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Management of Cement Slurry Loss in Permeable Zones during Geothermal Well Cementing. A Case Study of Olkaria Domes Geothermal Field

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Abstract: *Olkaria Domes Geothermal field is one of the sectors, within the Olkaria Geothermal field and is a high temperature geothermal system. Kenya Electricity Generation Company Limited (KenGen) and the privately owned Orpower Geothermal limited have an obligation to explore and exploit the Geothermal Energy in the field. This is in line with the Government of Kenya Big 4 Agenda which aims to increase the output of renewable energy to 5000 MWe by the year 2030. This has resulted to exploration activities being carried out in that area and several hundredsgeothermal wells have been drilled and some have experienced large amounts of cement slurry losses to permeable zones due to the nature of their geological formations.*

During drilling the geothermal well has to be well cemented to prevents cold fluids from getting into the wells. Cementing also prevent the well from collapsing and hence led to difficulties in drilling or unproductive well which make drilling quite expensive and cumbersome. Cement is very expensive and therefore it is always good to ensure that a drilled well does not have caves and fractures/ faults where the cement can get lost before the cementing works begins. In case these caves, fractures and faults are available it's in order to take the necessary measures to ensure that enough and quality cement is procured on time or the cement slurry is mixed with other lost circulation materials to reduce the amount of cement used during geothermal well cementing.

Several geothermal wells in the Olkaria Domes Geothermal field were sampled and used in this thesis. The collected data was analysed using Rockworks software to create maps, logs and cross sections. Result indicated that the permeability of the first zones and permeability/ loss of circulation below the production casing of the sampled wells within the Olkaria Domes field.

We report and recommend how management of cement slurry loss in permeable formations to ensure that quality and enough cement is procured on time during geothermal well drilling in Olkaria Domes Geothermal field because drilling of wells is still on going. With procurement of enough cement, the drilling cost will not increase due to reduced downtime during drilling and the production of the wells will not be affected and will save on time.

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I. Introduction

The Olkaria Domes Geothermal field is located to the west of Longonot Volcano in the southern sector ofthe Kenya rift system (Figure *1*). Olkaria Geothermal field is located south of Lake Naivasha, and about 120 km to the northwest of Nairobi City. The greater Olkaria geothermal field covers an area of more than 120 km^2(Ofwona, 2003).

The Kenya rift is part of the East African rift system that runs from Afar triple junction at the Gulf of Eden in the north to Beira, Mozambique in the south(Abbate et al.,1995). The rift is part of a continental divergent zone where spreading occurs resulting to the thinning of the crust hence eruption of lavas and associated volcanic activities. Olkaria Domes geothermal field is a high temperature geothermal field.

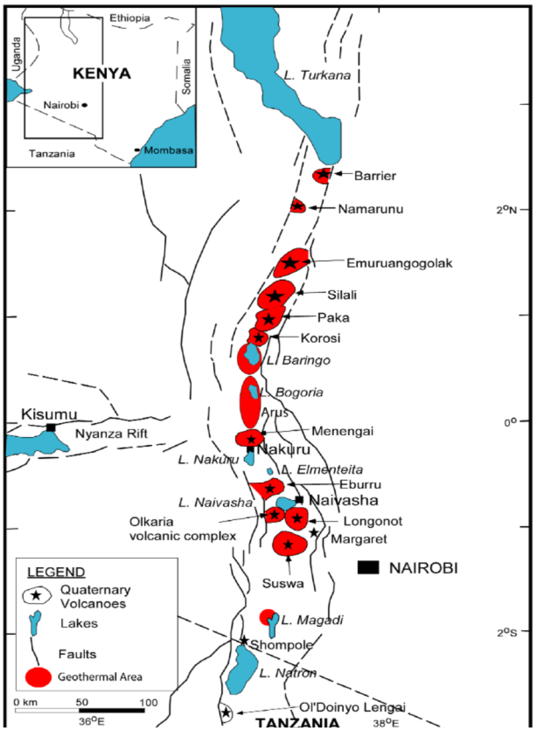

Figure 1: Location of Olkaria geothermal field and other Quaternary volcanoes along the rift axis of the Kenya(Omenda, 2012)

Olkaria Geothermal Field (OGF) sits within the Central Kenyan Rift and is one of the late Quaternary central volcanoes with proven geothermal potential(Mwangi, 1988)(Ofwona, 2002)(Musonye, 2015)(Kanda, 2010)(Wanjohi, 2015). The surface geology is dominated by comenditic rhyolites which are present as scattered lava flow fields throughout the OGF(Lagat, 2005). Volcanic ashes, pumaceous deposits, and trachytes are also present along with rare lacustrine sediments in the vicinity of Lake Naivasha. In the subsurface, the rocks consist of basalts, trachytes, rhyolites lavas and tuffs of ages ranging from Pliocene to Holocene(Omenda, 1998)(Omenda et al., 2014). The Olkaria geothermal license area is situated immediately south of Lake Naivashaand it'sdivided into several sectors for development purposes, namely:

- Olkaria East
- Olkaria Northeast
- Olkaria North west
- Olkaria Central
- Olkaria South east
- Olkaria West
- Olkaria Domes
-

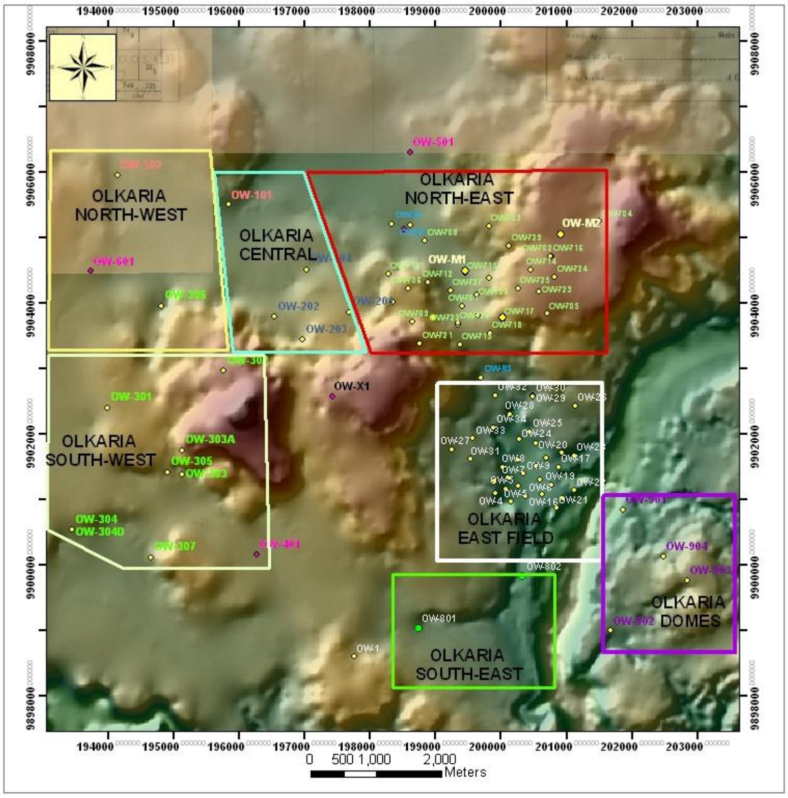

Figure2:Different sectors in the Greater Olkaria Geothermal Field(Otieno&Kubai, 2013)

The Olkaria geothermal field is inside a major volcanic complex that has been cut by N-S trending normal rifting faults. It is characterized by numerous volcanic (mostly rhyolitic) domes, some of which form a ring structure, which has been interpreted as indicating the presence of a buried volcanic caldera(Okoo et al., 2017). Other prominent structures in the complex are: the Ol' Njorowa gorge, the N-S trending Ololbutot fault, the NE trending Olkaria fault, the Olkaria fracture, the Suswa fault and the Gorge Farm fault(Figure3)(Munyiri, 2016). Eruptions associated with the Olkaria volcano and Ololbutot fault zone have produced rhyolitic and obsidian flows while eruptions in Longonot and Suswa volcanoeshave ejected pyroclastic ash, which has blanketed much of the area. Permeability in the Olkaria system is controlled by predominantly NW-SE and NE-SW trending faults (Omenda, 1998).

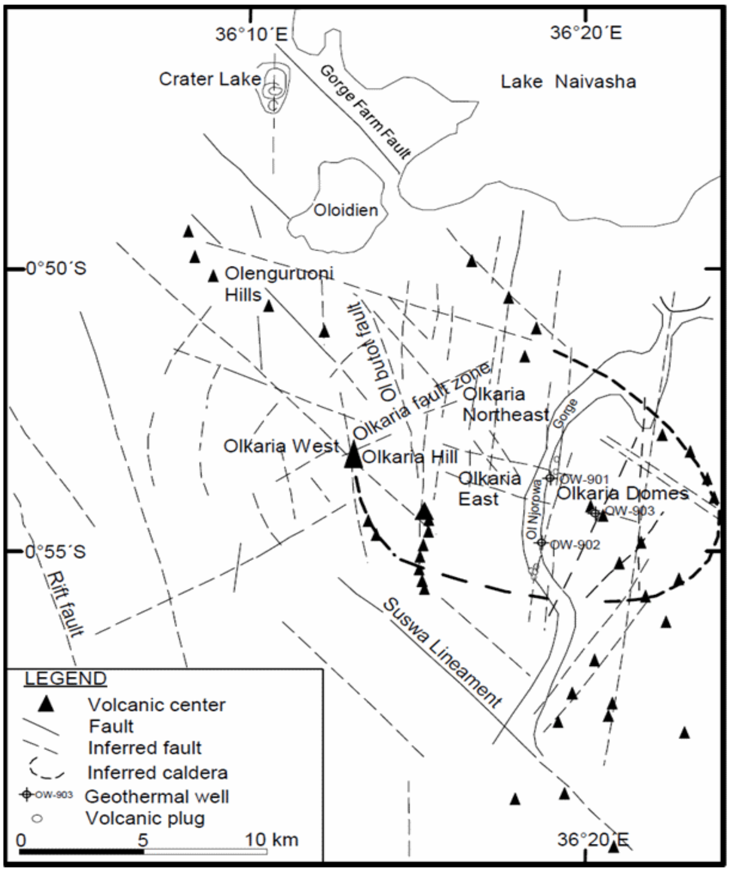

Figure3:The volcano tectonic map of the greater Olkaria volcanic complex showing the structures in the area(Lagat, 2005)

Olkaria Domes geothermal field is one of the several sections of the Olkaria geothermal field (Figure 2). It is located on the south east of the Olkaria geothermal field and it's the most productive sector within the Olkaria fields; hence the focus of this study.

During geothermal well drilling in Olkaria Domes field, cementing is very vital and its carried out to ensure the whole length of the annulus is completely filled with sound cement that can withstand long term exposure to geothermal fluids and temperatures(Shryock, 2007)(Hole, 2008). Cementing is usually carried out above the production casing until the well is productive. Cementing is used to condition the well to seal loss of circulation zones; Lost circulation is very common in geothermal wells because of the typically fractured nature of the formations in a geothermal field or lost circulation while cement operation(Cole et al., 2017). Cementing is divided into Primary and remedial cementing. The main fundamental function of the cementitious slurries (once they harden) is to minimize the fluid movement between the formations and to bonding and supporting the casing during well drilling.

Olkaria Domes Geothermal field is the most productive sector within the great Olkaria Geothermal field and most of the wells drilled in the field encounterfirst loss of zones or permeability. This result to loss of return or loss of cement slurry in those permeable zones/ formations. This makes drilling to be very expensive due to down time as they procure more cement to seal off the permeable zones

II. Methodology

Data sets and methods

A sample of fifteen(15) geothermal wells data was obtainedwhich mainly consisted of geological well logging stratigraphy and wasanalyzed with permission from KenGenmanagement; the data is imported into datasheet in rockworks. An excel sheet comprising of well name, & location information,orientation of the well, lithology, stratigraphy is input in the Rockwork software to enable create 2D and 3D maps, logs sections, cross sections, and geological models. 3D geological model and log cross section were modeled in the study by use of rockworks software and then modified. The 3D geological model (Figure 5) and log cross-section (Figure4)clearly shows the permeable zones or loss of circulation zones(formations where loss of cement slurry occurs) due to minor fractures, major fractures and faults on the formations.

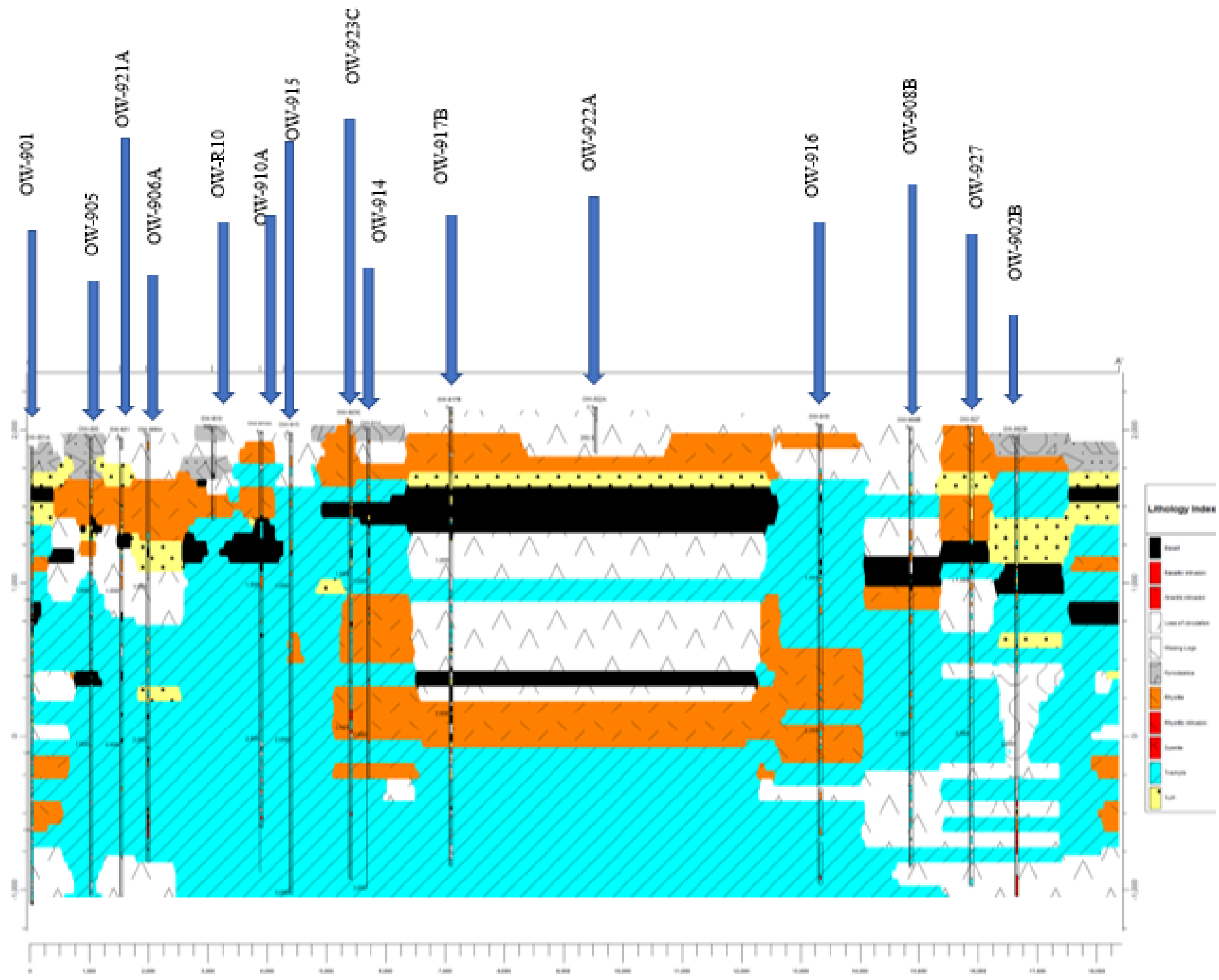

Figure4:Cross section map of Olkaria Domes geothermal field, constructed from well geological data

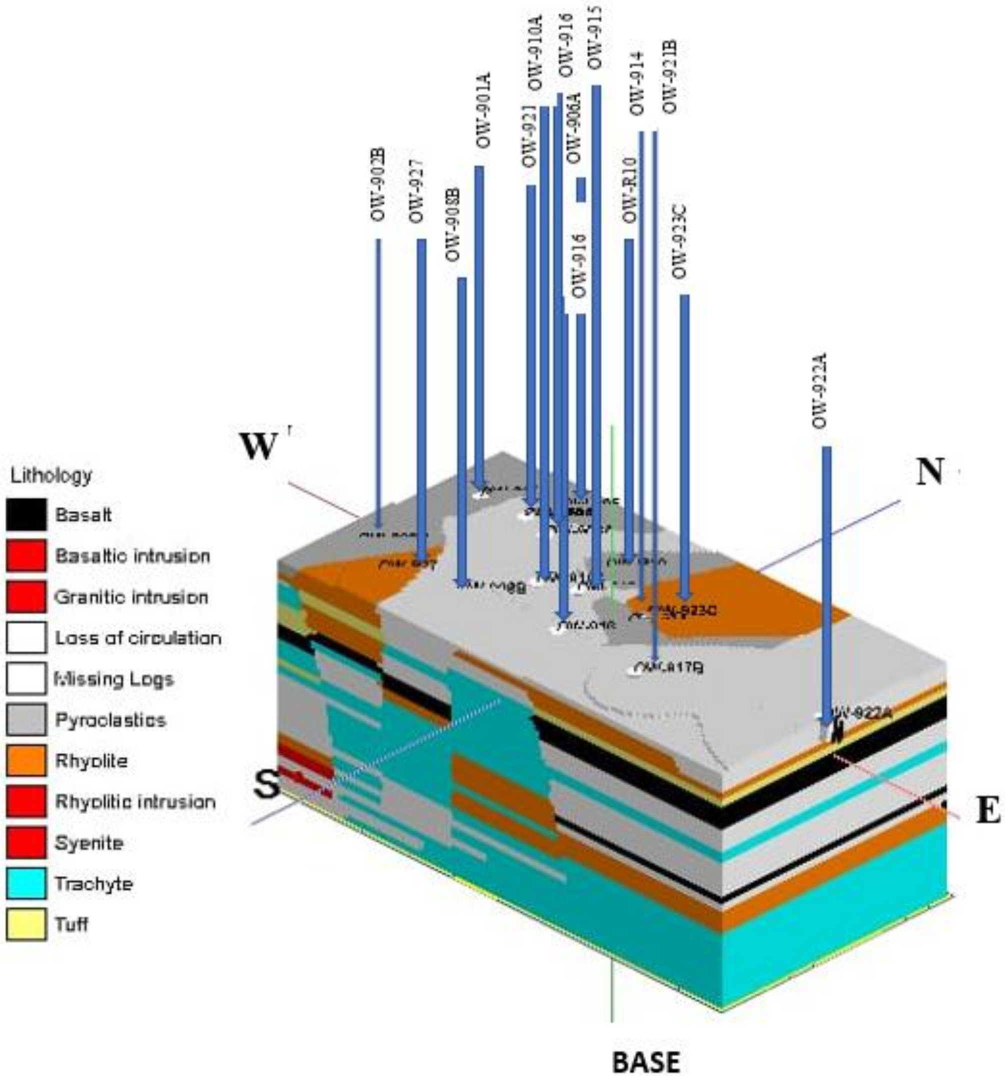

Figure 5: 3D geological map of Olkaria Domes geothermal field, constructed from well geological data

III. Results and Discussion

It is observed that all the wells encountered first permeable zone at different metersbelow ground level. It's shown that the minor fractures (low permeability) occurred at OW-901A and major fractures (highly permeable) at OW-922A.The indicators of permeability include; loss of circulation of returns within selected geothermal wells in the Olkaria Domes field (Table 1). Other indicators of permeability include:

i) Zones with characteristically high oxidation and alteration intensities.
ii) Stratigraphic sections characterized by intense veining and high vesicular content of the host rocks.
iii) Specific indicator minerals such as pyritization, within specific sections of the selected wells.

For this study, analysis and interpretation was restricted to loss of circulation returns. The first encounter of permeable zones of each well log in the Olkaria Domes field is tabulated in Table 1.

Table 1: First encounter of permeable zone in Olkaria Domes geothermal wells

S/No.	Well	First Depth (mbgl)	Last Depth (mbgl)	Thickness (M)
1.	OW-901A	574	580	6
2.	OW-902B	234	300	66
3.	OW-905	266	304	38
4.	OW-906A	108	310	202
5.	OW-908B	108	294	186
6.	OW-910A	2022	2052	30
7.	OW-914	96	232	136
8.	OW-915	56	150	94
9.	OW-916	174	294	120
10.	OW-917B	58	84	26

11.	OW-921A	498	518	20
12.	OW-922A	94	300	206
13.	OW-923C	33	100	77
14.	OW-927	58	96	38
15.	OW-R10	94	186	92

It is observed that most geothermal wells in the Olkaria Domes field, experiences lost circulation below 0 – 750mbgl. Most of these losses are encountered in soft and moderately to highly altered lithologic units. The pyroclastic rock which flanks the uppermost zones of the wells are the most vulnerable to loss of circulation returns. The losses are also dominant in fractured and highly vesicular zones of the compact and massive rocks (i.e., rhyolites, trachyte and basalt). The less altered or relatively fresh rock units (e.g., the intrusions) experiences minimal or nil loss of circulation returns.

The permeable zones were first experienced (mbgl) in the area of focus (Table 1). Most of the geothermal wells on the eastern side encounter first permeable zones at a depth below 100 mbgl as in case of OW-914, OW-915, OW-917B, OW-922A, OW-923C, OW-927 and OW- R10 while those on the western side at a depth below 200 mbgl as it is in wells OW-906, OW-908 and OW-916.

The wells on the North West side they encounter their first permeable zones at a depth of around 500 mbgl (OW-901A and OW-921A) while those at the South West side at a depth of around 250 mbgl (OW-902B and OW-905)

The reason why loss permeable zones are found in these depths/zones is attribute to the nature of the (hardness/porosity) of these lithological units. For instance, pyroclastic rocks which are found in the upper sections of the wells (between 0-200 mbgl), are unconsolidated, thus vulnerable to voids/porous zones, translated to loss zones, during drilling process.

IV. Conclusion

The major permeable zones were located in sections characterized by loss of circulation, high oxidation, intense and vein filling. The major contributor of permeability (based on this study), is the presence of major and minor loss zones, as observed in specific wells in the Olkaria Domes area. Most of the loss zones are encountered in the upper sections of the wells (i.e., above the production casings). This is attributed to lithological competence (i.e., unconsolidated, and porous rocks).

Most of the permeable zones (below ground level, matches those observed at elevation above sea level). The wells located at shallower elevations have more loss of circulation zones while those at deeper elevation have less loss of circulation zones.

With the information of the depth at which the loss of first circulation is occurring within the area of focus, then drilling engineers will be able to predict and advise at which drilling depths more quality cement is required to take care of the cement slurry losses which occurs in permeable zones. This will ensure drilling cost will not increase due to reduced downtime during drilling and the production of the wells will not be affected and this will also save on time.

Therefore, enough and quality cement should be procured on time to take care of the cement slurry loss in permeable zones and this will avoid downtime when procuring for more cement. Hence, this will help in management of cement slurry loss in permeable zones during geothermal well cementing.

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