatures heat up profiles. Figure 1 shows how Logplot software have been used to describe the lithology, alteration mineralogy and temperature profiles.

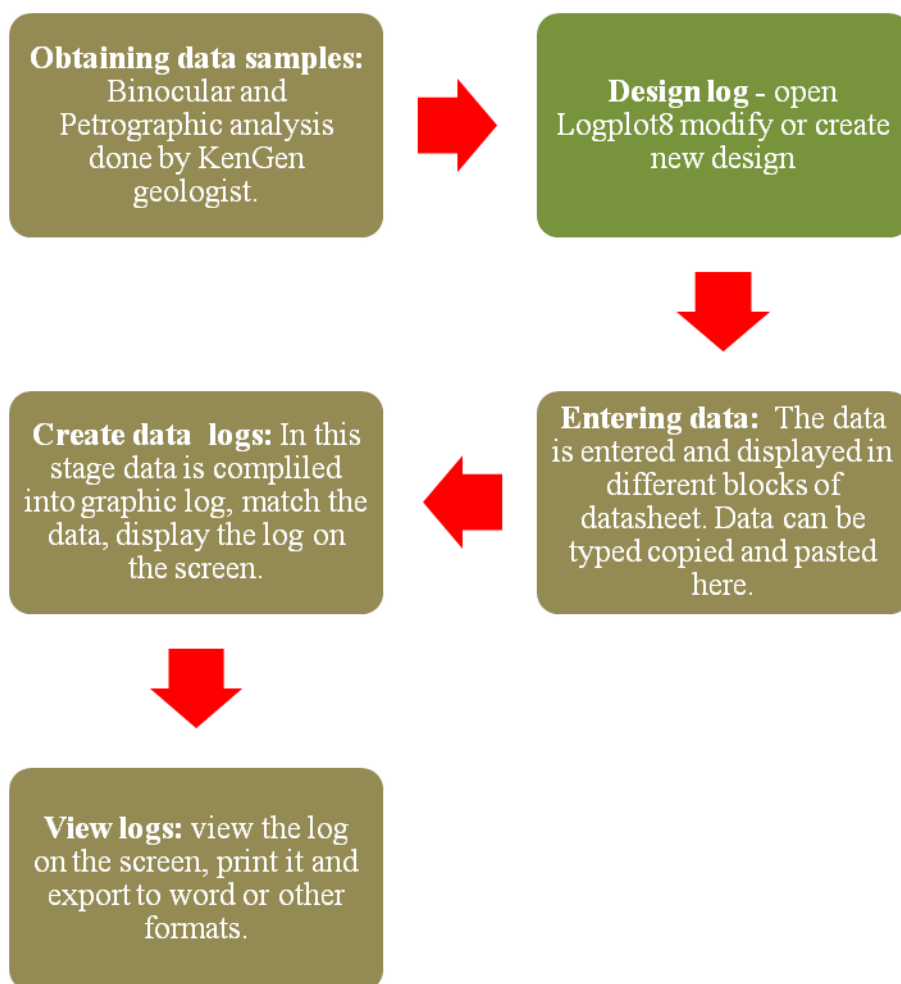


Figure 1: Steps followed in describing the rock type and alteration mineralogy.

#### IV. Results and discussion

The lithology and alteration minerals from wells OW 924A, OW 923A, OW914B, OW914A OW917A which cut the ring structures while OW 710C, OW 731C and OW39B which cut across the Ololbutot structure were analyzed Table 1.

Table 1: Data for wells OW 924A, OW 923A, OW 914B, OW 914A OW 917A OW 710C, OW 731C and OW 39B

Well number	East (m)	North (m)	Elevation in m.a.s.l	Total depth (m)	Deviation/Direction	Production (MW)
OW 924A	205396.942	9900697.551	2040	2990	N30 <sup>o</sup>	6.3
OW 923A	205435.289	9900079.295	2029.826	2980	N30 <sup>o</sup>	5.7
OW 914B	205278.203	9899865.637	2009.288	2988	N45 <sup>o</sup>	7.1
OW 917A	206182.15	9898932.30	2146.06	2990	N315 <sup>o</sup>	3.0
OW 710C	198124	9904203	2068.90	3136	N292.5 <sup>o</sup>	3.0
OW 731C	198321.560	9903395.836	2214.11	2990	N255 <sup>o</sup>	6.4
OW 39B	198136.304	9901792.502	2145.346	2990	N340 <sup>o</sup>	< 5

#### Descriptions of rock types

##### Pyroclastic

Pyroclastic in Olkaria Geothermal Field occur between a depths of 0 – 100m. The rock samples are of mixed fragments and consists tuffs, pumice, volcanic glass, obsidian and rhyolitic fragment.

##### Rhyolite

Rhyolite underlie the pyroclastic and generally rhyolite are white to light grey, the rock is characterized with abundant of quartz phenocryst. The alteration intensity of rhyolite rock is very poor due to abundance of quartz, this makes it a good impermeable rock.

### **Tuff and Basalt**

These rocks occur between depths of 400-850 m in Olkaria Geothermal Field. They are easily altered when it comes in-contact with fluid movement. Tuff and basalts are the cap rock in Olkaria. Basalt is a dark grey fine grained composed of calcic plagioclase, clinopyroxene and iron ore.

### **Trachytes**

It is an igneous volcanic rock with aphanitic or porphyritic texture of sanidine phenocryst. Trachyte do exist from the depth of 900m to 3000 m depending on wells. The trachyte form the reservoir rock in Olkaria Geothermal Field.

### **Loss of circulation**

Is the partial or complete loss of drilling fluid during drilling (The drilling fluid carry samples cuttings to the surface to be analyzed) this lost zones are associated to faults and fractures in the subsurface. At shallow depths, lost zones should be cased off and probably cemented to avoid cold inflow in to the well. When lost zones are found on a deeper depths it is a good sign of ease of fluid flow in convectional well it acts as a conduits for allowing inflow and outflow of geothermal wells.

### **Distribution of alteration mineralogy within the study area**

The distribution of each mineral in relation to the study wells of Olkaria is as follows;

#### **Zeolites**

Zeolites group usually occur as a secondary mineral in rock cavities. They commonly indicate low temperature condition of about 50°C. From the study well zeolites are found at shallower depth for less than 200 m and wells OW 917A at 118 m, OW 731C at 114 m and OW 39B at 66 m.

#### **Chalcedony**

Chalcedony occurs mostly as a cavity filling and the walls of vesicles, it is abundant in the upper part of most wells showing brownish yellow layering in the bottom of amygdalae. Chalcedony indicates a temperature of about 100°C. Chalcedony is observed within a depth of less than 500 m from most of study wells. OW 924A at 468 m, OW 917A at 446 m, OW 731C at 406 m, OW 710C at 494 m and OW 39B at 428 m.

#### **Quartz**

Quartz is colorless to white in color and occurs in euhedral to sub-hedral crystals. It is recognized both as in vesicles filling and vein filling mineral. It was observed on the most of study wells except on OW 39B, in from OW 924A – 1070 m, OW 923A at 636 m, OW 917A at 136 m, OW 914A at 746 m, OW 731C at 1568 m and OW 710C at 416 m.

#### **Calcite**

Calcite is white in color and occurs as a replacement mineral for feldspars, volcanic glass and pyroxene. Calcite is observed as precipitates in veins and vesicles and as platy calcite, perhaps indicating deposition through mixing of fluids with different works. Platy calcite suggests boiling within reservoir. Calcite is stable over a range of temperature from 50°C to about 300°C.

#### **Epidote**

Epidote occurs as euhedral crystal form and occurs in groups as well as individual crystal. As a depositional mineral, it fills vesicles and veins while as a replacement mineral it replaces feldspars and pyroxene. Epidote was observed in all the study wells at OW 924A at 1120m, OW 923A at 636 m, OW 917A at 1144 m, OW 914A at 476 m, OW 731C at 954 m, OW 710C at 1142 m and OW 39B at 742 m. In Olkaria geothermal complex, the first appearance of epidote is used as a marker for casing depth.

#### **Prehnite**

Prehnite are usually pale green platy crystal. prehnite was first observed at OW 924A at 934 m, OW 923A at 2620 m, OW 917A at 1090 m, OW 731C at 1644 m and OW 39B.

Prehnite is a high temperature mineral and occur in association with other high temperature minerals comprising epidote and actinolite. It is placed at a minimum temperature of around 240°C.

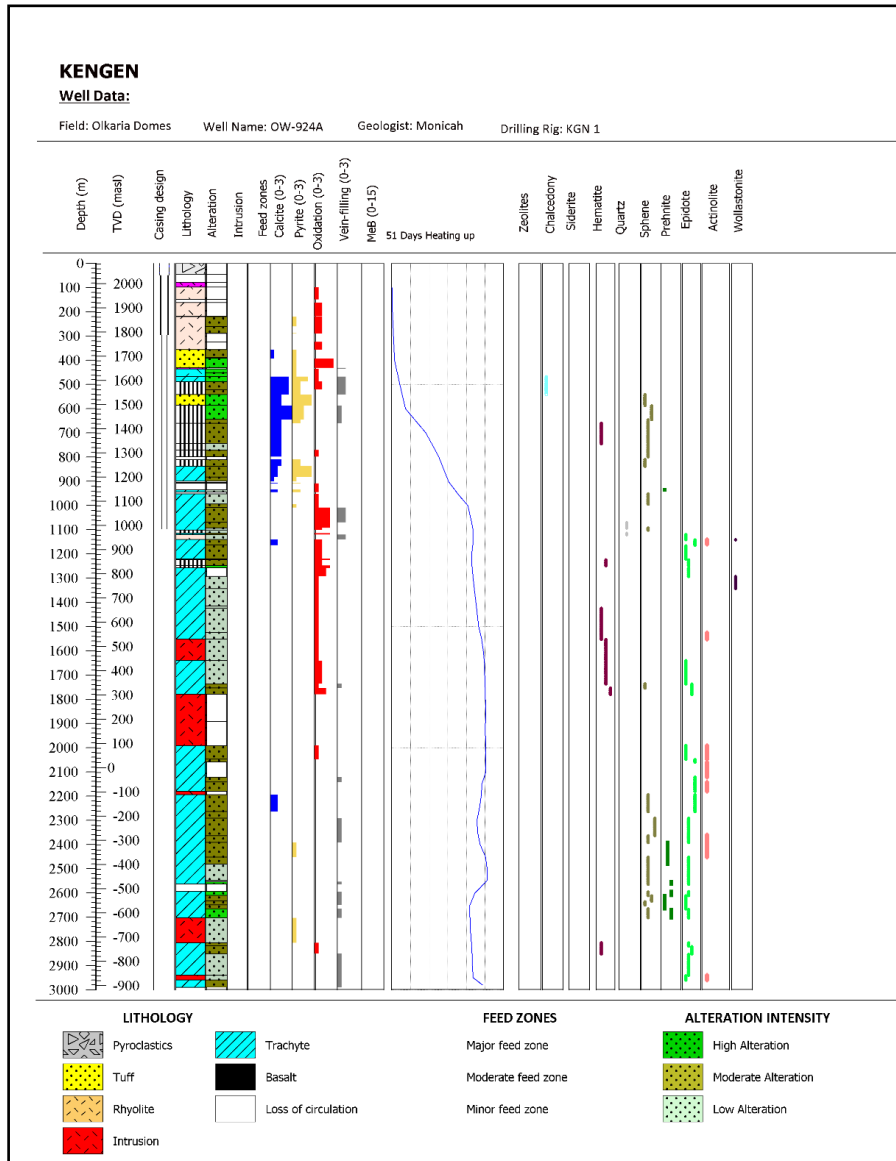
#### **Wollastonite**

Wollastonite was only observed in OW 924A at 1140 m and 923A at 1764 m. Wollastonite occurred as an aggregate of white needle-like elongated crystals and most it was associated with epidote. It is a high temperature mineral with a smallest deposit temperature of around 270°C.

**Actinolite**

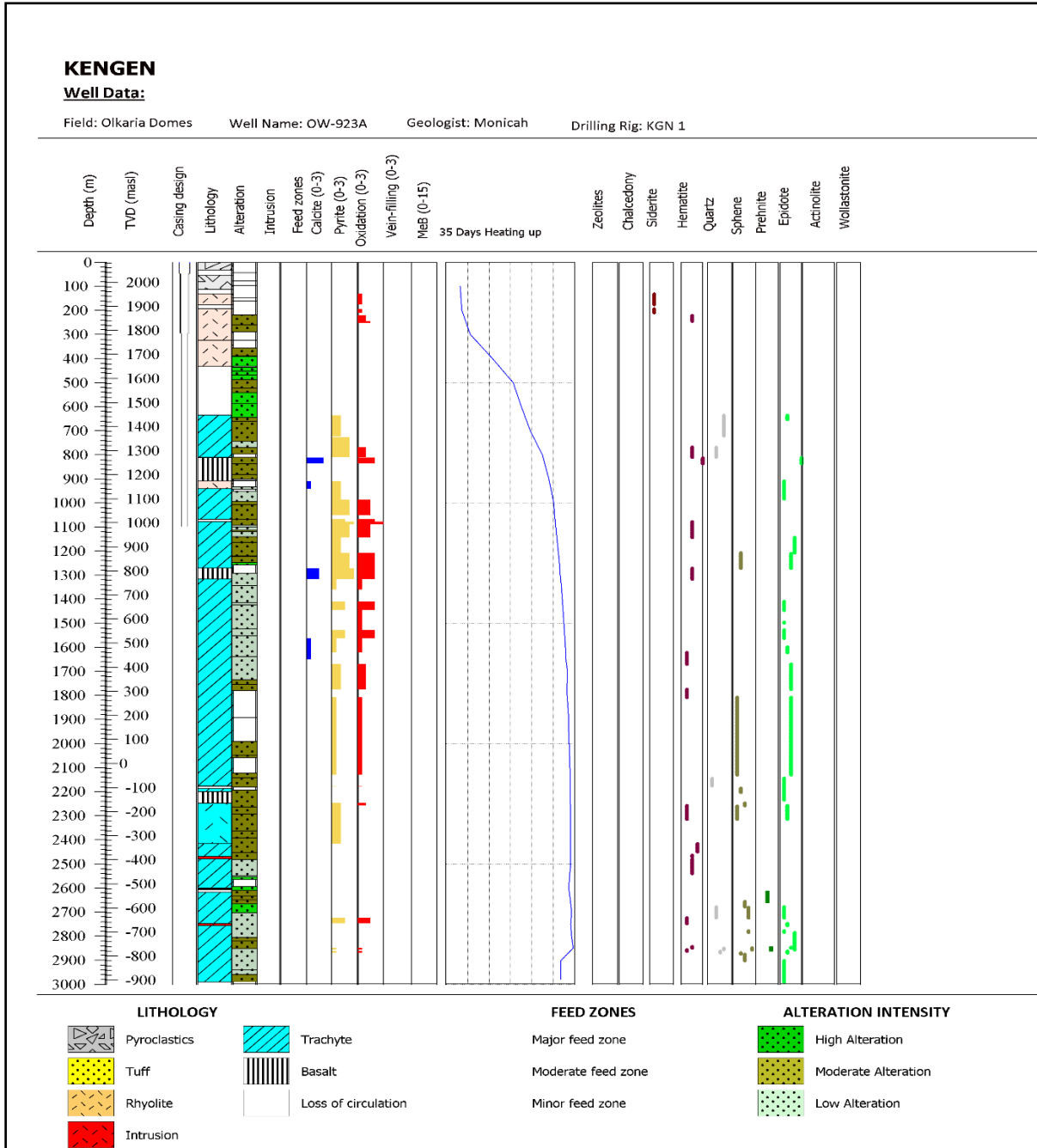
Actinolite is a green to greyish green in color, was forming a radiating fibers or acicular crystals and also massive to granular aggregates in the groundmass. The mineral was formed as a replacement of ferromagnesian minerals. Actinolite occur in deeper hotter parts of OW 924A at 1140 m, OW 923A at 2130 m and OW 1844 m. The lowest depositional temperature of actinolite is about 290°C.

Figure 2 indicates that at 850 m there is basalt which is the cap rock, the trachyte acts as the reservoir rock from the depth of 1500 m. The intrusions act as the heat sources in the well. Presence of calcite, pyrite and vein filling indicate the well is very permeable. Epidote, actinolite and wollastonite present from a depth of 1200 m indicating the formation temperature is above 250°C. From the 51 days heat up profile at 1000 m a kick of the graph which signify the feed zone at this zone is heating up, the second feed-zone is at 2600 m and allow cold inflow.



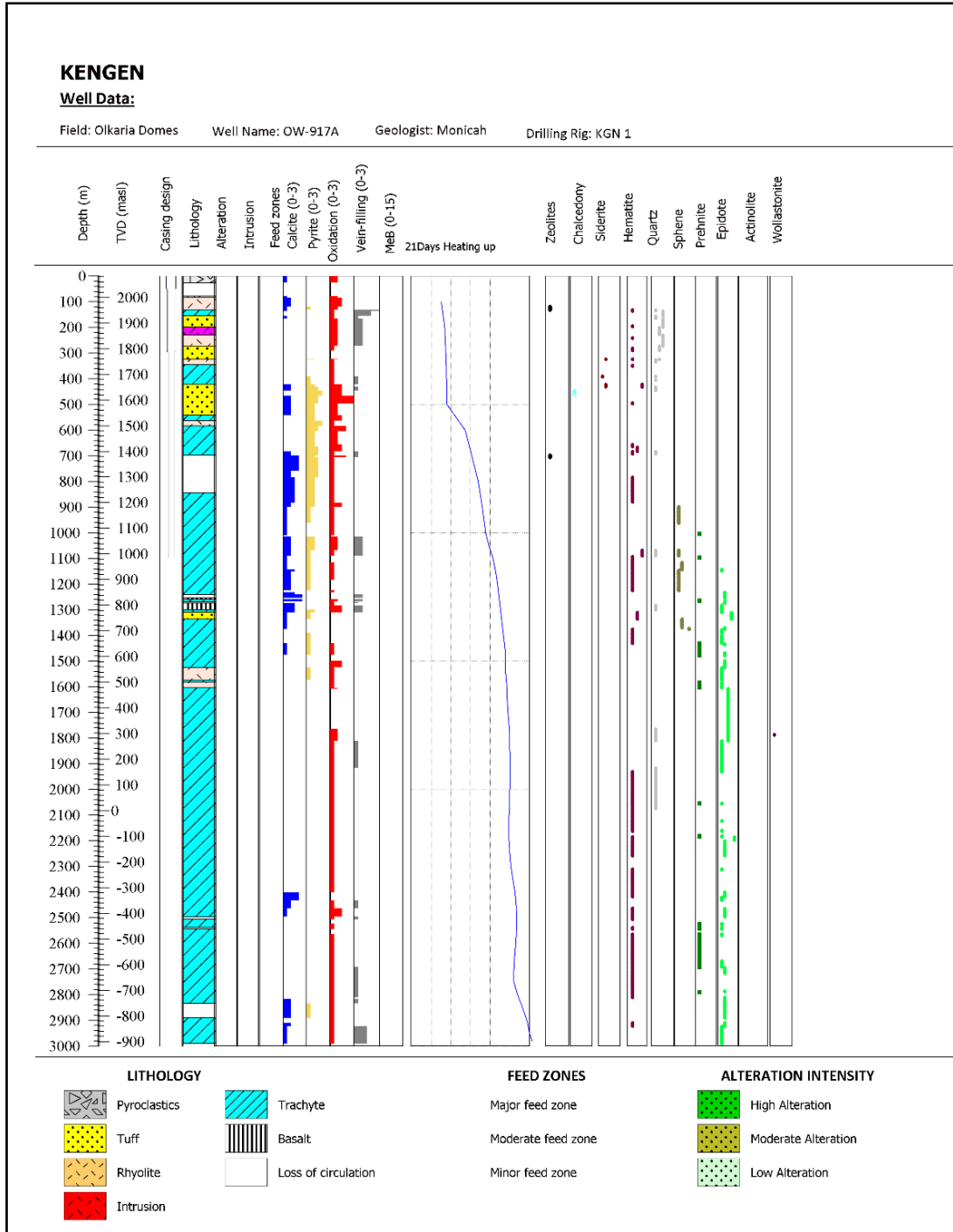
**Figure 2: Lithology, permeability, heat up temperature and Alteration mineralogy of well OW 924A in Olkaria Geothermal Field.**

OW 923A is a production well which was drilled in the year 2015, it is a directional well (N30°) targeting the ring structure. The lithology of well OW 923A in Olkaria Geothermal Field is shown in Figure 3. The 35 days heating up profile indicates that at 950 m, temperatures increase to almost the bottom of the well which tend to decrease slightly. Pyroclastic occur from the depth of 0 to 120 m in OW 923A then underlay by rhyolite from 120 to 450 m. loss of circulation exist from 450 – 650 m which should be cased off, basalt rock of about 100 m is noted to cap the steam in this well and from 1000 m to 2900 m trachyte dominate the well.



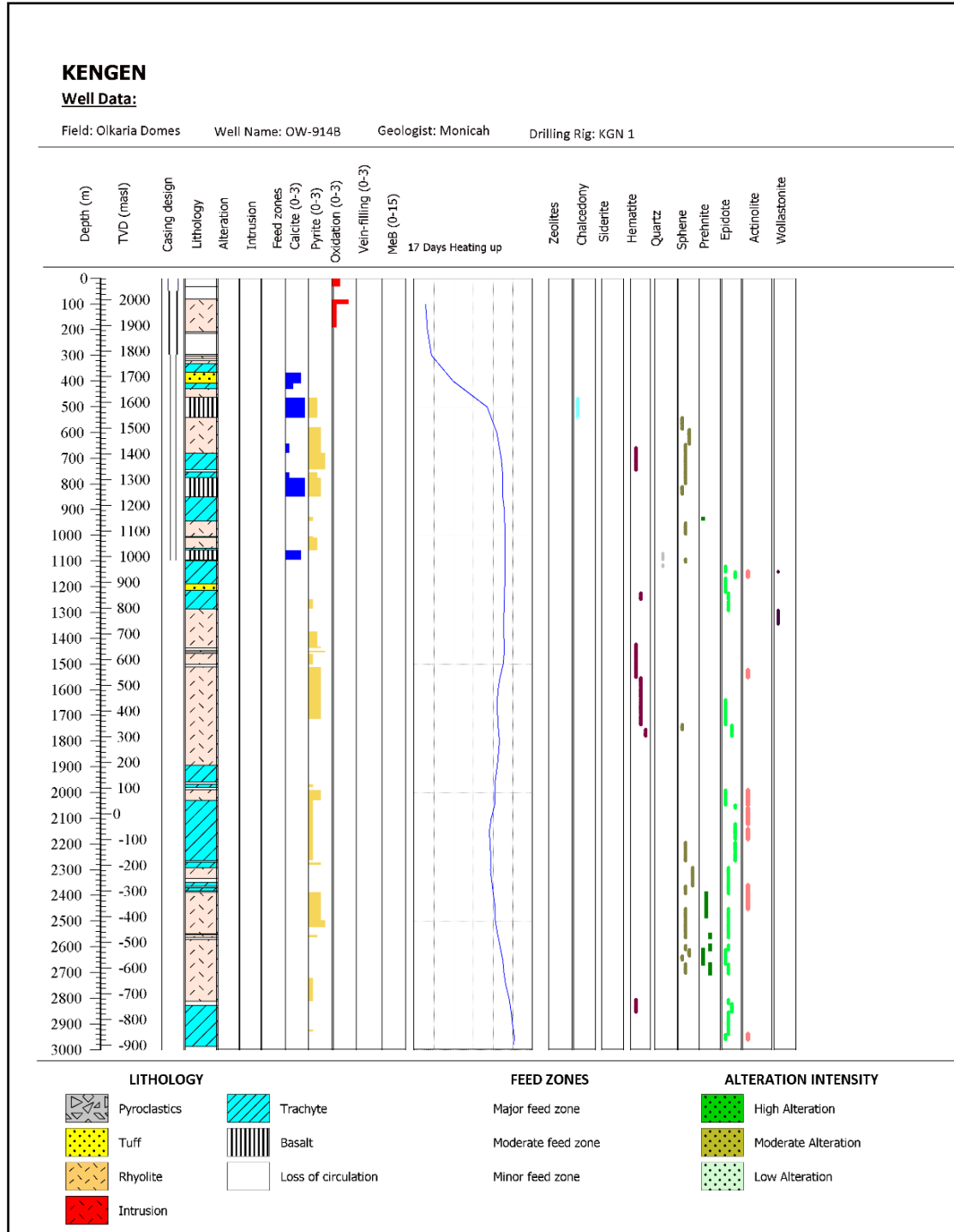
**Figure 3: Lithology, permeability, heat up temperature and Alteration mineralogy of well OW 923A in Olkaria Geothermal Field.**

OW 917A is located in Olkaria domes, it produces steam capacity of 3.0 Mw power. The well was drilled in 2014 with direction of N315° targeting the ring structure. Like OW 923A, epidote is the only high temperature mineral which is present in the well OW 917A from a depth of 1550 – 3000 m. Oxidation intensity in the well is thought to occur from 0-3000 m but in low intensity, thus indicate slow cooling of the well. Figure 4 is the lithology logs with permeability and high temperature indicator minerals.



**Figure 4: Lithology, permeability, heat up temperature and Alteration mineralogy of well OW 917A in Olkaria Geothermal Field.**

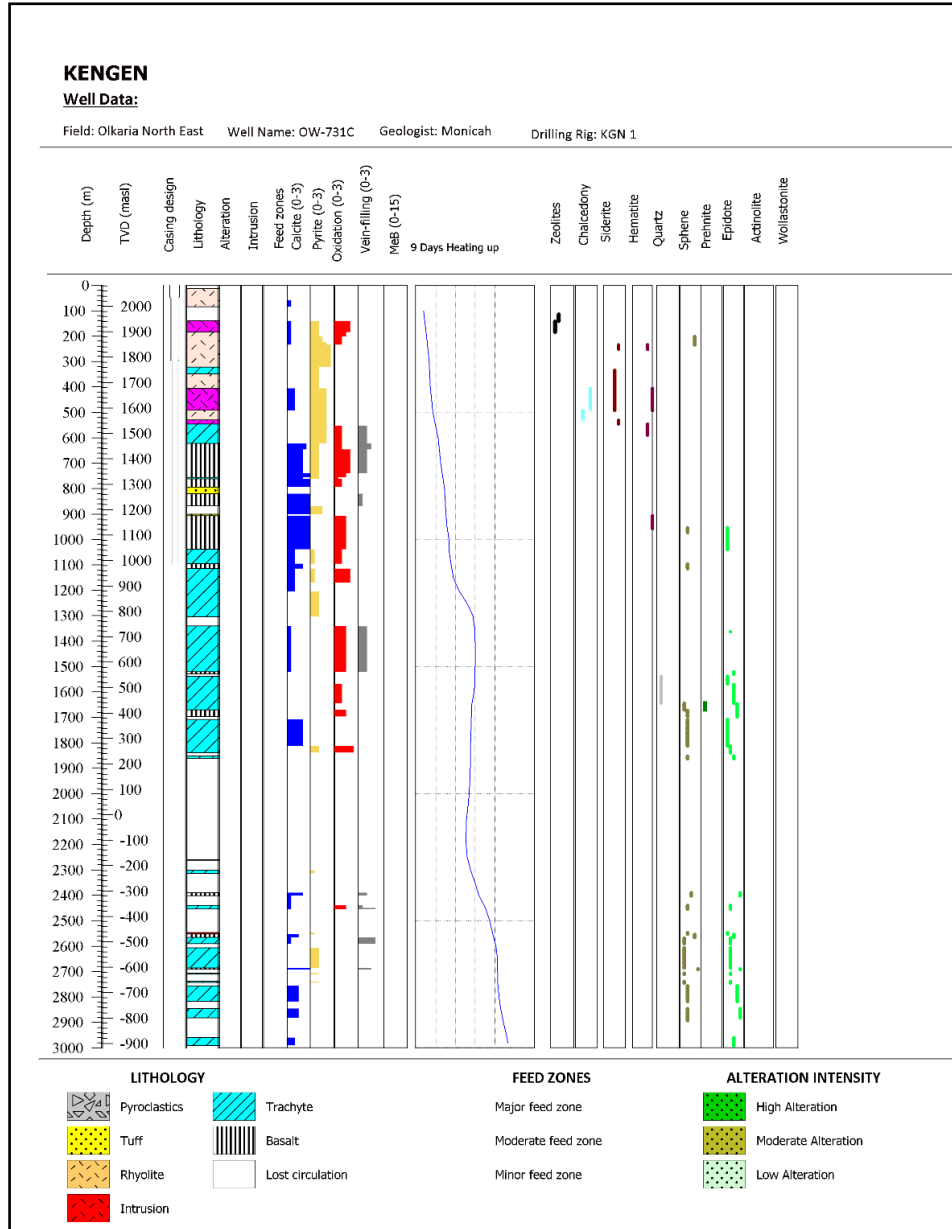
Figure 5 is the lithological description of OW 914B the figure shows that rhyolite formation dominate the well from top to bottom, trachyte and basalt is also absorbed.



**Figure 5: Lithology, permeability, heat up temperature and Alteration mineralogy of well OW 914B in Olkaria Geothermal Field.**

OW 731C is located in the North East field of Olkaria Geothermal Field. It produces a steam capacity of 6.4 MW of geothermal power. The structural map indicates that the well cuts two intersecting structure that is the Ololbutot fault and the Olkaria fault. The faults are indicated by a layer of loss of circulation at the deeper depth 1900 – 2550 m. Figure 6





**Figure 6: Lithology, permeability, heat up temperature and Alteration mineralogy of well OW 731C in Olkaria Geothermal Field.**

OW 39B is a production well located in Olkaria East geothermal field; it was drilled in the year 2014 with the purpose of providing steam for ongoing construction of Olkaria I AU 6. The well cuts the Ololbutot fault shallower depth. Figure 7 suggest that from 1200 m to 3000 m the wells has loss of circulation and trachytic formation, the thicker length of loss of circulation could be associated to structural faults.

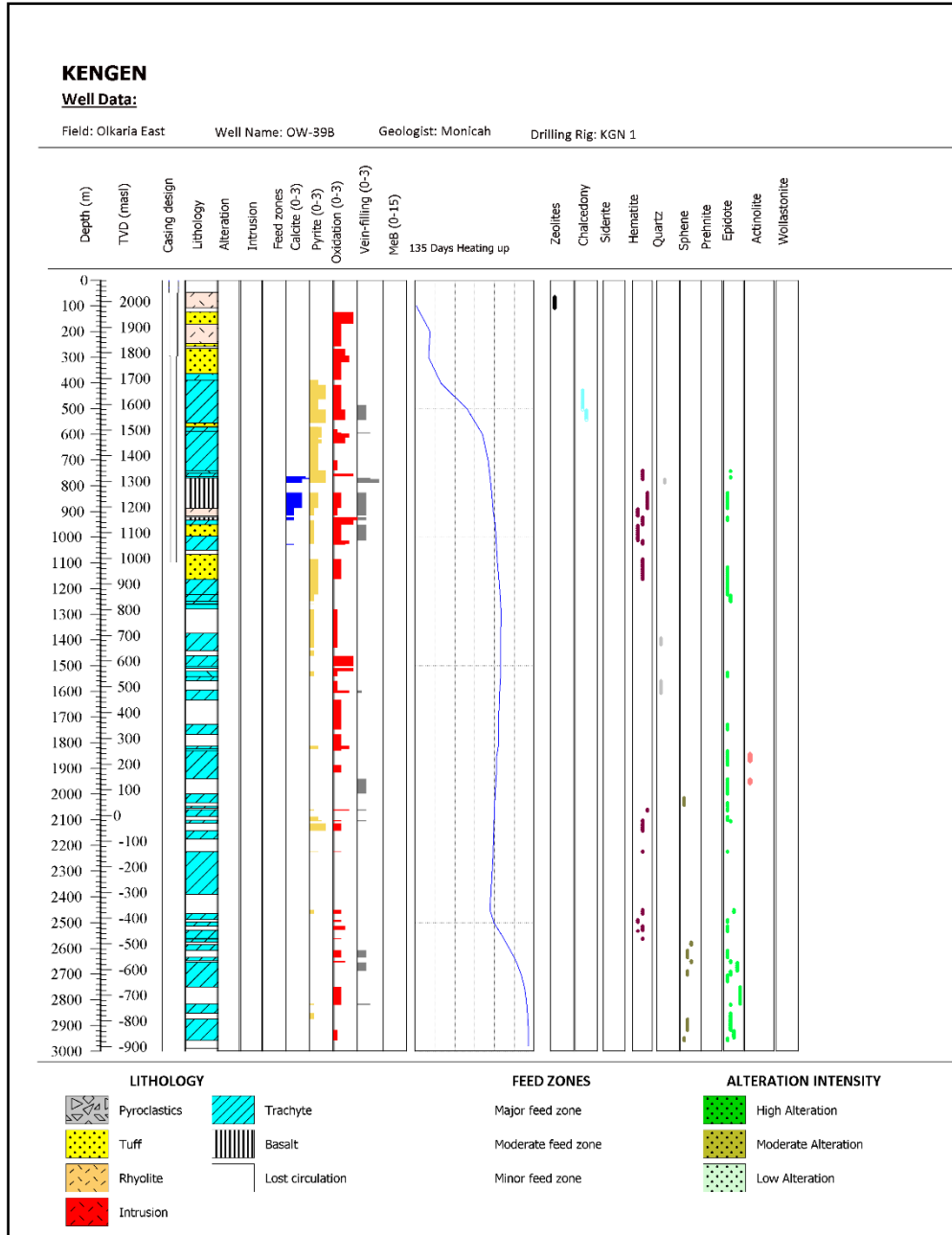


Figure 7: Lithology, permeability, heat up temperature and Alteration mineralogy of well OW 39B in Olkaria Geothermal Field

### V. Conclusion

The main rock types identified in the study wells are pyroclastic, rhyolite, tuff, basalt, trachyte and intrusion. Basalt and tuff acts as the cap-rock and trachyte is the reservoir rock with intrusion indicating the heat source is near geothermal systems in Olkaria. Presence of pyrite, calcite and oxidation signify that the wells within Olkaria geothermal systems are permeable. The alteration mineral distribution of wells shows a trend where low alteration temperature minerals like zeolite and chalcedony occur at the upper part of the well. Then it is replaced by moderate temperature alteration minerals like quartz, wairakite and sphene. Later at deeper depth higher temperature minerals like prehnite, epidote and actinolite do exist.

### References

- [1]. Clarke, Woodhall, Allen, & Darling. (1990). Geological, volcanological and hydrogeological controls of the occurrence of geothermal activity in the area surrounding Lake Naivasha, Kenya. Kenya: Ministry of Energy report., Kenya.
- [2]. Lagat, J. (2009). Hydrothermal alteration mineralogy in geothermal fields with case examples from Olkaria domes Geothermal Field, Kenya. Paper presented at the Short course IV on exploration for Geothermal Resources, Lake Naivasha, Kenya.

- [3]. Macdonald, R., & Scaillet, B. (2006). The central Kenya Peralkaline province: insights into the evolution of peralkaline salic magmas. *Petrology*, P. 59 - 73.
- [4]. Mariita, N. (2009). Exploration history of Olkaria geothermal field by use of geophysics: UNU GTP.
- [5]. Marshall, Macdonald, Rogers, Fitton, Tindle, Nejbart, & ., K. (2009). Fractionation of peralkaline silicic magmas: The Greater Olkaria volcanic complex, Kenya Rift valley. *J. Petroleum*, 50, 323 - 359.
- [6]. Mwangi, D. W. (2012). Borehole geology and hydrothermal mineralisation of well OW-916, Olkaria Domes geothermal field, Naivasha, Kenya: KENGEN.
- [7]. Okoo, J. A. (2013). Borehole geology and hydrothermal mineralisation of well OW-39A, Olkaria East geothermal field, Naivasha, Kenya. Kenya.
- [8]. Omenda, P. A. (1998). The geology and structural controls of the Olkaria geothermal system, Kenya. *Geothermics*, 27-1, 55-74pp.
- [9]. Otieno, V. O. (2016). Borehole geology and sub-surface petrochemistry of the Domes area, Olkaria geothermal field, Kenya, in relation to well OW-922. (MSc).
- [10]. Thomson. (1964). Geology of Kijabe area, Ministry of Natural Resources, [Press release]
- [11]. Wamalwa, R. N., Nyamai, C. M., Ambusso, W. J., Mulwa, J., & Waswa, A. K. (2016). Structural controls on the Geochemistry and Output of wells in Olkaria Geothermal field of the Kenya Rift Valley. *International Journal of Geoscience*, 7(12299-1309). doi: 10.4236/ijg.2016.711094
- [12]. Woodhall. (1987). Geology of Longonot Volcano, The Greater Olkaria Volcanic complex and adjacent area. British.

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