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Characterization of Subsurface Permeability of the Olkaria East Geothermal Field

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ABSTRACT

Subsurface permeability refers to the conditions that favors a productive well. Permeability forms an important aspect of a productive geothermal well. The notable permeability parameters of a geothermal well include intense loss circulation zones, veining, fracturing and micro fracturing, and faulting. Fault and fracture identification is essential in defining subsurface permeability. Mineralogical sequencing in a geothermal well such as pyrite dissemination and calcite precipitation among others are essential in characterizing its permeability. The study area (Olkaria Geothermal field) is located in the Eastern Rift-Valley of Kenya. It is divided into East, North East, West, Domes, North West and Central areas. It is structurally controlled, dominated by faults, fissures, volcanic centers, and domes among others. The main tectonic structures in the Olkaria volcanic complex include fractures, faults, the Ol'Njorowa gorge and the ring structure. The main faults are the ENE-WSW Olkaria fault and the N-S Ololbutot fault, as well as NNE-SSW, NW-SE and WNWESE trending faults. Surface manifestation features such as fumaroles, hot-grounds, geothermal grass, and sulfur deposits are found in the study area. The Olkaria East Geothermal field forms a section of the seven divisions of the whole Olkaria field. The study approach includes modelling of existing wells stratigraphy, geological cross-sections, mapping of fault boundaries, among others. Correlation of loss circulation zones and alteration intensity was also done. The knowledge will be essential in locating new geothermal wells and updating of the existing conceptual model.

1. INTRODUCTION

Geothermal systems occur where subsurface permeability and temperature are sufficiently high to drive fluid circulation (Siler & Glen, 2018). Characterization requires thorough understanding of the physics that governs the flow of mass through a geothermal reservoir (Julliusson, 2012). Characterization of geothermal systems can be established by observation of fracture networks using geothermal well production data. Geological parameters such as micro-faulting, fracturing, veining, alteration intensity, loss of circulation returns, the presence of calcite, and abundance of pyrite can determine a well's subsurface permeability. An analysis of geological logs of some selected wells in the Olkaria East field was used to define the permeability within the field. These wells are OW-37, OW-41, OW-40 and OW-41A was used for the study.

1.1. Study area

The Olkaria East Geothermal is a subdivision of the Olkaria Geothermal field, which is located in the Eastern Rift-Valley of Kenya (Figure 1). It is structurally controlled, dominated by faults, fissures, volcanic centers, and domes, among other features. It is a high temperature geothermal field.

1.2. Study objective

The objective of the study is to characterize the subsurface permeability of the Olkaria East Geothermal field by examining geological features related to permeability such as fractures, faults, circulation losses and selected indicator minerals like calcite, quartz and pyrite of specific wells within the Olkaria Geothermal field.

2. LITERATURE REVIEW

The known data on the mentioned parameters are discussed in the following subsections.

2.1. Loss circulation zones

Circulation losses are important in the interpretation of feed zones in geothermal wells, which indicate good permeability. Loss circulation zones are associated with fracture zones and high-grade alteration. Total circulation losses, which are areas with no circulation returns, were identified in each well, mapped and correlated.

2.2. Veins and veinlets

Veins and veinlets are fractures and micro-fractures, respectively, filled up by secondary minerals deposited from hydrothermal fluids, which can be of primary origin due to the formation of joints or secondary, due to tectonic movements (Otieno, 2016). Within the Olkaria Geothermal field, most veins were infilled and now present secondary minerals such as calcite, quartz and oxides.

2.3. Faults and fractures

Faults and fractures are formed when rocks are subjected to pressure resulting in varying degree of openings. During periods of volcanic unrest, fractures are started by magma resurgence and driven open to the earth's surface (Galland et al., 2014). When fractures/micro-fractures are infilled, they form veins and veinlets. They are the main conducts for fluids to move in the Olkaria geothermal reservoir, and are responsible for bulk fluid transport. Fractures in Olkaria geothermal field are aligned along the NW-SE, NE-SW and NNW-SSE directions. Fracture propagation is attributed to tensile stress that causes rifting or to magma resurgence

Fractures are also found in close proximity to volcanic centers and volcanic plugs (Munyiri, 2016). Faults act as carriers for gases from magmatic sources and brings them to the surface. The presence of faults in the geothermal field is essential in fluid movement.

In the Olkaria geothermal field, normal faults are observed along erosional gullies. Most of the faults in the area are oriented in the NW-SE, NNW-SSE, ENE-WSW and NE-SW directions while a few of the faults are oriented in E-W and N-S direction. Faults of the highest displacement are encountered along the Olnjorowa Gorge. The structural map of the Olkaria Geothermal Area showing local faults is presented in Figure 2.

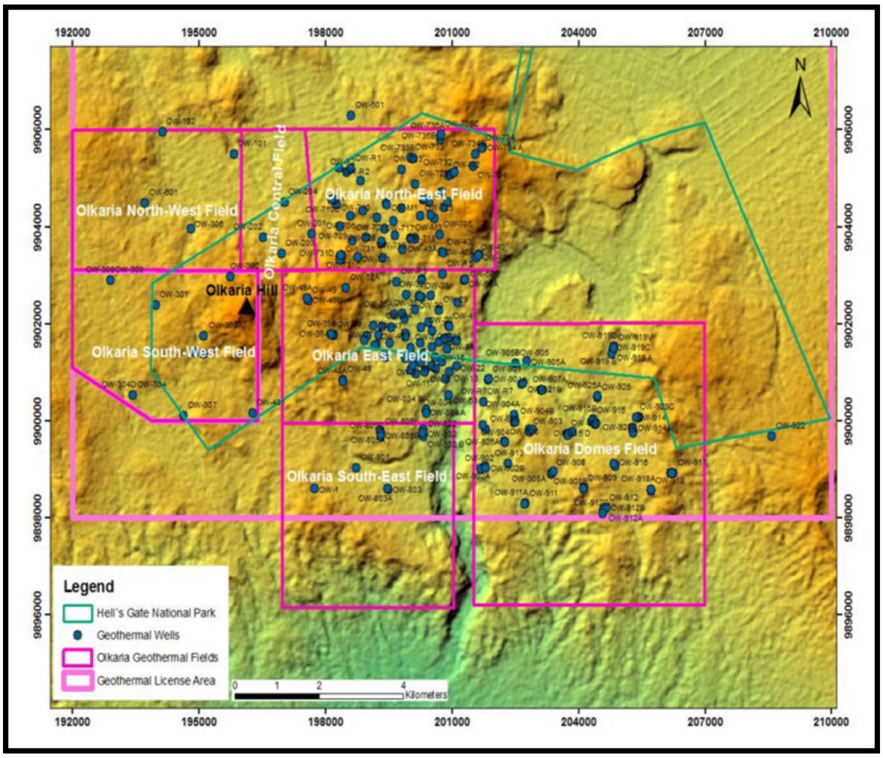

Figure 1: Resource map showing the Olkaria Geothermal field, its subdivisions and wells (blue dots).

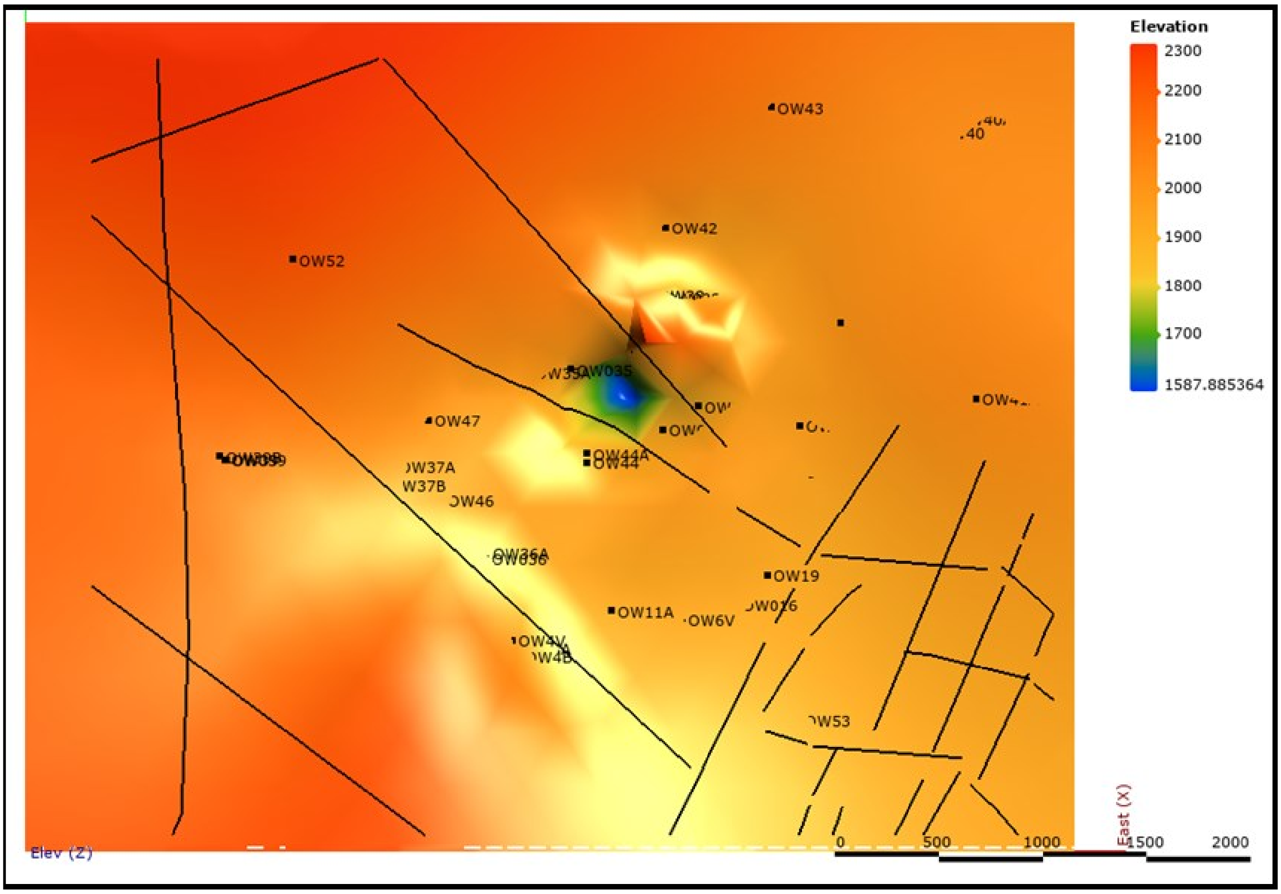

Figure 2: Fault distribution map in the Olkaria East field.

2.4. Pyrite mineralization

Pyrite is observed under the binocular microscope as euhedral cubic crystals with brassy-yellow lustre. Pyrite presence in significant amounts has been associated with permeable zones in most geothermal systems (Otieno, 2016). Hydrothermal pyritization results from precipitation and recrystallization of mackinawite after upwelling of thermal water (Wagner et al., 2005).

2.5. Calcite deposition

Calcite is a product of the replacement of calcium alumino-silicate minerals such as plagioclase, pyroxene phenocrysts, and discrete silicic volcanic fragments (Otieno, 2016; Simmons and Christenson, 1994). It is observed in veins and vesicles of rocks in the Olkaria East field. The presence of platy calcite indicates mixing of fluids with different compositions. In active geothermal systems, it is regarded to be stable in broad temperatures ranging from 50 to 300°C (Simmons and Christenson, 1994).

3. RESULTS AND INTERPRETATION

3.1. Circulation loss zones

Figure 3 is a 2D model representation of the distribution of loss circulation zones within the Olkaria East Geothermal field.

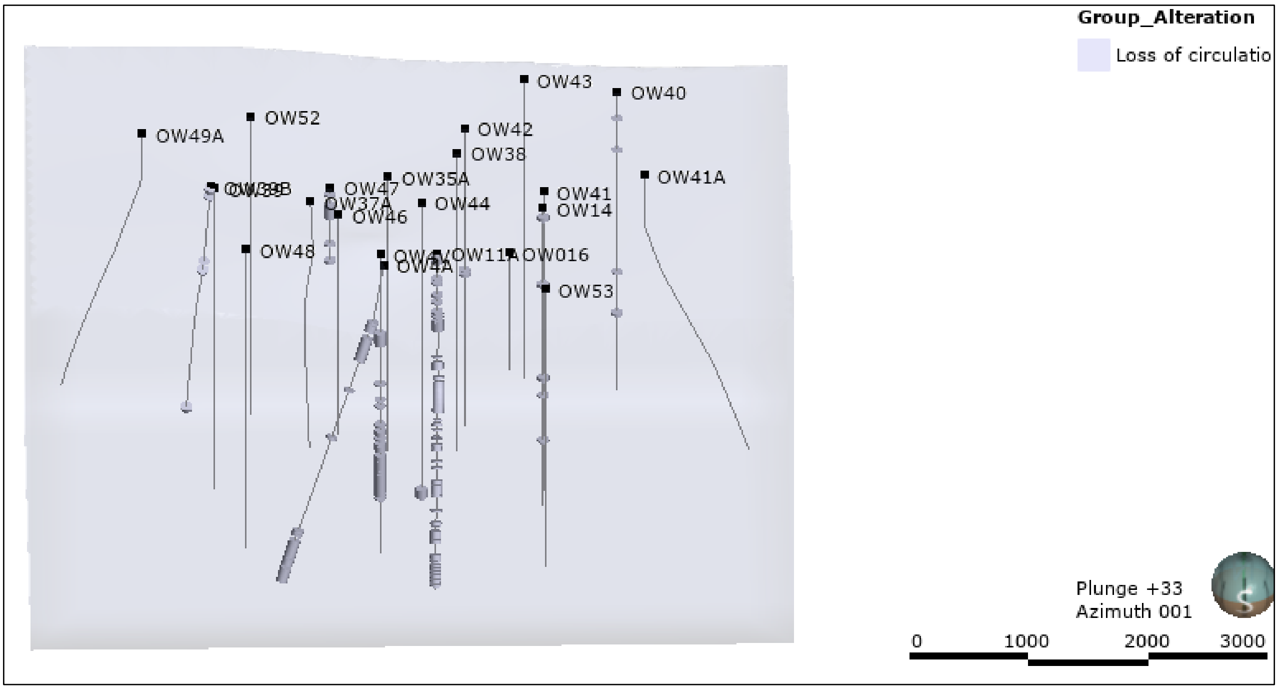

Figure 3: Zones of loss circulation identified in wells of the Olkaria East geothermal field.

The following key observations were made from Figure 2: Loss circulation zones occur in shallow depths at wells OW-49A, OW-52 and OW-4. They are also observed at greater depths at 800-900m (OW-30), 1000-1100m (OW-38), 850-1000m (OW-42A), 1500-1600m (OW-43A) and at even greater depths of 1848m and 2800m in the well OW-41A. Wells OW-49A, OW-41A, OW-48, OW-52, OW-44, OW-42, OW-43 and OW-48 had no loss circulation zones.

3.2. Veins

Veins were observed in most wells in Olkaria East. In well 43A, veins in the uppermost zone below 850m were mainly filled with quartz, presenting vesicles infilled with both calcite and quartz. Down the hole from 1000m, most veins and vesicles are mainly infilled with clays, chlorite and epidote, with minor pyrite. In well OW-41, quartz is infilling veins between 2100-2424m, pyrite was observed in moderate concentrations at 356-700m, 862-1550m, 2190-2704m and 2884-2942m. In the upper part of the well OW-37A, above 570 m, vesicles are mainly filled with calcite, quartz and clays. At greater depths, 616 m and below, vesicles were noted to be filled with wairakite (616 m), prehnite (696 m) and epidote (1210 m), indicating a considerable increase in temperature with depth (Otieno et al., 2014). An interval model showing the distribution of veins within the Olkaria East geothermal field is shown in Figure 4.

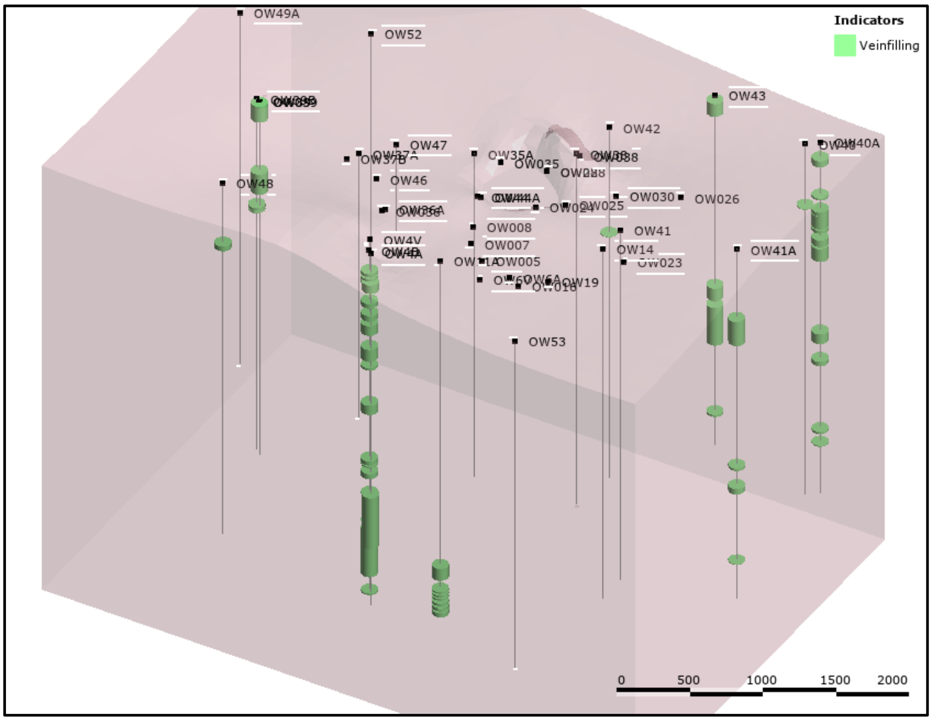

Figure 4: Veins distribution in the Olkaria East Field

3.3. Faults and fracture

A fault model was created using structural data as shown in Figure 5.

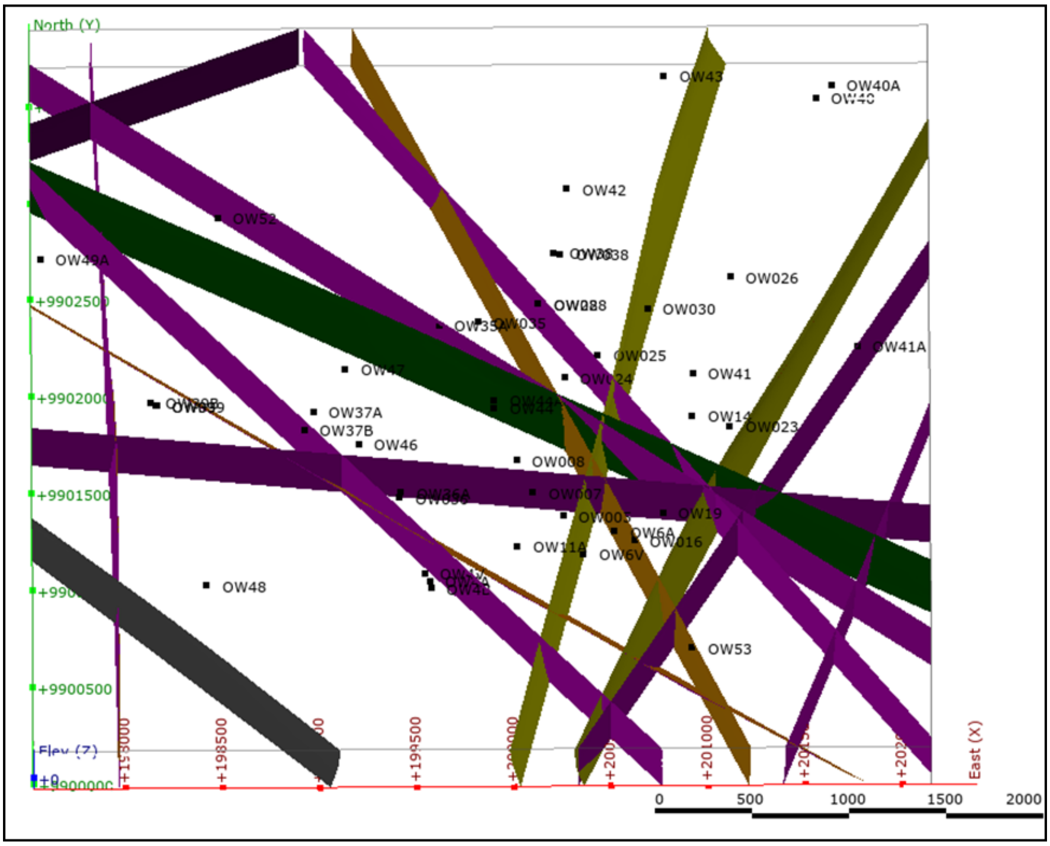

Figure 5: Fault Distribution in Olkaria East

It can be noted in Figure 6, that wells OW-11, OW-43, OW-53, OW-6V, OW-005, OW-007, and OW-35 are located adjacent to SE-NW trending faults. On the other hand, wells OW-36, OW-007, and OW-19 are sited adjacent to the N-S trending faults. The wells OW-6V, OW-005, OW-25, OW-030, OW-023 and OW-41 are sited adjacent to NE-SW trending faults. In general, areas in the eastern zone of the study area depict a large concentration of intersecting faults, where several wells have been drilled. The fracture zones identified in the wells of Olkaria East are shown in Figure 6.

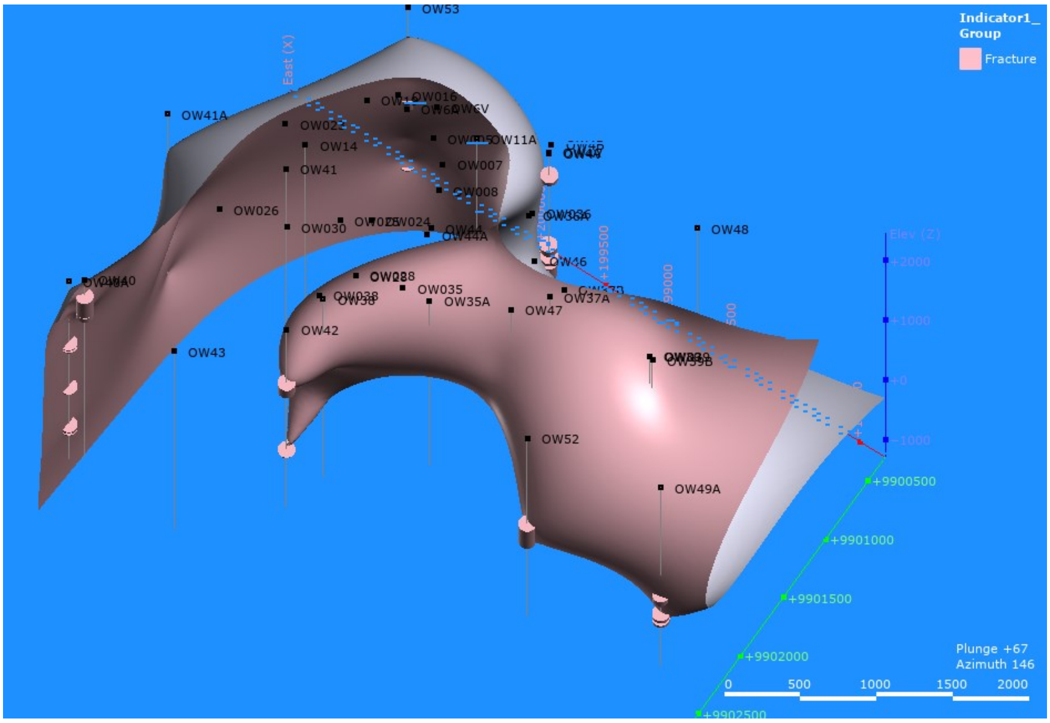

Figure 6: Zones of fracture identified in selected wells of the Olkaria East Geothermal Field

From Figure 6, it was observed that subsurface fracturing was intense in shallow depths at wells OW-40 (190-264m, 270-340m), OW-41A (422-574m), OW-46 (440-452m) and OW-52 (0-112m). Fractures are observed at greater depths in wells OW-49A (2138-2156m, 2178-2280m, 2664-2750m), OW-42 (2654-2688m) and OW-53 (2676-2700m).

3.4. Pyrite mineralization

In the well OW-41, pyrite is observed in moderate quantities between 356-500m, 862-942m and 2292-2578m. In OW-42, pyritization is observed in moderate intensity between 322-360m, 456-644m and 2600-2800m (minor intensity). It is also noted in moderate to high intensity in OW-40 between 516-746m, 1838-2024m. These zones generally exhibit moderate to high permeability. The general distribution of pyrite in the Olkaria East wells is shown in Figure 7.

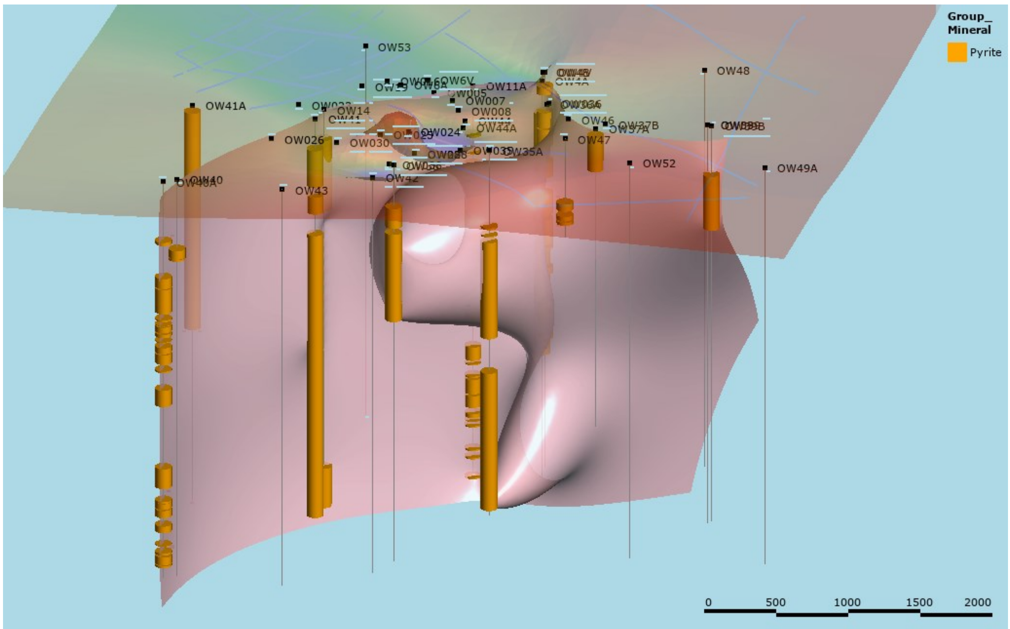

Figure 7: Pyrite distribution in wells of Olkaria East.

3.4. Calcite deposition

Calcite coexists with pyrite in most wells in the Olkaria East. It occurs at shallow depths in zones encompassing th wells OW-42, OW-47, OW-35, and OW-48. It is observed at greater depths in OW-4A. There is significant low concentration of calcite in the wells OW-53, OW-49, OW-52 and OW-43. The calcite distribution is shown in Figure 9.

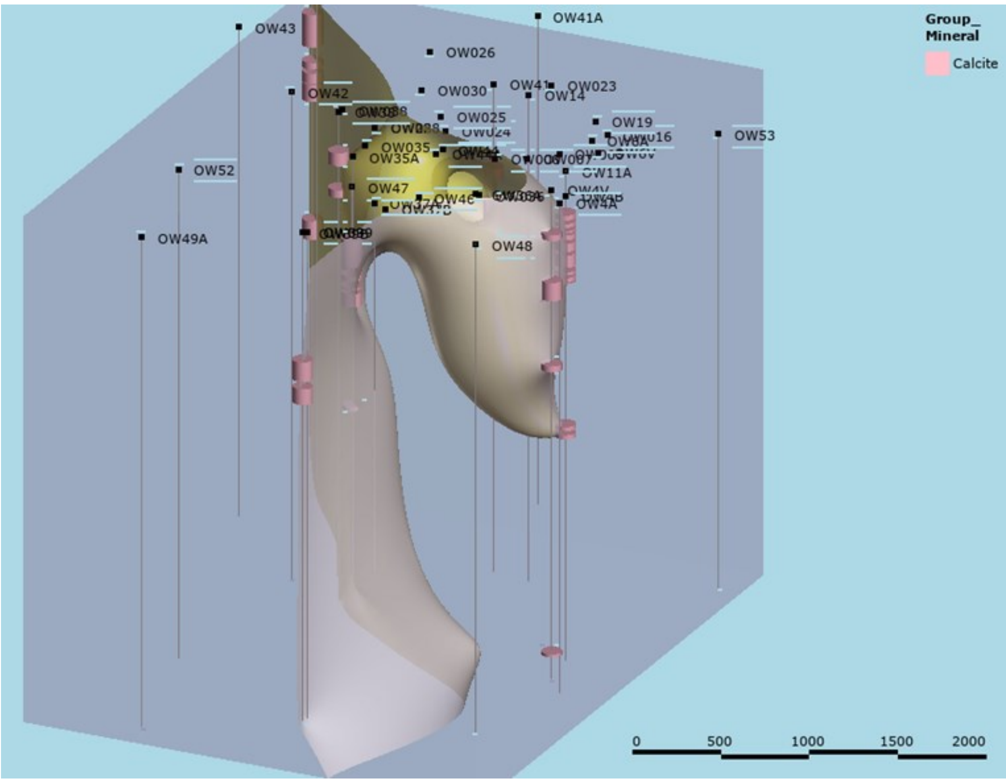

Figure 8: Calcite distribution in wells of Olkaria East geothermal field

3.5. Combined permeability factors model

Two cross-sections (E-W) as shown in Figure 9 presents all the discussed factors that favor permeability in the wells of Olkaria East geothermal field, i.e. faults, pyrite mineralization, calcite deposition loss circulation zones. Alteration mineralogy data from (Epidote, chlorite, and actinolite zones) was also integrated in the model. It is assumed that the depth intervals where most of those factor are coincident, are the most permeable zones in the wells.

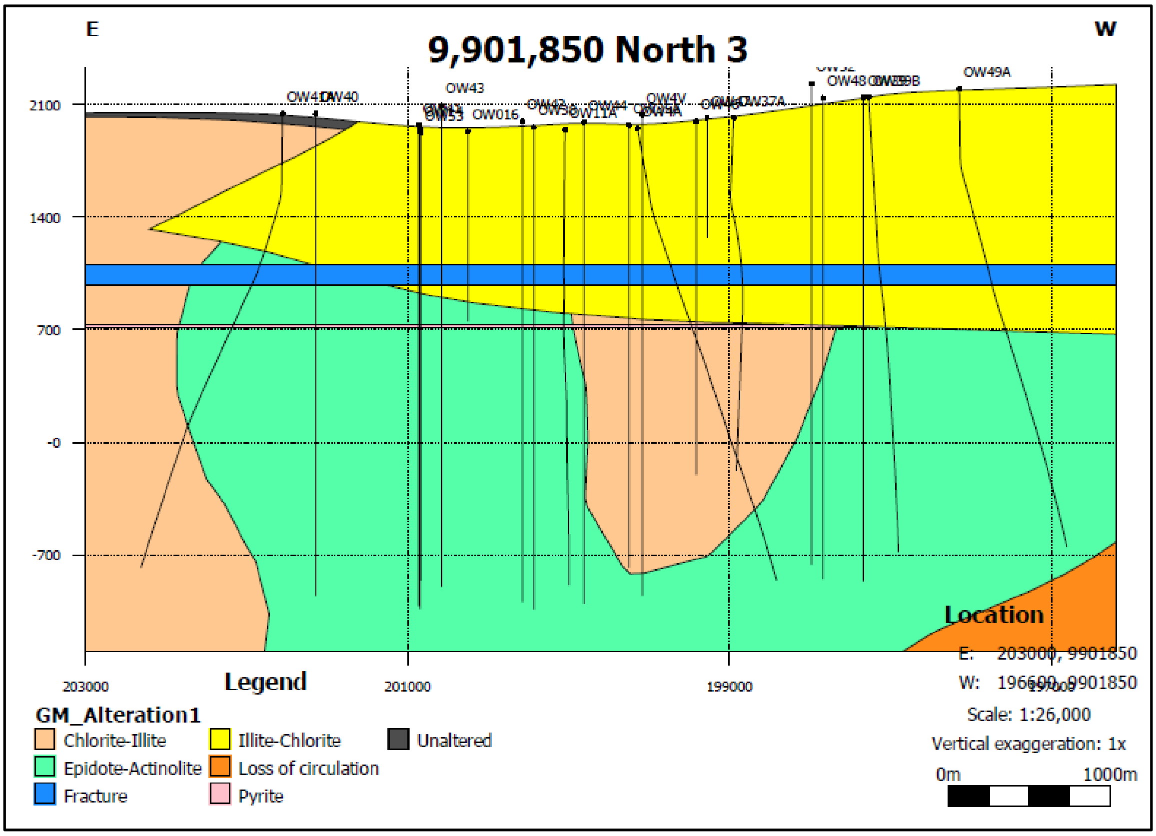

Figure 9: Cross section showing some wells of Olkaria East geothermal field, with the location of the main factor favoring permeability.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

Subsurface permeability was identified at the subsurface of the Olkaria East geothermal field by characterizing some features related to it, such as faults, fractures, loss-circulation zones, pyrite mineralization, and calcite deposition. Most faults are observed along erosional gullies oriented in the NW-SE, NNW-SSE, ENE-WSW and NE-SW direction while a few of the faults are oriented in E-W and N-S direction. Loss circulation zones were observed in the wells both at shallow and deep zones in the study area. Similarly, pyrite mineralization was observed in most wells at varying depths. Calcite coexisted with pyrite. It can be concluded that areas with high concentration of those features exhibit the highest subsurface permeability. From the study, most geothermal wells in the Olkaria East geothermal field are fairly permeable.

4.2. Recommendations

Following are the recommendations based on study findings:

1. Incorporate reservior data (temperature, pressure and vapor saturation) in modelling subsurface permeability, preferably using TOUGH-2 software.
2. More studies to be carried out in Olkaria Domes and South East areas to establish the overlall extent of subsurface permeability beyond the study area.
3. Establish the role of alteration mineralogy and its effect on the subsurface permeability of the field.

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