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Characterization of Subsurface Permeability of the Olkaria East Geothermal Field

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ABSTRACT

Subsurface permeability affects the output of a productive geothermal wells. Permeability forms an important aspect of a productive geothermal well. The notable permeability parameters of a geothermal well include intense loss zones, veining, fracturing and micro faulting. Fault and fracture identification is essential in defining subsurface permeability. Mineralogical sequencing in a geothermal systems such as pyrite dissemination, calcite precipitation among others are essential in characterizing the permeability of drilled wells. 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 centres, 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, NNESSW, NW-SE and WNWESE trending faults. Surface manifestation features such as fumaroles, hot-grounds, geothermal grass; sulphur deposits are found in the study area. The Olkaria East Geothermal field forms a section of the seven divisions of the Olkaria field. The study approach includes modelling of existing well stratigraphies, geological cross-sections, mapping of fault boundaries among others. Correlation of loss zones and alteration intensity was also done. The knowledge will be essential in siting of new geothermal wells and updating of the existing conceptual model.

1. INTRODUCTION

Characterization requires thorough understanding of the physics that governs the flow of mass through a geothermal reservoir (Julliusson, 2012). Subsurface permeabilty is determined observation of wells for veining, alteration intensity, circulation losses, the presence of calcite, and an abundance of pyrite. For this study, an analysis of the well properties of selected in the Olkaria East field was done. Data from OW-37, OW-41, OW-40 and OW-41A were used to establish subsurface permeability in the study area.

1.2. Study area

The Olkaria East Geothermal is a subdivision of the wider Olkaria field, which is located in the Eastern Rift-Valley of Kenya. It is structurally controlled, dominated by faults, fissures, volcanic centers, Domes among others (Figure 1). 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, NNESSW, NW-SE and WNWESE trending faults. It is a high temperature geothermal field.

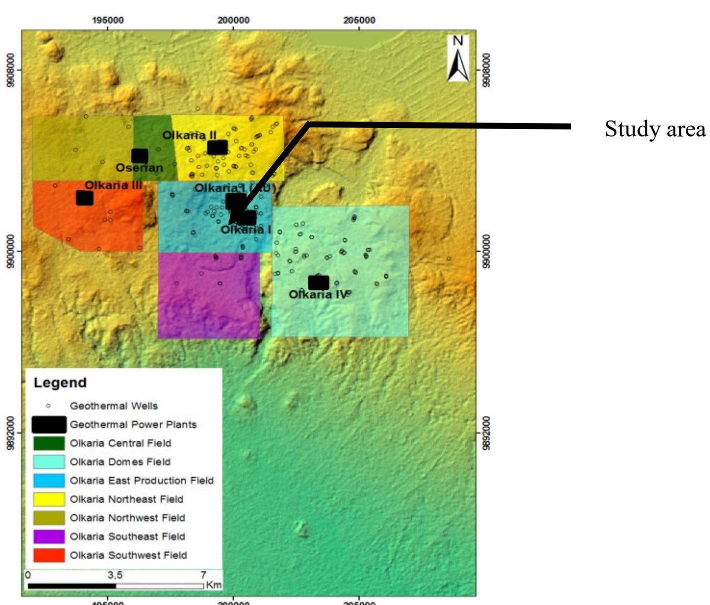

Figure 1: Resource map showing numerous wells drilled in the Olkaria Geothermal field

1.3. Study objective

To characterize subsurface permeability of the Olkaria East Geothermal field using geological information

2. RESULTS

2.1. Loss zones

Circulation losses are important in the interpretation of feed zones in geothermal wells. Loss zones are associated with fracture zones and high-grade alteration. Genuine losses (areas of total loss of circulation returns) was identified, mapped and correlated. Figure 2 represents a cross-sectional correlation of selected wells in the Olkaria East Geothermal field (Figure 2).

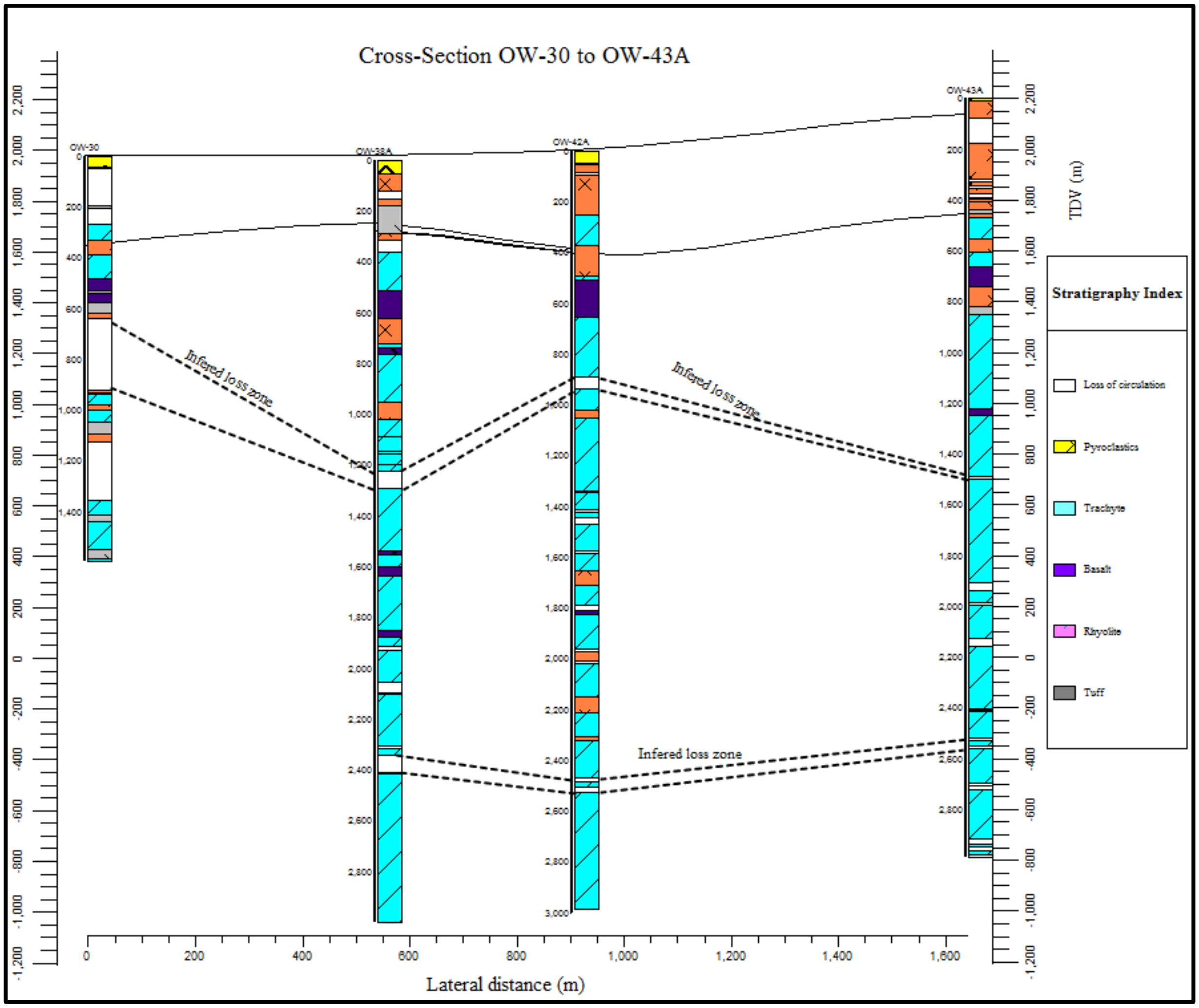

Figure 2: Loss zones correlation in Olkaria East Geothermal field

The major loss zones in the selected geothermal wells in Olkaria East, were encountered between 800-900m (OW-30), 1000-1100m (OW-38), 850-1000m (OW-42A), 1500-1600m (OW-43A) and at greater depths of 1848m and 2800m in the OW-41A. Trachyte and basalts dominate these zones, which are the field's reservoir lithological units.

2.2. Veinfilling

Veins are micro-fractures that are filled up by either fluid or by the deposition of secondary minerals, which can be due to primary jointing or later tectonic fractures (Otieno *etal*., 2014). Vesicles, on the other hand, are pore spaces formed in the rock during an eruption as gas exsolves from magma (Gebrehiwot, 2010). In well 43A, the uppermost zone below 850m was mainly vein-filled with quartz with vesicles being infilled with both calcite and quartz. Down the hole from 1000m, most veins and vesicles are mainly infilled with clays (chlorite) and Epidote but with minor Pyrite.

In well OW-41, Quartz infil veins between 2100-2424m, pyrite was observed in moderate concentrations at 356-700m, 862-1550m, 2190-2704m and 2884-2942m (Figure 2). In OW-37A, the upper part of the well above 570 m, vesicles are mainly filled with calcite, quartz and clays (Figure 3). 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).

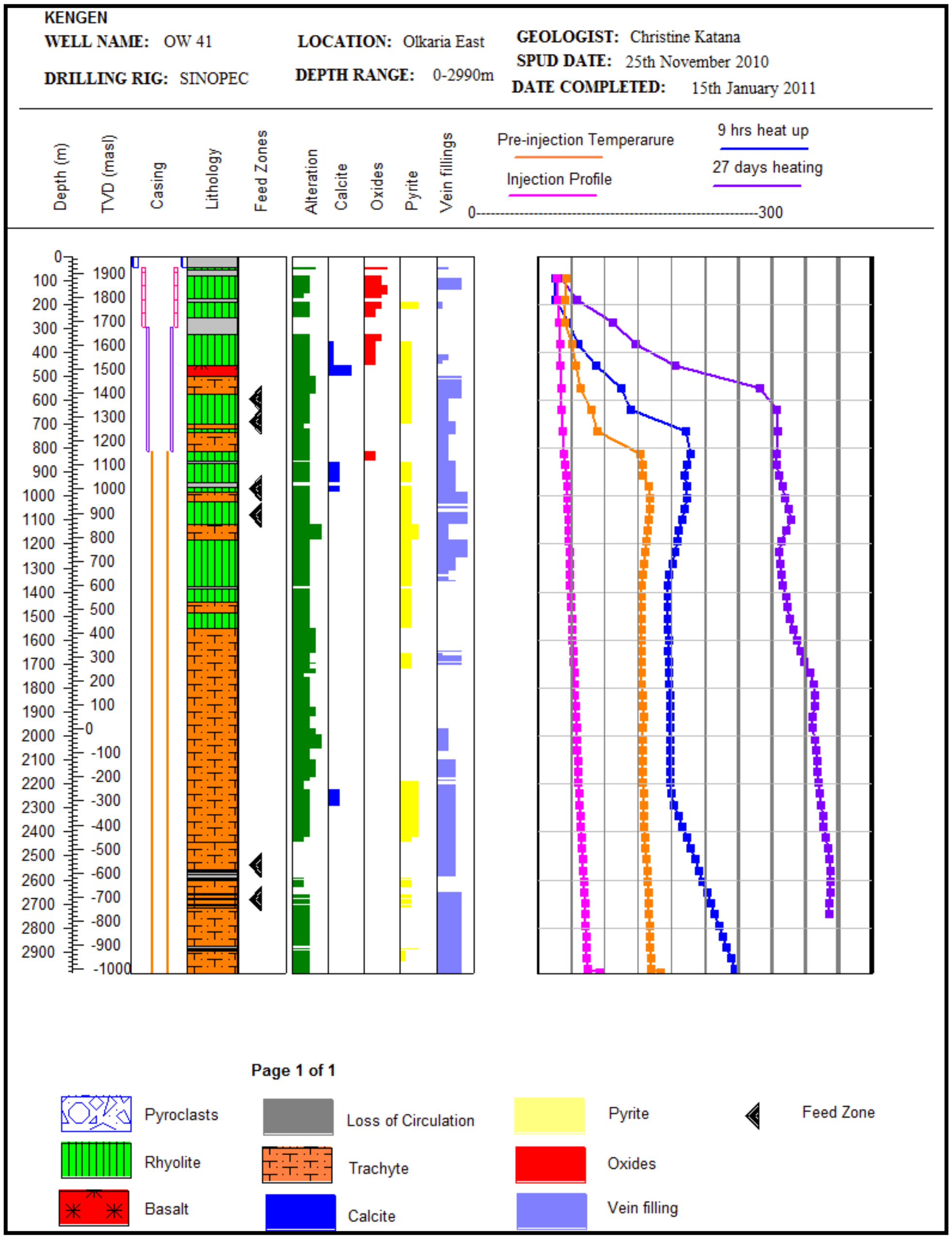

Figure 3: Lithological logs feed points and mineral distribution of OW-41

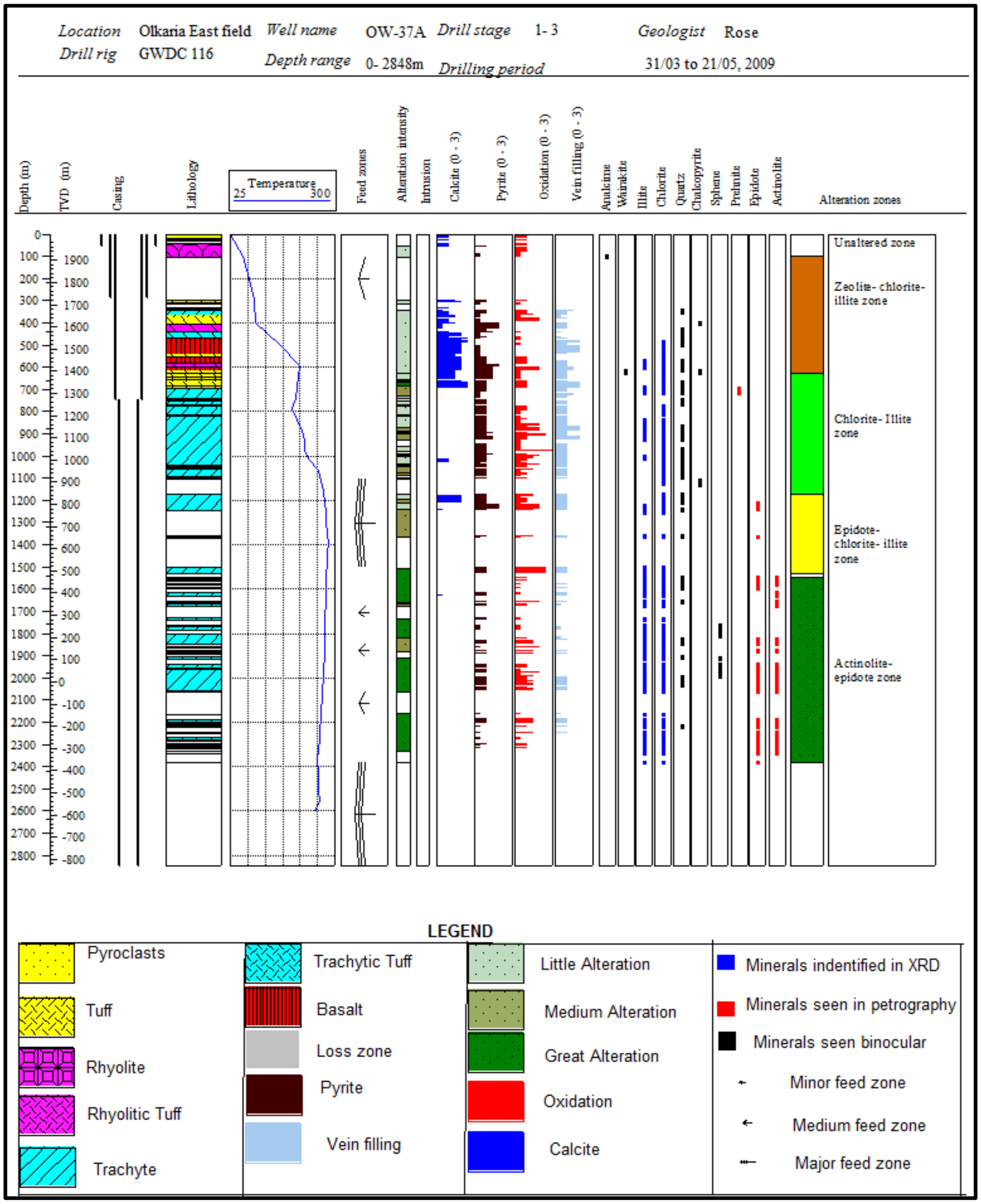

Figure 4: Alteration minerals and alteration zones for well OW-37A

2.2. Fault and fractures

The paper discusses the faults and fractures in the Olkaria area and their influence on subsurface permeability of the area. Fractures and faults are extensional features and are related to subsurface permeability.

2.2.1. Fractures

During periods of volcanic unrest, fractures are initiated 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 formed when rocks are subjected to pressure resulting in varying degree of openings. They are the main avenues of fluid movement in the Olkaria geothermal reservoir. They are responsible for bulk fluid transport. Fractures in Olkaria geothermal field are aligned along the NW-SE, NE-SW and NNW-SSE direction. Fracture propagation is attributed to tensile stress that causes rifting or due to magma resurgence. It was noted that fractures are found in close proximity to volcanic centers and volcanic plugs (Munyiri, 2016).

2.2.2. Faults

Forces acting on the plane and surface of a rock form them. The most common type of fault in the Rift system is the tensile fault (Peacork, et al., 2000). 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 often observed along erosional gullies. Most of the faults in the area are 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. Faults of the highest displacement are encountered along the Olnjorowa Gorge (Figure 5 and 6).

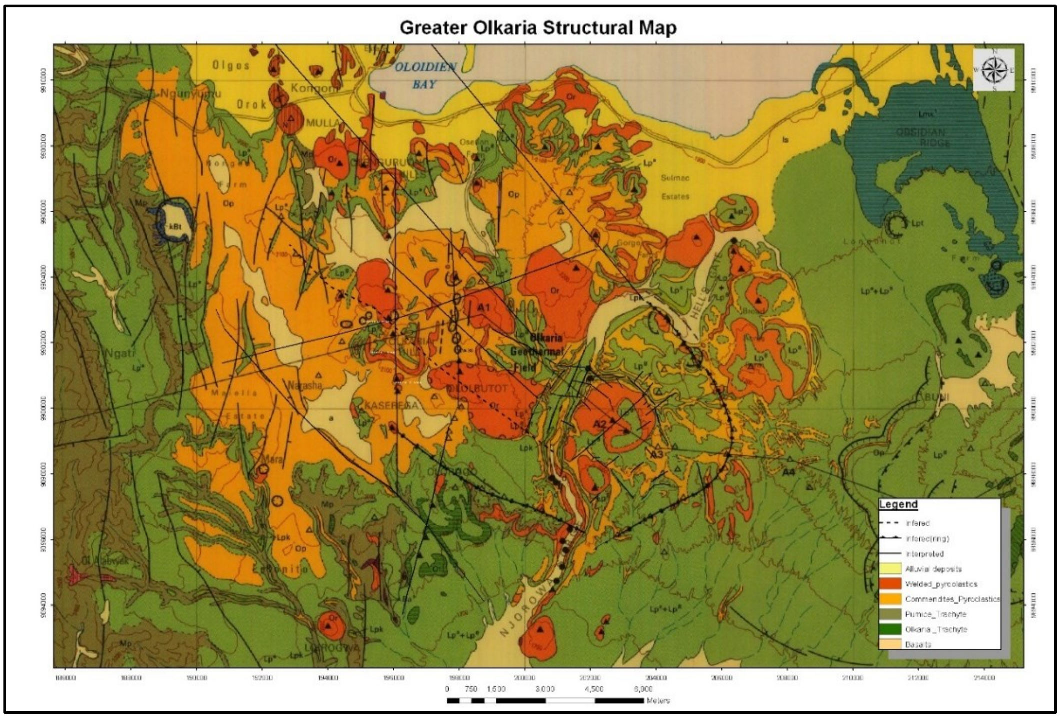

Figure 5: Structural map of Olkaria Geothermal field showing distribution of faults (Modified from Clarke et al., 1990)

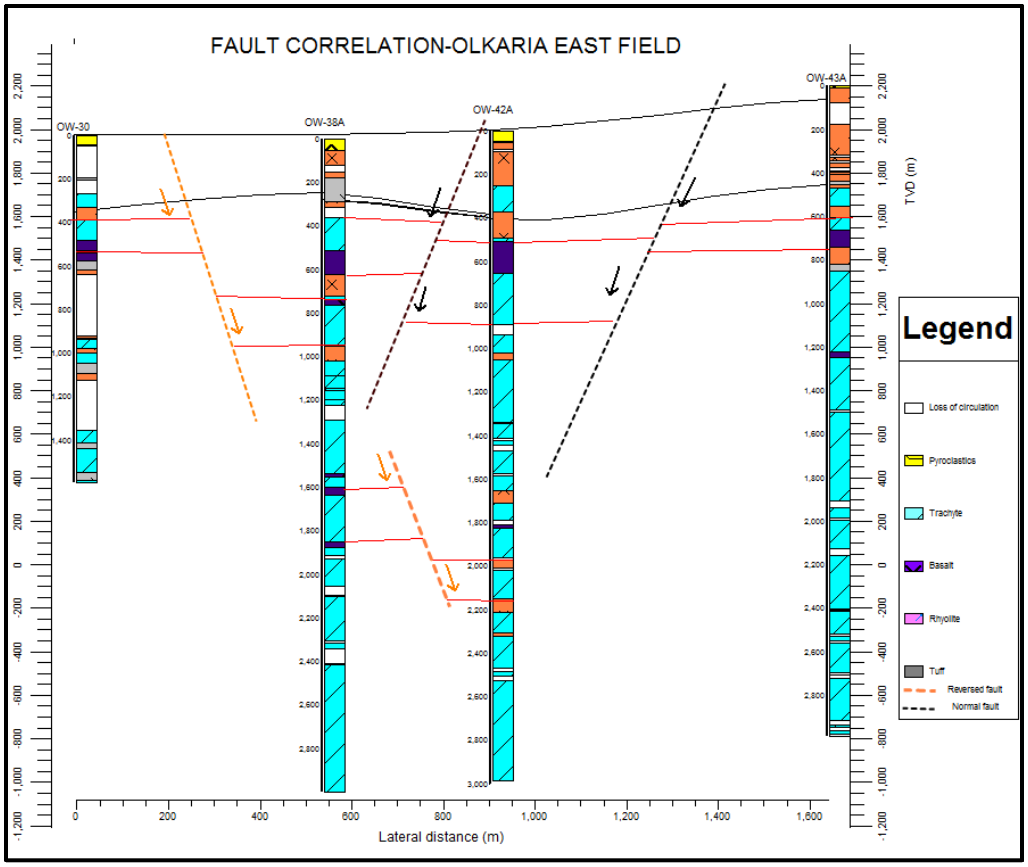

Figure 6: Fault correlation using lithostratigraphy of selected wells in the Olkaria East Geothermal Field

2.3. Other indicators of subsurface permeability

Intense presence of pyrite disseminations on the rock's surface, calcite precipitation and alteration mineralogy are essential in determining and characterizing the well permeability in an active geothermal system. In Olkaria East geothermal field, the following geological indicators characterize the subsurface permeability:

2.3.1. Pyrite mineralization

Pyrite appear under the binocular microscope as euhedral cubic crystals with brassy-yellow luster. Pyrite presence in significant amounts has been associated with permeable zones in most geothermal systems (Otieno, 2016). Hydrothermal pyritization is caused by precipitation and recrystallization of mackinawite after upwelling of thermal water (Wagner et al., 2005). For this study, the distribution of pyrite in selected wells within the Olkaria East field was done. For instance, in OW-41, pyite is occurs 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). They also also occur in moderate to high intensity in OW-40 between 516-746m and 1838-2024m. Such zones are also characterized by moderate to high alteration intensity.

2.3.2. Calcite deposition

Calcite is formed as a replacement of calcium alumino-silicate minerals such as plagioclase, pyroxene phenocrysts, and discrete silicic volcanic fragments (Otieno, 2016; Simmons and Christenson, 1994). 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 50-300^{o}C. (Simmons and Christenson, 1994). Within the Olkaria East field, it is observed in veins and vesicles of the local volcanic rocks. From data analysis of selected wells within the study area, calcite coexists with pyrite at OW-42 between 322-360m, 456-644m and 2600-2800m.

3.0. CONCLUSION

Characterization involves the understanding of wells properties within the Olkaria East geothermal filed. This paper dealt with the the geological indicators of subsurface permeability; special emphasis on the Olkaria East Geothermal field. The notable factors that enhance subsurface permeability include fracturing, faulting, pyritization, intense loss zones and calcite deposition. From the analysis of the lithostratigraphies of OW-41, OW-42, OW-41A it was established that the wells are relatively permeable.

However, for detailed understanding of the field's subsurface permeability, there is need to incorporate image modelling for discernment of location of individual fractures/faults in wells.

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