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CHARACTERIZATION AND SIGNIFICANCE OF INTRUSIVE ROCKS IN GEOTHERMAL RESERVOIRS - OLKARIA EAST AND SOUTH EAST FIELDS.

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ABSTRACT

The Olkaria Geothermal Complex is a high temperature field in the East African Rift System. The litho-stratigraphy of the Olkaria geothermal area as revealed by data from geothermal wells is characterised by pyroclastics, rhyolites, basalts, trachytes and intrusive rocks. Recent drilling activities within the Olkaria East and South East fields encountered intrusives in various geothermal wells from as shallow as 2200m below ground level. The need to characterise the nature and distribution of the intrusives is significant in understanding their influence to the geothermal system. Microscopic examination of drill cuttings in thin section, indicate the intrusions are mainly micro-granites with a granophyric texture; composed of coarse grains of quartz interlocking with feldspars and pyroxenes (augite). Syenitic intrusions are also encountered in some wells but occur intermittently with trachytes as thin dykes.

From this study, it is evident that the intrusives have a positive influence on the reservoir temperatures either by directly heating reservoir fluids or heating the overlying rocks which in turn heat up the reservoir fluids. However, more studies need to be carried out to ascertain this phenomenon.

1.INTRODUCTION

The area described in this paper covers an area of about 15km^2 and includes part of Olkaria East and Olkaria South East fields. The Olkaria South east field is still in the early stages of exploitation with about 20 geothermal wells drilled. This study is based on data collected during and after drilling of the wells. A total of 19 wells drilled to approximately 3000m depth were studied. The datasets used include the stratigraphies of the wells and the downhole temperatures measured.

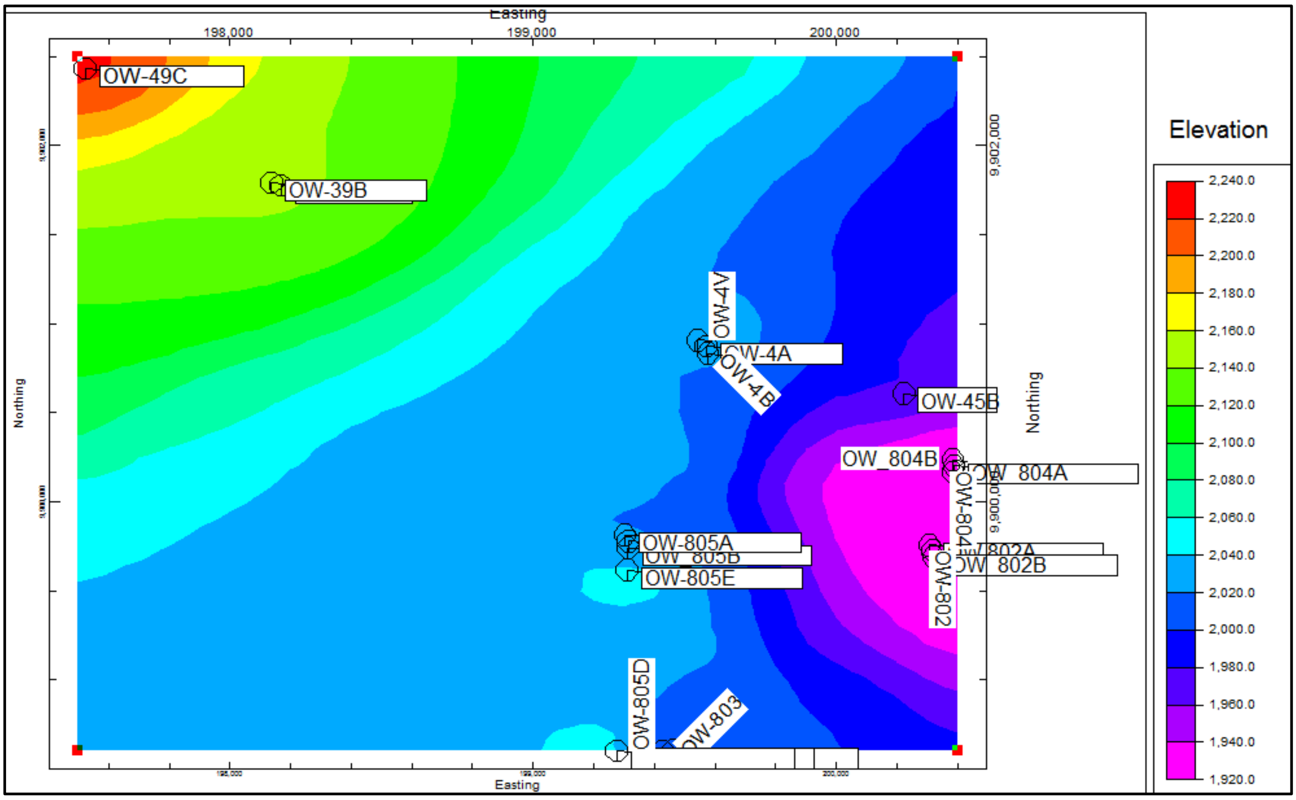

Figure 1: Surface map showing the locations of the wells studied.

The correlation between the downhole temperatures and the corresponding lithologies can be used to determine the heat source.

2.GEOLOGY OF THE GREATER OLKARIA VOLCANIC COMPLEX (GOVC)

Located at the central Kenya Rift Valley, the GOVC can be described as a multi-centered system mainly represented by rhyolites with vast and significant composition (Marshall, et al., 2008). The GOVC coincides with an area of crustal upwarping; Kenya Dome. According to (Mechie et al, 1997), the crustal thickness beneath the dome is given at 30-35km.

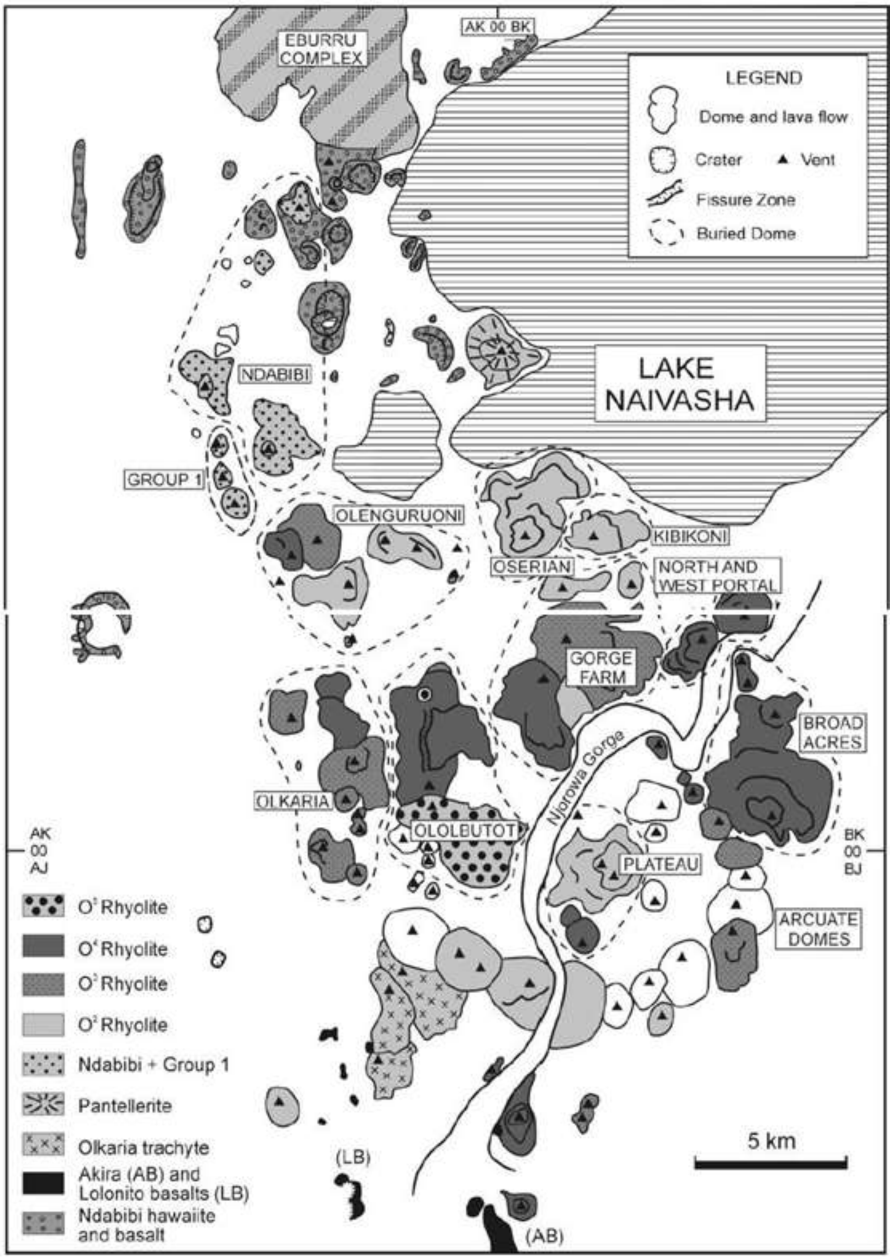

Figure 2: The geology of GOVC (Marshall, et al., 2008)

(Omenda, 2000) divided the GOVC rock types into six major categories; the Proterozoic basement formation, pre-Mau volcanics, Mau tuffs, plateau trachytes, Olkaria basalt and upper Olkaria volcanics. The pre Mau volcanics, comprising of basalts and ignimbrites of unknown thickness is underlain by Mau tuffs. The latter are absent to the east of Olkaria Hill due to the high dipping angle fault passing through the Olkaria Hill.

The GOVC according to Figure 3 is characterized by comendite lava flows and pyroclastics on the surface and basalts, trachytes and tuffs in the subsurface (Marshall, et al., 2008). Olkaria wells have plateau trachytes occurring from a depth of ≈1000m-3000m. These trachytes often appear in conjunction with minor basalts, tuffs and rhyolites. The Olkaria basalts underlie the upper Olkaria volcanics east to the Olkaria Hill and consist of basalts with minor pyroclastics and trachytes to the west of the Olkaria Hill. The formation which acts as the cap rock of the Olkaria Geothermal system ranges in thickness from ≈50-500m (Ambusso & Ouma, 1991; Haukwa, 1984; Omenda, 1998).

3.STRUCTURAL SETTING

A bend from the N-W rift orientation from northern Kenya to the N-S rift orientation towards southern Kenya characterizes this region of the Kenya Rift Valley (Musonye, 2012). (Omenda., 1998)and (Lagat, 2004) observed the main tectonic structures in GOVC to include fractures, faults, the OlNjorowa Gorge and the ring structure.

From the Figure 4 below, the ENE-WSW Olkaria fault and the N-S Ololbutot fault and NNE-SSW, NNW-SSE, NW-SE and WNW-ESE trending faults represent the main fault trends. The conspicuously displayed high-angle NNW-SSE faults which are by the Mau escarpment cut the Olkaria geothermal area to the west of the Olkaria Hill. The eastern-most of this NNW-SSE trending faults runs through Olkaria Hill but most of it is buried by the Quaternary volcanics(Omenda., 1998)

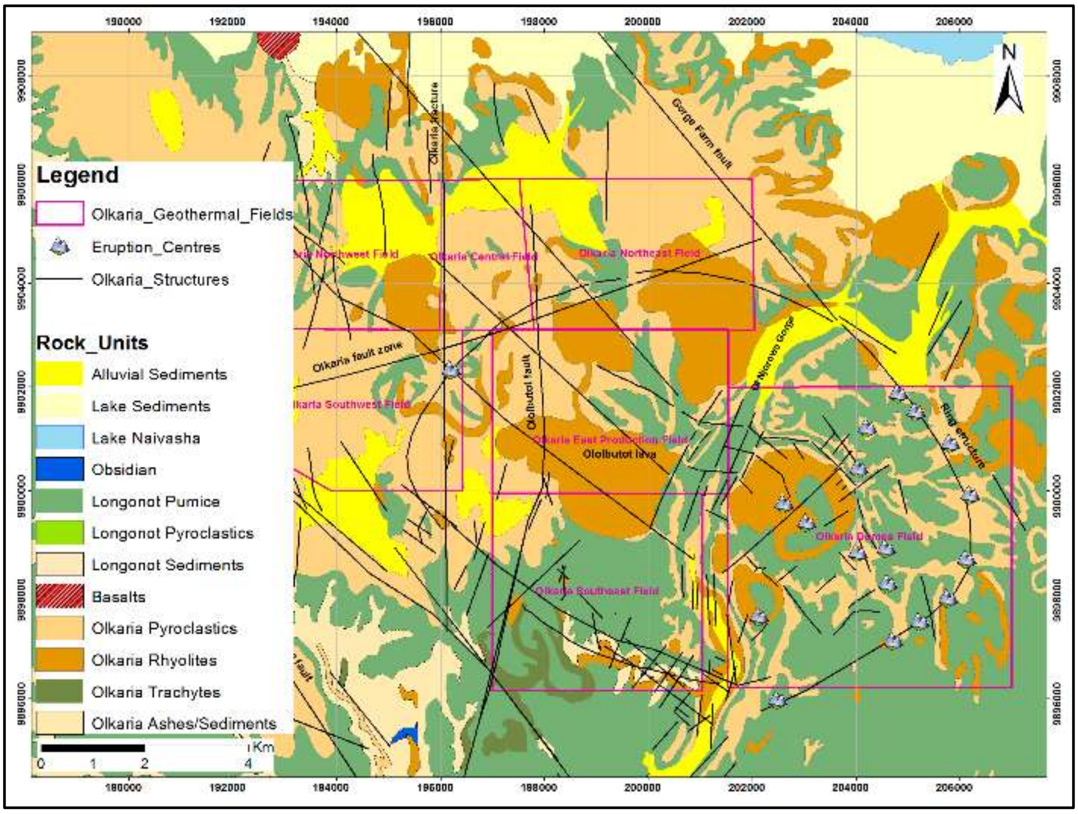

Figure 3: Structural map of GOVC (Munyiri, 2016)

The NW-SE and the WNW-ESE trending faults believed to be the oldest faults; are assumed to have been associated with the rift graben formation. Both the N-S and the NNE-SSW trending faults are the youngest faults (Lagat, 2004).

From Figure 4, the most conspicuous feature of this youngest trending fault is the Ololbutot fault. The ENE-WSW fault, believed to be an old rejuvenated structure, is observable on the surface covering a width ≈50-100m. This fault, as an altered surface, traverses through the Olkaria Hill.

Based on (Musonye, 2012), the absence of surface expression of faults in the Domes Field can be attributed to the thick pyroclastics cover. On further study in the area, he observed that the faults in the area can be inferred from Stratigraphic correlation studies, losses of drill cuttings, cave-ins and total collapse in extreme cases during drilling.

(Clarke et al, 1990)discuss the OlNjorowa Gorge as a steep sided deep gully initiated by faulting and steepening by erosion from the overflowing Lake Naivasha water during one of its high stands.

4. SAMPLING AND DATA ANALYSIS

A total of 20 geothermal wells were studied and their lithologies modelled using RockWorks 16 software to give a geological model as shown in the figures below. Rock cuttings were sampled at 2 metre intervals in each well during drilling. They were then observed under a binocular microscope at the rig-site. The samples were washed to remove any dust or other impurities from it; they were later placed on a Petri dish and mounted onto the stage of the binocular microscope. This is done to identify the type of formation, primary minerals, colour(s), grain size, rock fabrics, alteration mineralogy and intensity, vein and vesicle infillings and lithological boundaries.
After drilling was completed, the wells were shut and left to heat up. The downhole temperatures were thereafter measured and recorded. The temperatures were then plotted and compared with the lithological formation using LogPlot7 to identify the feed zones and a temperature model produced using Rockworks 16 Software.
The two models were then compared to correlate the formation temperatures with the lithology drilled.

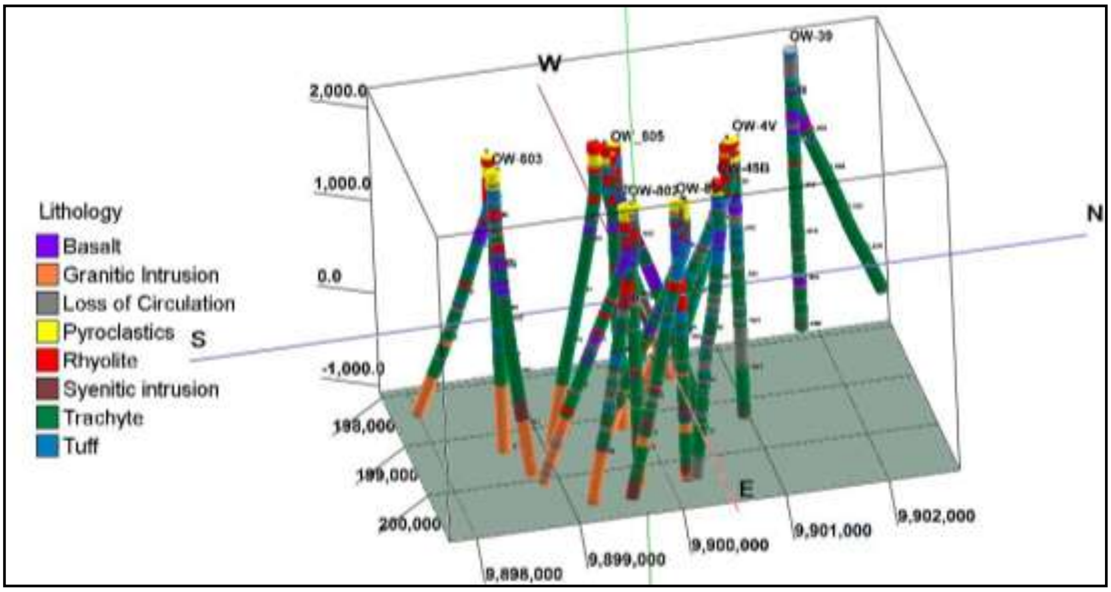

Figure 4: Wells studied with their respective trajectories.

5. RESULTS

Granitic intrusions were intercepted at an average depth of 2400m below ground level in Olkaria South East field. The shallowest granitic intrusion was encountered in Olkaria well 805C at a depth of 2254m bgl. In Olkaria East field, the granitic intrusions were encountered at much deeper depths as compared to South East field with the exception of Well 48A where it occurred at 2306m bgl.
Syenitic intrusions were also encountered at some wells with the shallowest at 2256m bgl in OW 803A. This formation occurred as thin dykes and sills and were encountered intermittently with trachytes.

The granitic intrusions observed under a binocular microscope are white, coarse grained and porphyritic with quartz and minor sanidine phenocrysts. Thin sections of the cuttings at OW 802 show a distinct granophyric texture with coarse quartz grains interlocking withsanidineand pyroxenes.

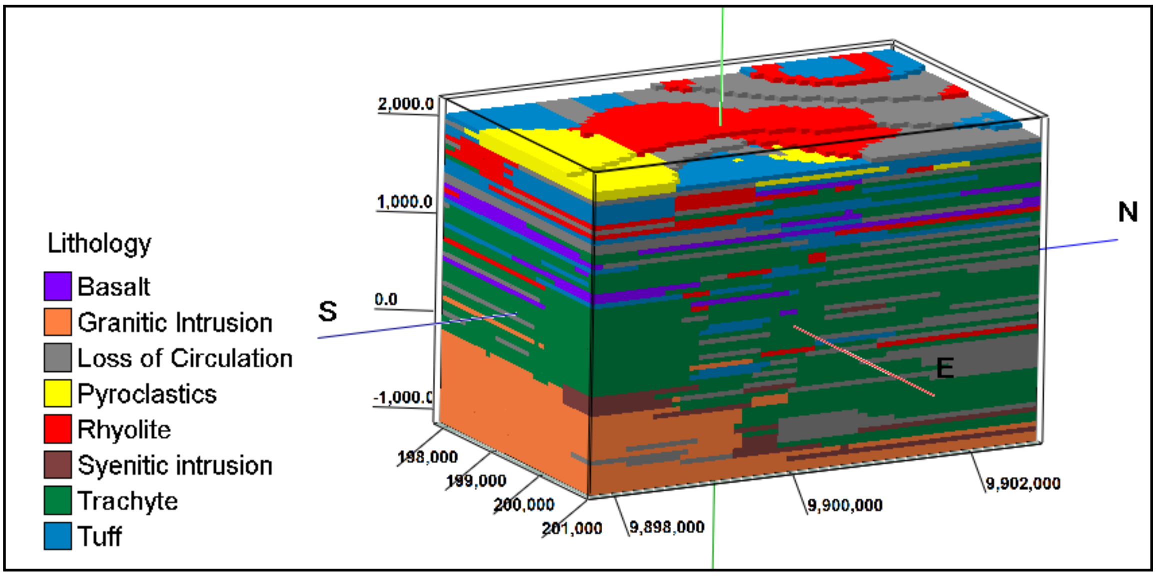

Figure 5: Geology model of study area (South East view)

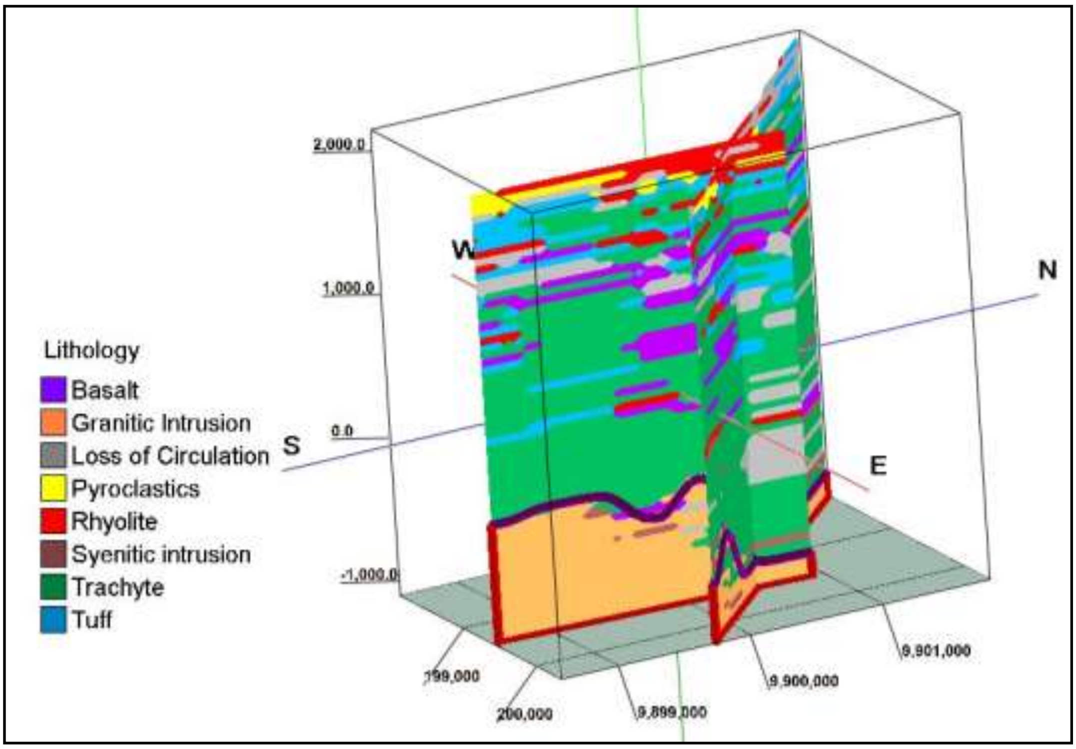

Figure 6: A fence diagram of the geological model

The geological model indicates an increasing size in the intrusion towards the southern side of the field. Trachytes take the largest portion of the model and this is where the reservoir is hosted (Figure 6).

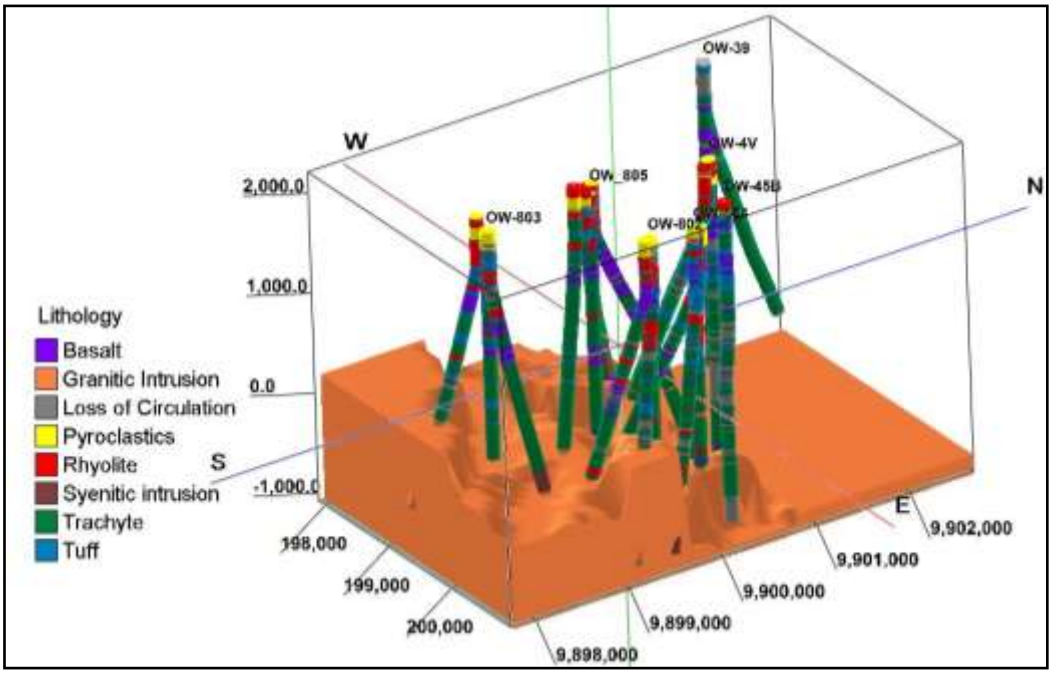

Figure 7: 3D Striplogs of the wells studied with their respective trajectories and the granitic intrusion solid model.

The figure above shows the wells studied their trajectories and the granitic intrusion solid model at depth. The intrusion occurs at shallower depths towards the southern part of the field as compared to the northern side.

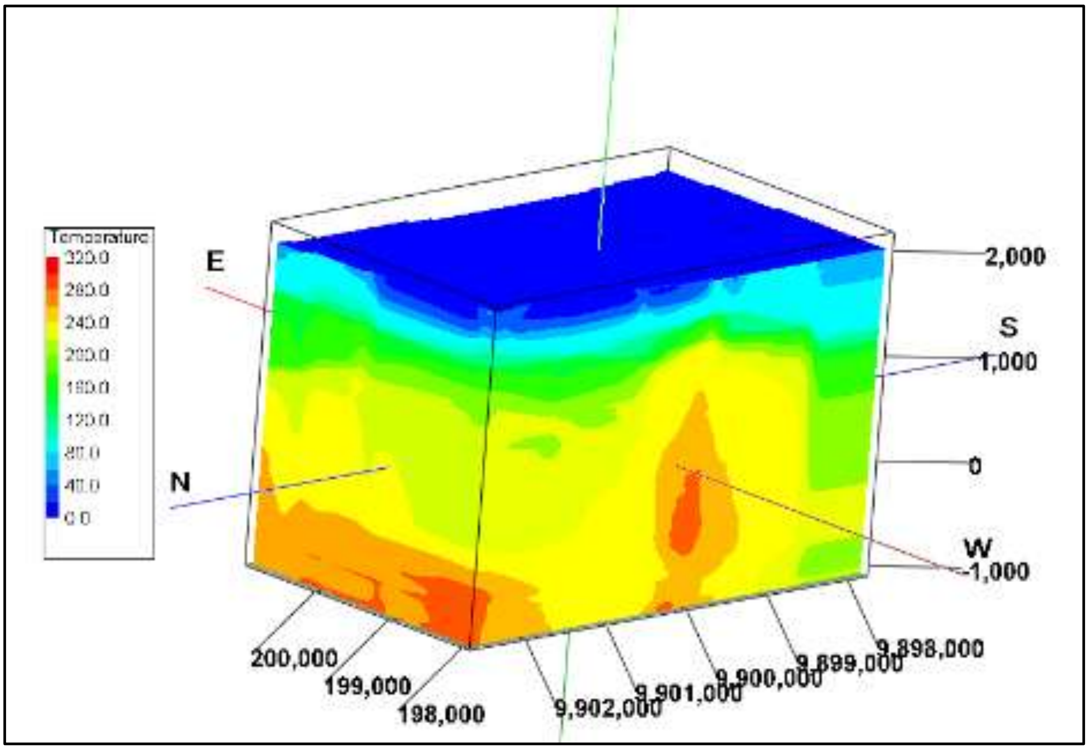

Figure 8: Temperature model of the study area.

The temperature model indicates higher temperatures on the northeastern side of the study area relative to the Southeastern side. The highest downhole temperature recorded was over 310^{o}C at a depth of about 2900m.

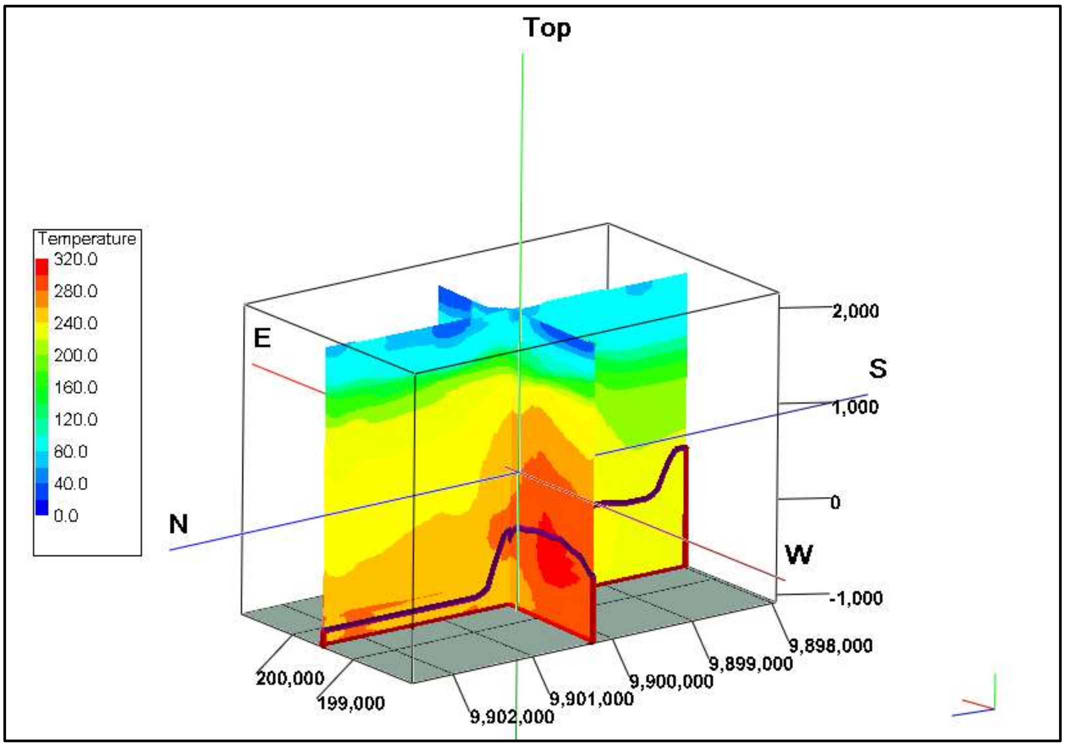

Figure 9: Temperature fence diagram. (NS, EW)

Figure 10 above is a three-dimensional temperature section crisscrossing the study area from North to South and east to west. It illustrates the influence of the intrusion on the reservoir temperatures. The region around the small plutonic plume at the centre of the model has temperatures of between 250-300^{o}C. This is a direct indication that the granitic intrusion around the area has retained heat and therefore positively influences the temperatures. However, downhole temperatures on the wells drilled on the Southern part of the area were relatively low with the highest recorded temperature being 217^{o}C at OW 803. Well 803A had temperatures ranging between 188-193^{o}C inside the intrusion which was intercepted at 2450m b.g.l. The trachytes that overlay the intrusive rock had slightly higher temperatures than the intrusive rock itself with temperatures of about 210^{o}C.

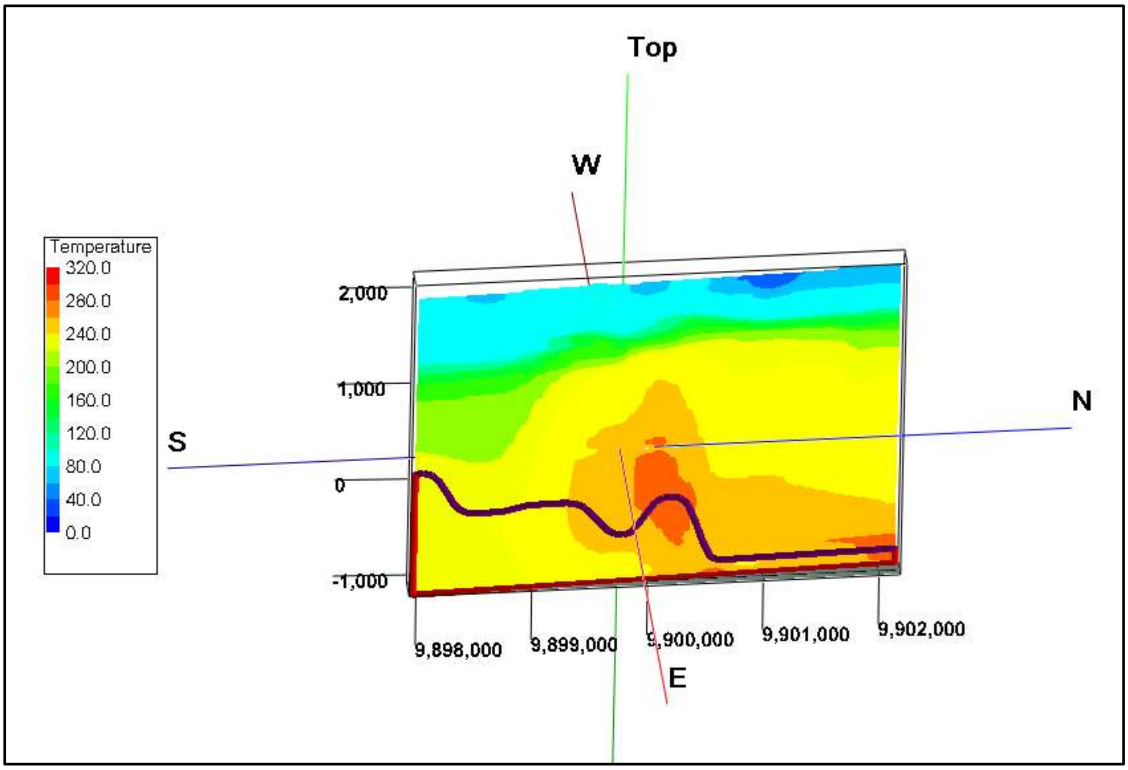

Figure 10: Temperature fence diagram of the study area along N-S

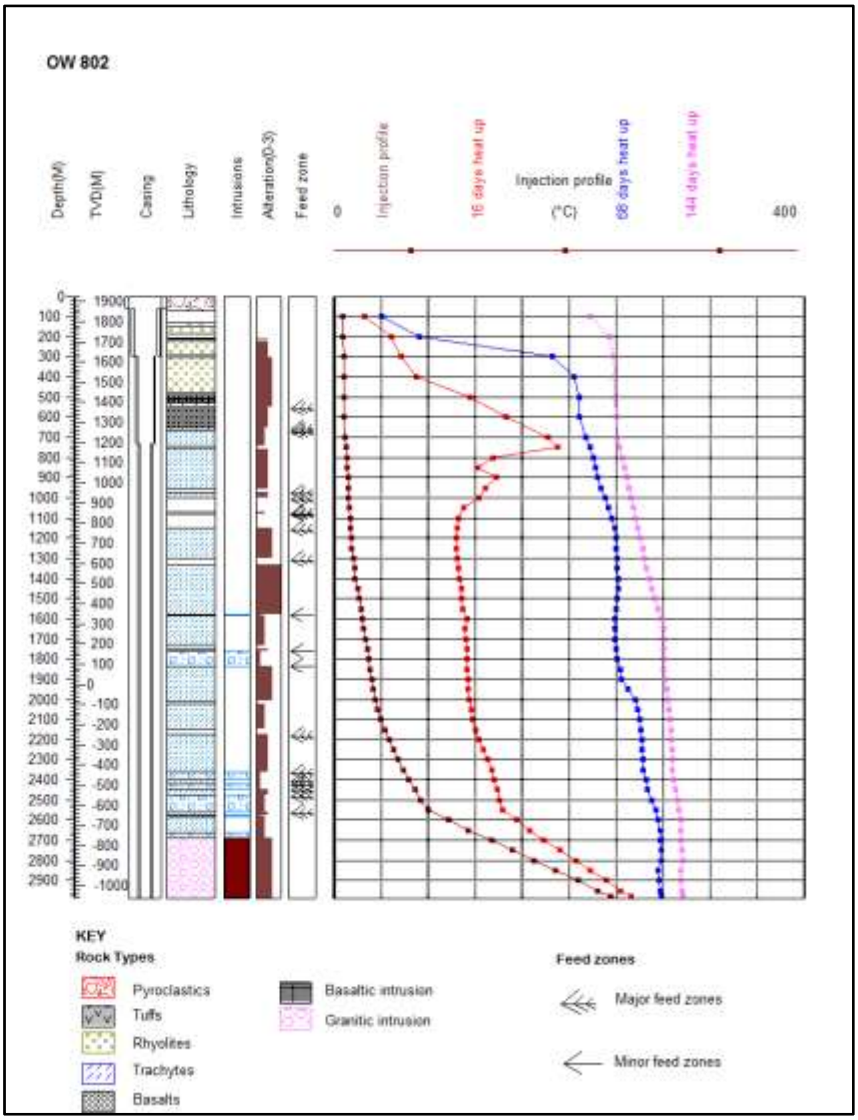

Figure 11: temperature profile of OW 802

The heat-up profile of OW 802 shows no sharp kicks where the granitic intrusion occurs.

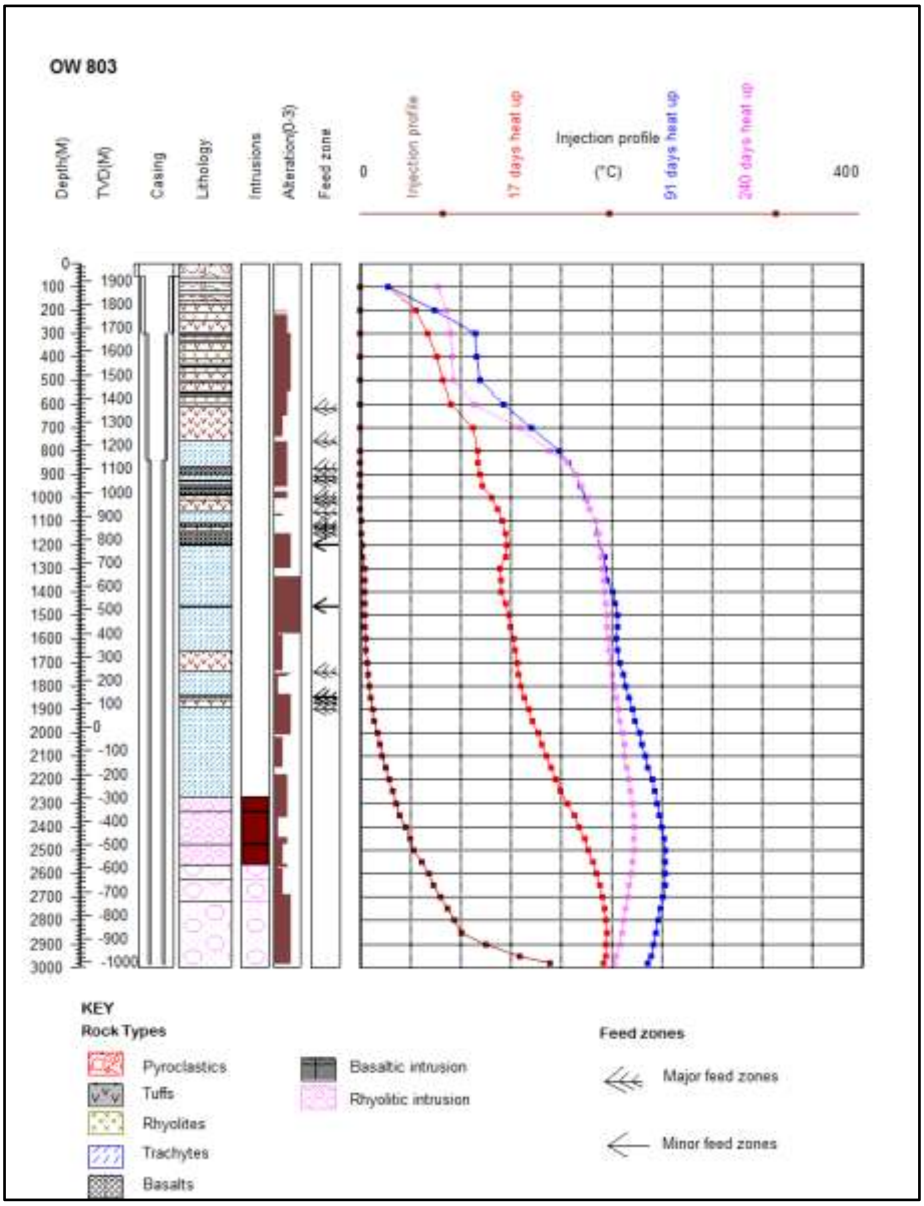

Figure 12: Lithology of OW 803 plotted against heat-up profiles

The lithological units encountered were compared to the downhole temperatures measured in order to determine the temperatures of the specific formations. OW 803 and 803A experienced temperature reversals in the granitic intrusion.

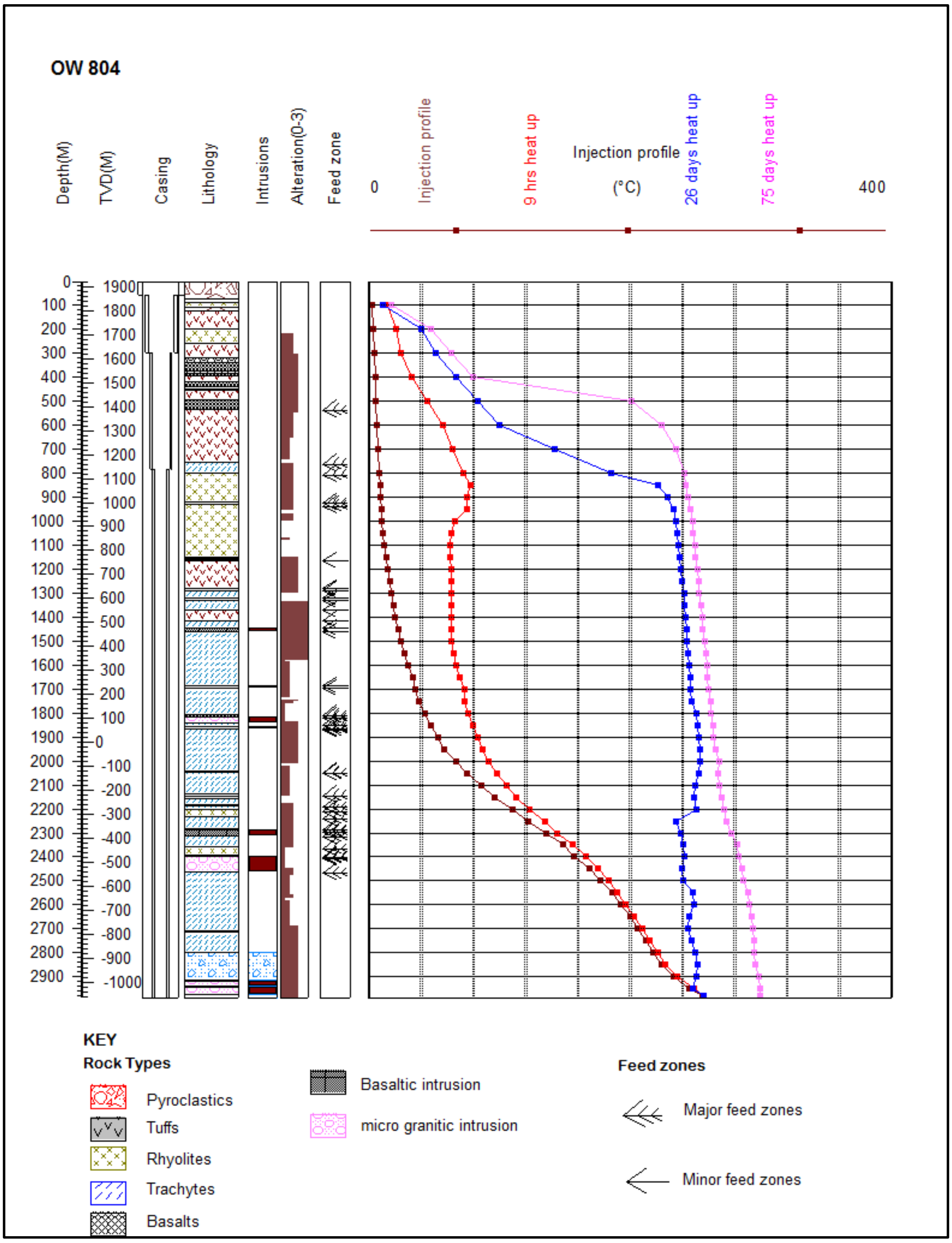

Figure 13: Lithology of OW 804 plotted against heat-up profiles

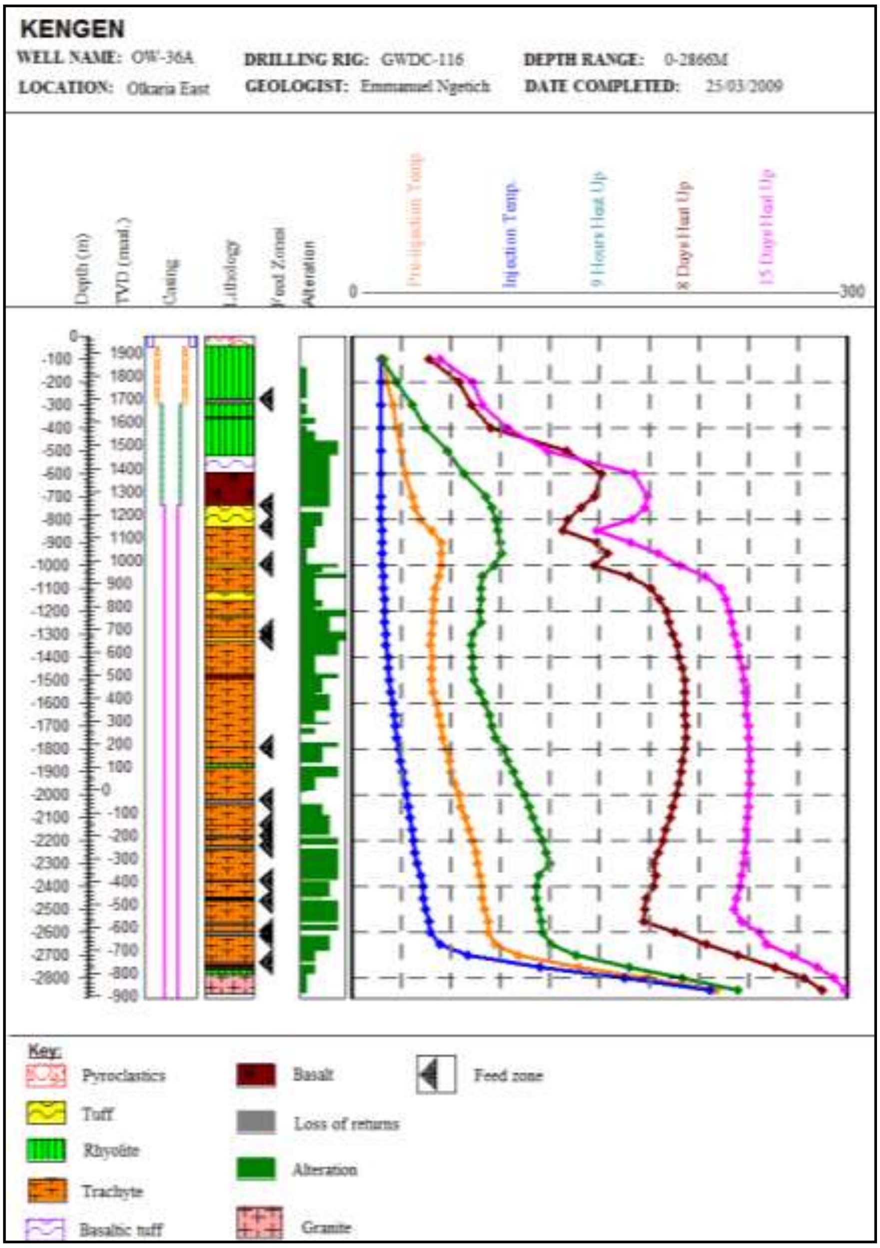

Figure 14: Lithology of OW 36A plotted against heat-up profiles

6. DISCUSSION

The Olkaria geothermal field is characterized by a two-phase (liquid+Vapour mix) system with reservoir temperatures ranging from 250^{o}C to slightly over 300^{o}C. The reservoir is mainly hosted by trachytes and tuffs as evident in the stratigraphies of the drilled geothermal wells. Permeability is attributed to highly fractured rocks, primary permeability in tuffs and lithological contacts. This can be confirmed by high alteration intensities at the feed zones, presence and abundance of pyrite and the sharp kicks in the temperature profiles.

From the correlation of the temperature and geological models of the area of study, it is evident that the granitic intrusion has high temperatures in most parts of the area. This therefore positively influences the formation temperatures of the rocks overlying the plutons.
A comparison of other geothermal fields in different geological settings also show that the igneous intrusions provide heat to geothermal reservoirs.
The heat source of the Geysers geothermal field corresponds to a Quaternary pluton complex (> 100 km3) of batholithic dimension known as “felsite” that occurs only in the subsurface.(A. Santilano, 2015). The heat source of Larderello and Mt Amiata geothermal fields in Italy are related to shallow igneous intrusions belonging to the Tuscan Magmatic Province (TMP). (Gianelli, 2008). The intrusive bodies in Larderello were cored in several deep wells and classified as two-mica granites (A. Santilano, 2015).

7. CONCLUSIONS

We can classify the deep intrusives encountered in the drilled wells as micro-granitic and granitic intrusions. The subsurface geology and downhole temperatures of the drilled wells in the area of study was modelled and compared in order to describe the relationship and subsequently the influence of the igneous intrusions to the thermal regime.
More studies need to be carried out on the southern part of the study area to determine the cause of temperature reversals in some of the wells.

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