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# Developing a geo-thermometry and measured down-hole temperature to identify feed-zones.

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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 OlkariaGeothermal Field is mainly dominated by commenditic lavas and pyroclastic. The aim of the paper was to develop a geo-thermometry and measured down-hole temperature profiles to identify feed-zones of OW 924A, OW 923A, OW917A, OW914B, OW731C, OW710C and OW39B wells.*
*Using alteration mineralogy to interpret the paleo-temperature in a geothermal system and measured formation temperatures represent present state of geothermal systems. Alteration mineralogy curves plotted relied on the first appearance of alteration minerals observed in the wells namely chalcedony, quartz, wairakite, prehnite epidote and actinolite.*
*Feed zone locations in Olkaria geothermal wells are located during completion test with a pressure Temperature spinner probe. After drilling a geothermal well and slotted liners landed, completion test is performed immediately with the purpose of identifying and characterizing the feed zones in the well. In Olkaria permeable zones are distributed from shallow depth to three kilometers deep. The feed zones are indicated in the curve by change in gradient.*
*Thermal models in the study area show that the wells around OW 923A and OW 39B have higher temperatures indicators of the up flow zones.*

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## I. Introduction

Based on studies carried out in the Olkaria field (Lagat, 2009)the minerals commonly used as geothermometers are shown in Figure 1. The first appearance of each mineral is indicated by the line for example smectite is an indicator of less than 220°C. The first appearance of epidote indicates temperature of 240°C, Garnet indicates temperature of over 300°C and actinolite – tremolite occurs at 280 – 350°C.

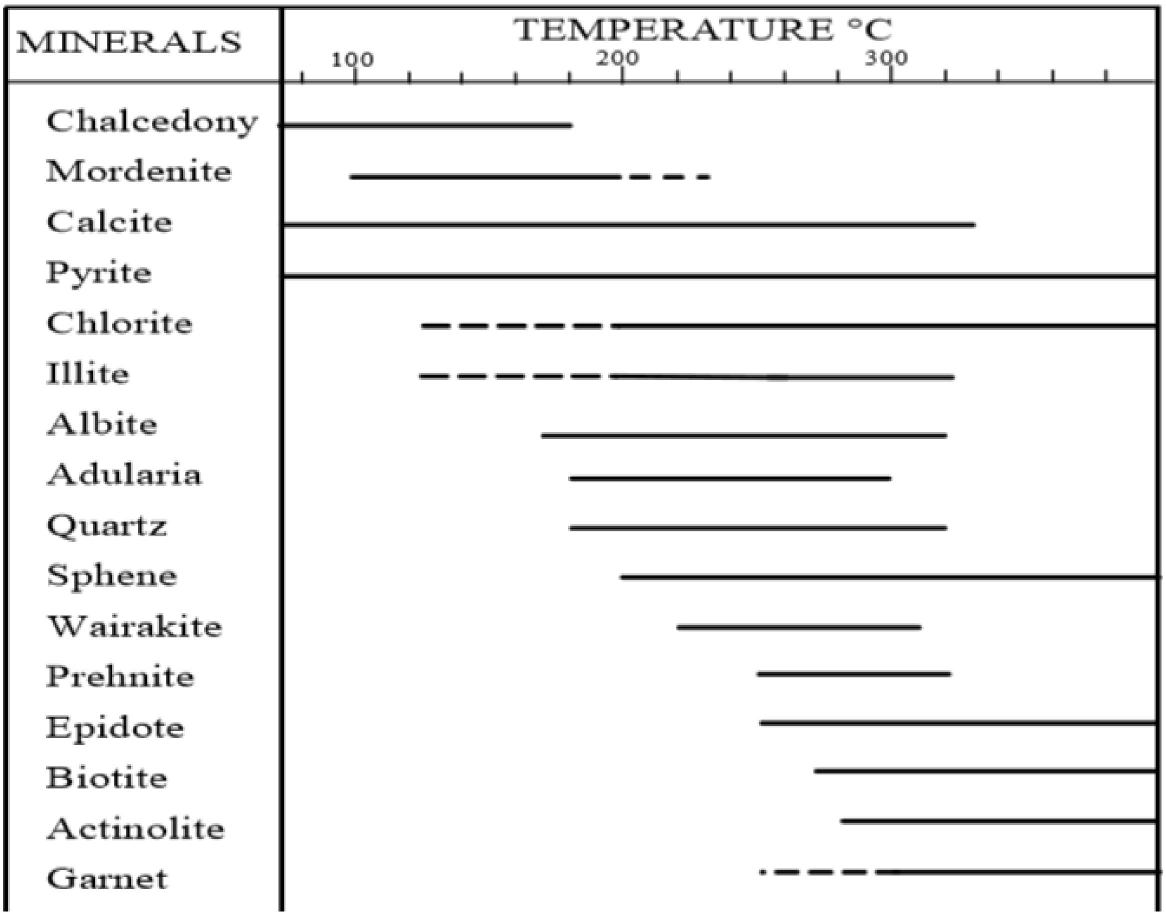


Figure 1: Hydrothermalalteration minerals used as geothermometers and their temperature stability ranges. (Reyes A.G., 1990)

Lithology and alteration of mineralogy of wellsOW 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(Kibet et al., 2019).

**Table 1:** Well information for OW 924A. OW 923A, OW 917A, OW 914B, OW 731C, OW 710C, 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 | $N30^{0}$ | 6.3 |
| OW 923A | 205435.289 | 9900079.295 | 2029.826 | 2980 | $N30^{0}$ | 5.7 |
| OW 914B | 205278.203 | 9899865.637 | 2009.288 | 2988 | $N45^{0}$ | 7.1 |
| OW 917A | 206182.15 | 9898932.30 | 2146.06 | 2990 | $N315^{0}$ | 3.0 |
| OW 710C | 198124 | 9904203 | 2068.90 | 3136 | $N292.5^{0}$ | 3.0 |
| OW 731C | 198321.560 | 9903395.836 | 2214.11 | 2990 | $N255^{0}$ | 6.4 |
| OW 39B | 198136.304 | 9901792.502 | 2145.346 | 2990 | $N340^{0}$ | < 5 |

## II. Methodology

Feed zone locations in Olkaria geothermal wells are located during completion test with a pressure Temperature spinner probe. After drilling a geothermal well and slotted liners landed, completion test is performed immediately with the purpose of identifying and characterizing the feed zones in the well (Mbithi, 2016). In Olkaria permeable zones are distributed from shallow depth to three kilometers deep. The feed zones are indicated in the curve by change in gradient. According to (Mbithi, 2016) feed zones in Olkaria domes are aligned in NW-SE, N-S and ENE – WSW directions which is in agreement with geological structure in the directions. Also feed zones indicate regional permeability distribution across the field.

We used Grapher II and Surfer to plot temperature profiles. Using temperatures profiles, permeability indicators (the calcite and pyrite) and alteration mineralogy to identify and characterize fluid pathways for Olkaria geothermal system,the fluid path are associated with the permeable zones (Vidal et al., 2017). Feed zones in Olkaria geothermal field are indicators of permeable zones in a well, when doing pressure Temperature Spinner not all permeable zones show feed zones.

**Developing thermal model within Olkaria geothermal field**

The purpose of penetrating deeper into a geothermal well is to pass as many permeable and hot feed zones as possible, below the production casing in order to maximize the well output. During drilling, feed-zones can be located when observations like lost or gain of circulation of formation, interacting with intrusions, lithological contact, changes in hydrothermal alteration and temperature recovery logs examined. For the purpose of this study temperature recovery from seven wells used to analyze feed-zones. With the help of computer software rockworks a temperature models were developed. Figure 2 show the location of the wells and the structures within the study area.

The heating of geothermal wells after drilling monitored carefully by temperature and pressure logs.

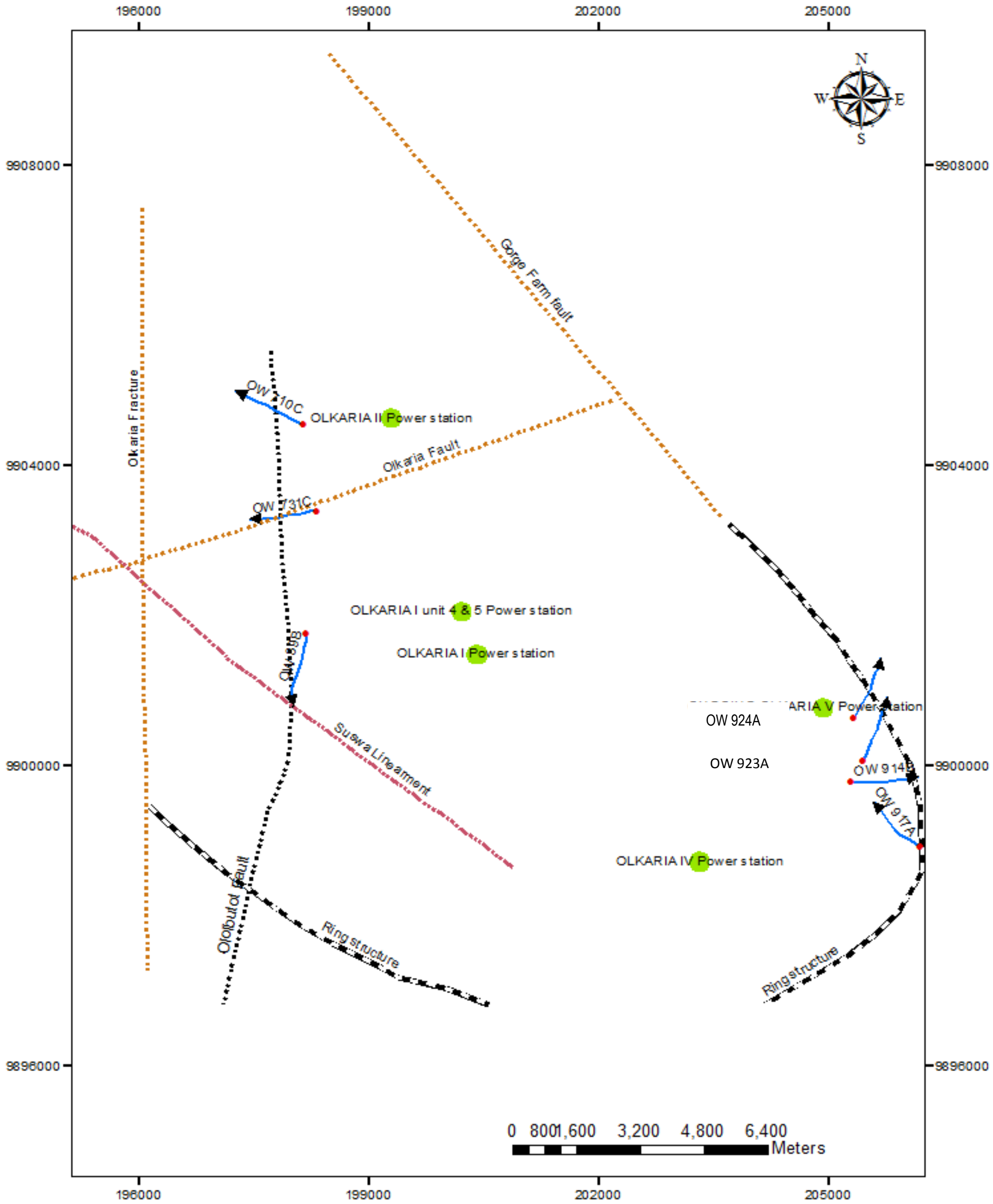


**Figure 2:** A map showing the wells location and geological structures on the ground

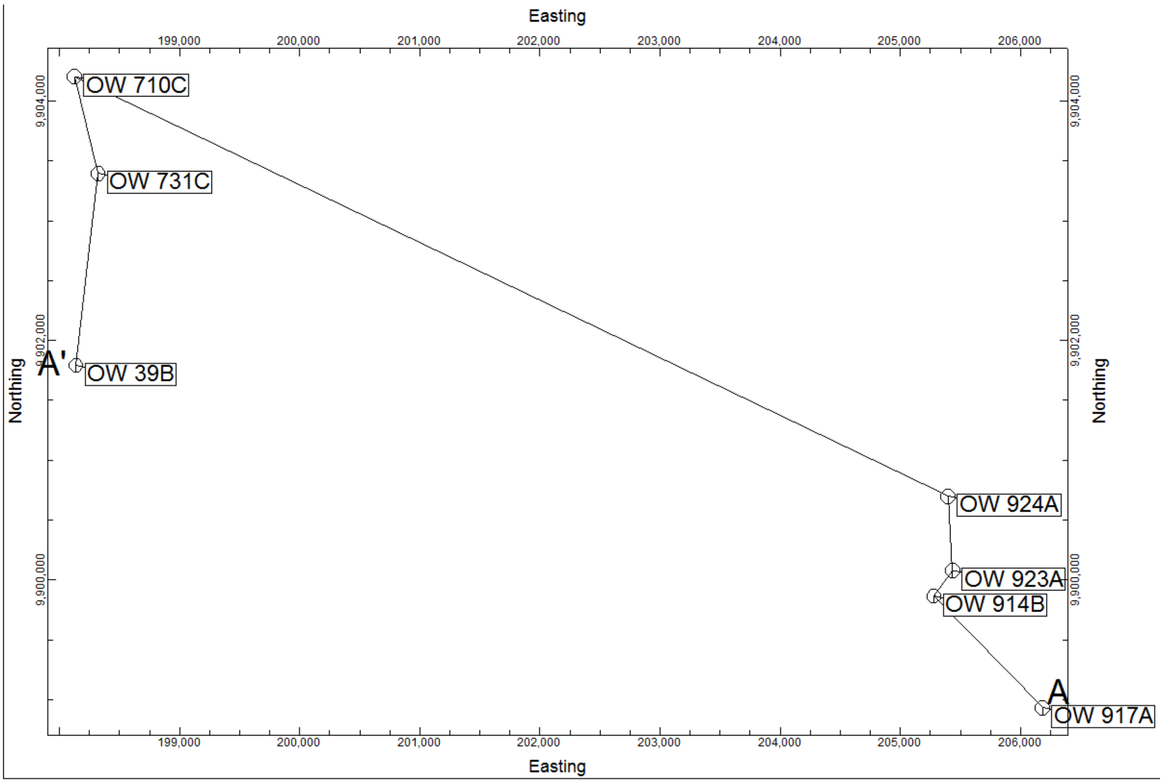


**Figure 3:** A map of well locations in Olkaria and cross sections across the study wells.

Cross section of A-A' was made to showthe vertical temperature distribution at Olkaria geothermalfield. Figure 3shows the well location and cross section from OW 917A to OW 39B. The surrounding area around OW 710C, OW 731C and OW 39B isprobably cooling,due to possible effect of the Ololbutot fault which allow inflow of colder fluids into the systems. At OW 917A area, cooling observed because the highest temperature is below 200°C in the well.
Wells OW 923A, OW924A and OW 914B are located at its main up-flow or heating up zones with temperature above 300°C (Figure 4).

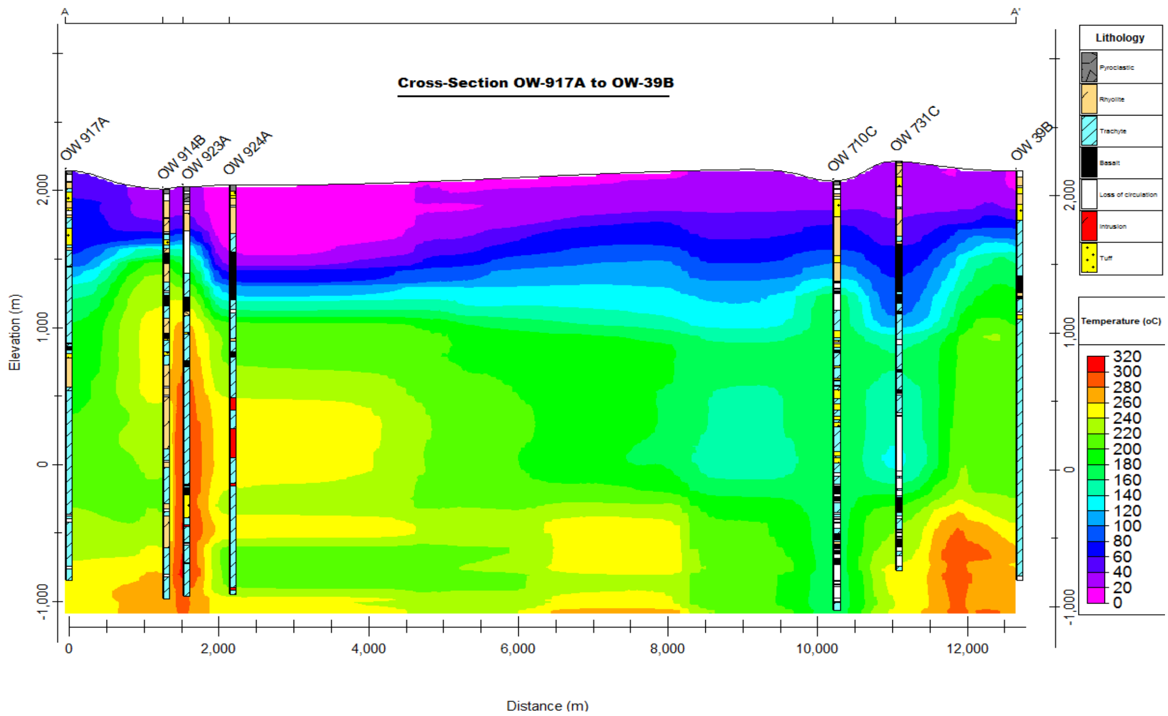


**Figure 4:** A map showing lithology and temperature model cross section A-A'

**Measured down-hole temperature to identify Feed-zones**

Thermal model indicate OW 924A is situated at the up flow zones, from the temperature profiles feed zones are interacted at 900 m, 1500 m and 2300 m. The deepest feed zone in the well is at 2950 m, which allow cold-water inflow into the well Figure 5. The feed zone at 1500 m is associated with the ring structure these conclusion based on a sharp kick that is decreasing instantly.

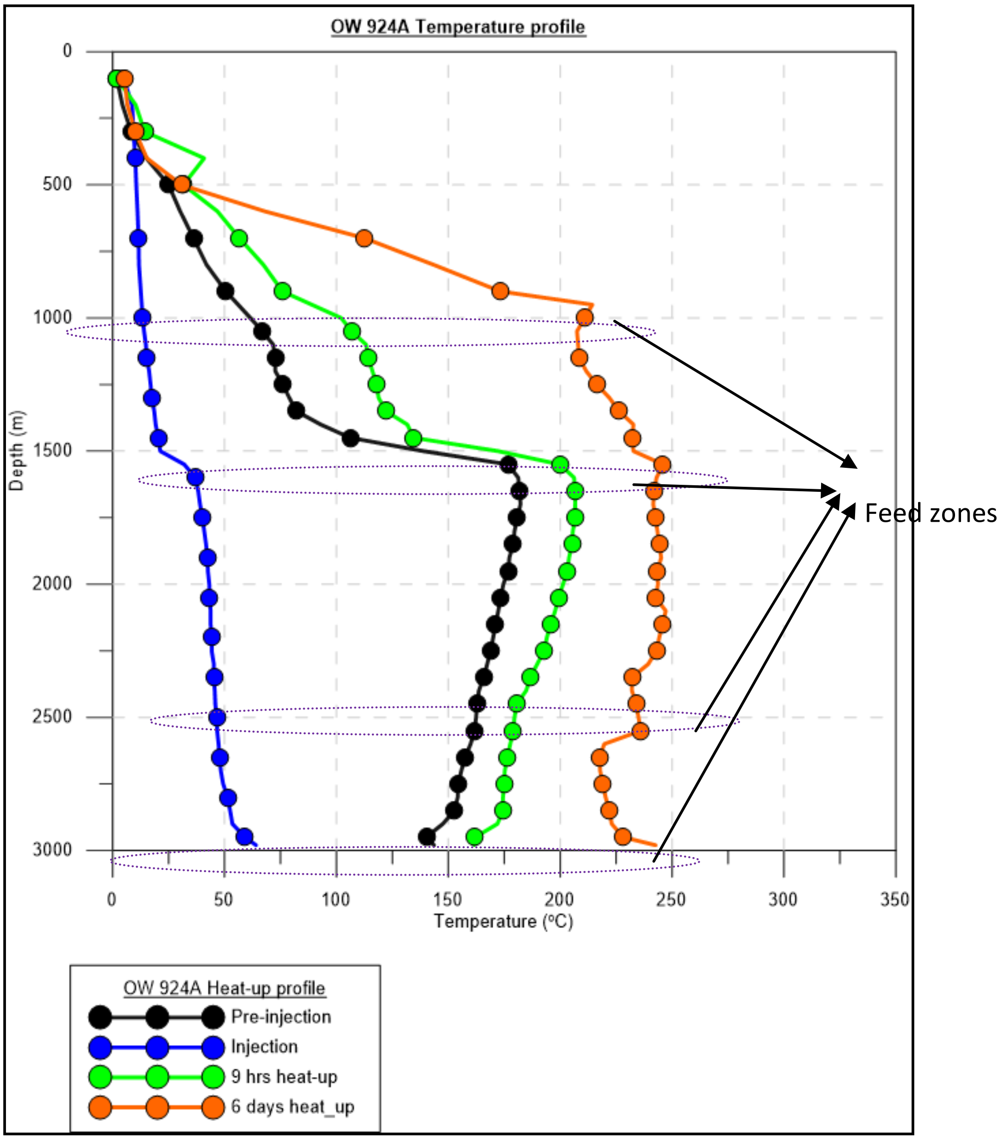


**Figure 5:** Heating profiles for and the location of feed zones of OW 924A

Well OW 923A is a productive well with 5.7 MWe, from the temperature profiles minor feed zones are interacted at 500 m, 720 m and 1090 m. The deepest feed zone in the well is at 2500 m and temperature reversal noted at depth. Figure 6 indicates that at 900 m, the well is heating up to a maximum temperature of 320˚C but at 2500 m, temperatures tend to decrease but with a small difference 300˚C. According to thermal model, OW 923A situated at the upflow zones, the effect of ring structure fault noted at 2500 m where temperature reversal seen.

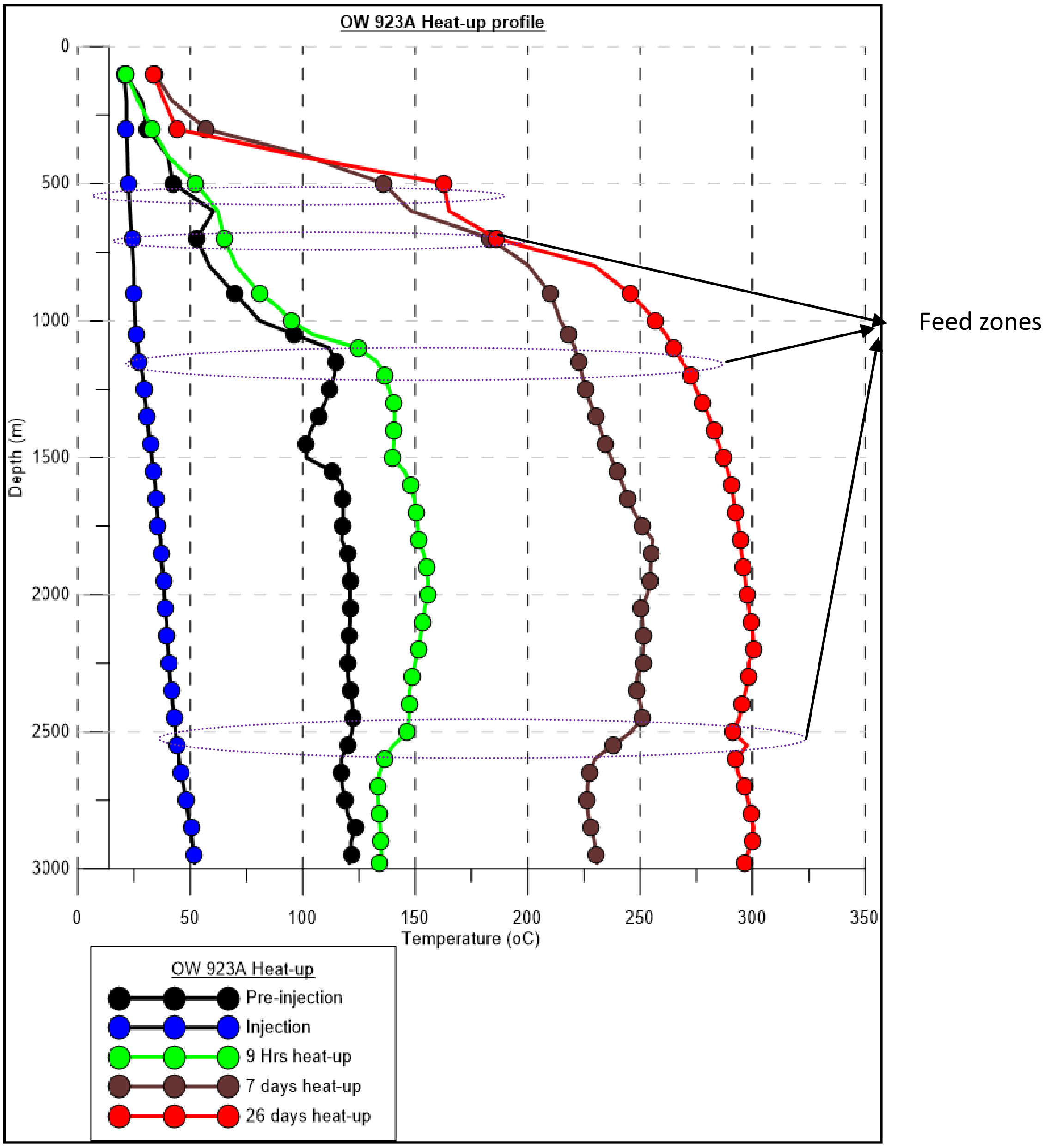


**Figure 6:** Heating profiles for with feed zones marked with blue OW 923A

Well OW 917A is a productive well with 3.0 MWe, from the temperature logs it has a main feed zone at 2700 m and is the deepest feed zone in the well. Below the main feed zone, the well exhibits conductive heating with a temperature of up to 350°C from 2700m to the well bottom Figure 7 we expect the well to be very productive but not. The reason is permeability is poor in well, with Injectivity index of 81 lpm/bar and from lithology, the rocks are very compact. The recovery profile carried out show minor feedzones at around 1400 m and 2400m. Temperature drop noted at 1500 m, which are associated with the ring structure.

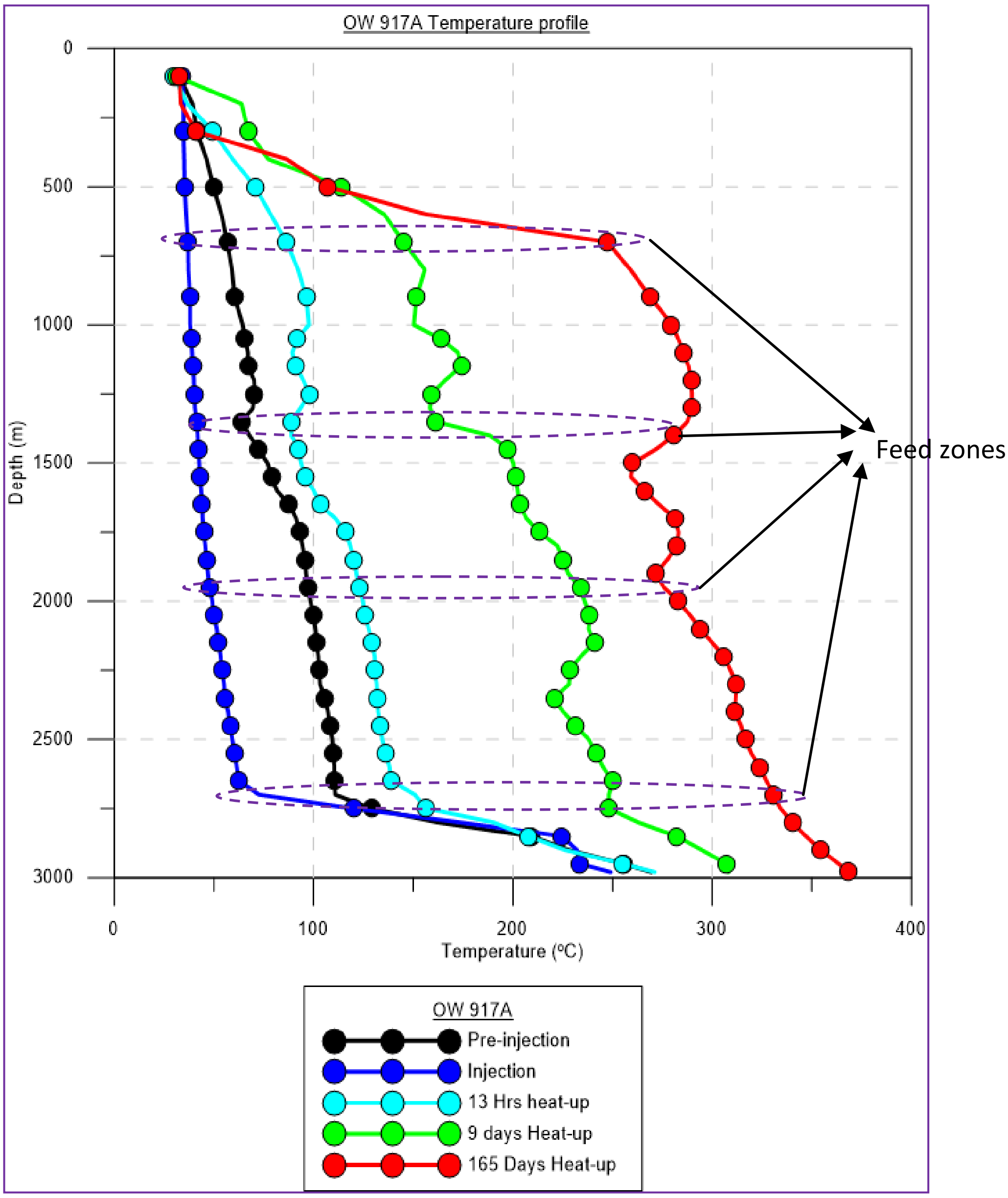


**Figure 7:** Heating profiles and feed zone located with blue color of OW 917A

Well OW 914B is a productive well with 7.1 MWe, from the temperature logs it has a main feed zone at 2250 m and is the deepest feed zone in the well Figure 8. Below the main feed zone, the well exhibits conductive heating from 2800m to the well bottom. The recovery profile carried out after 6 days heating show minor feed zones at around 700 and 1500m.

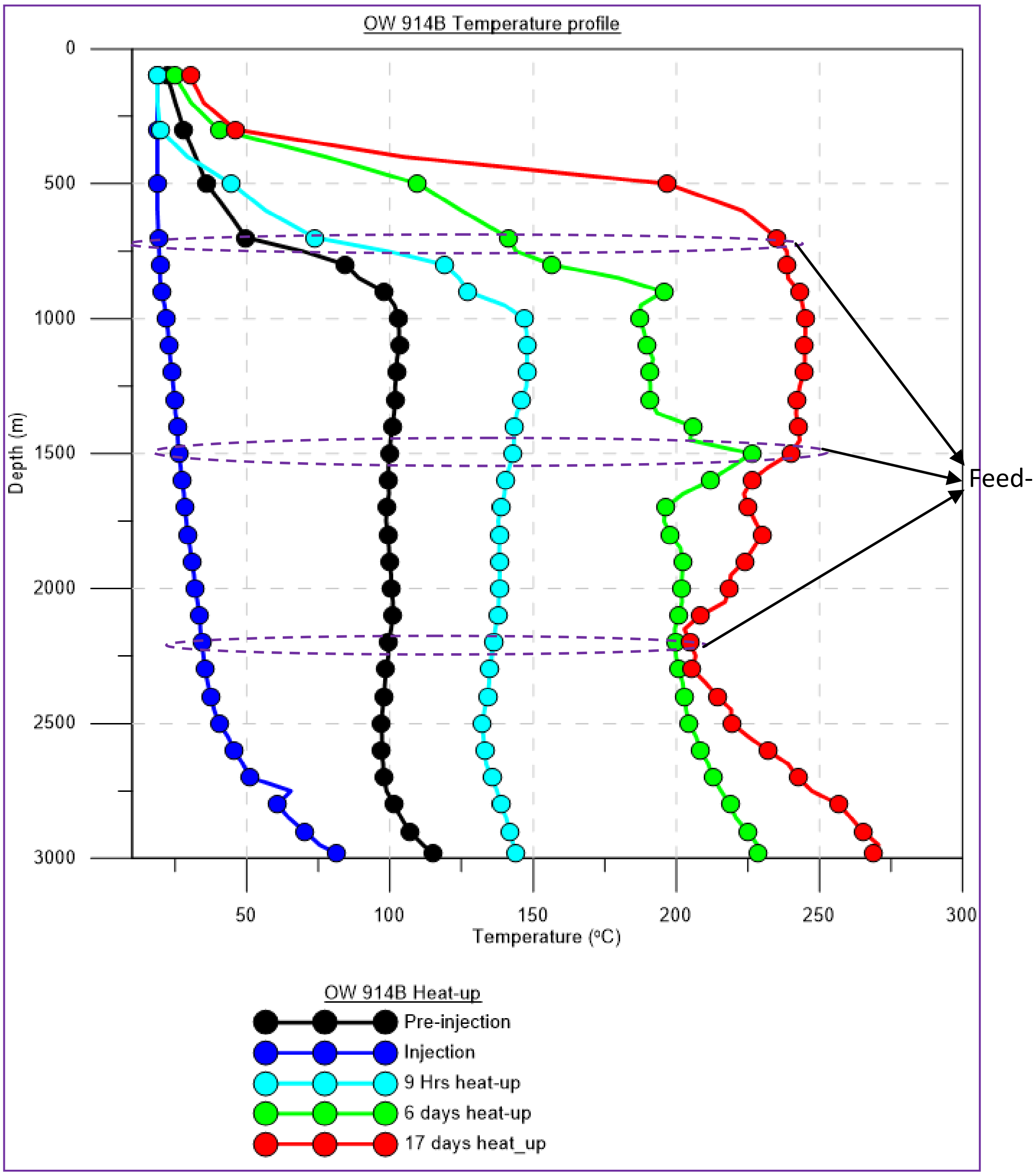


**Figure 8:** Heating profiles and feed zones indicated with purple dotted circle of OW 914B

Well OW 731C is a productive well with 6.4 MWe, from the temperature profiles it has a main feed zone at 1300 m, 2100 m and 2600 m which is the deepest feed zone in the well Figure 9. The well intercept the Olkaria fault and the Ololbutot at 1300 m. Temperature profile indicate there is an increase in temperature up to a maximum temperature of $250^{O}$C.

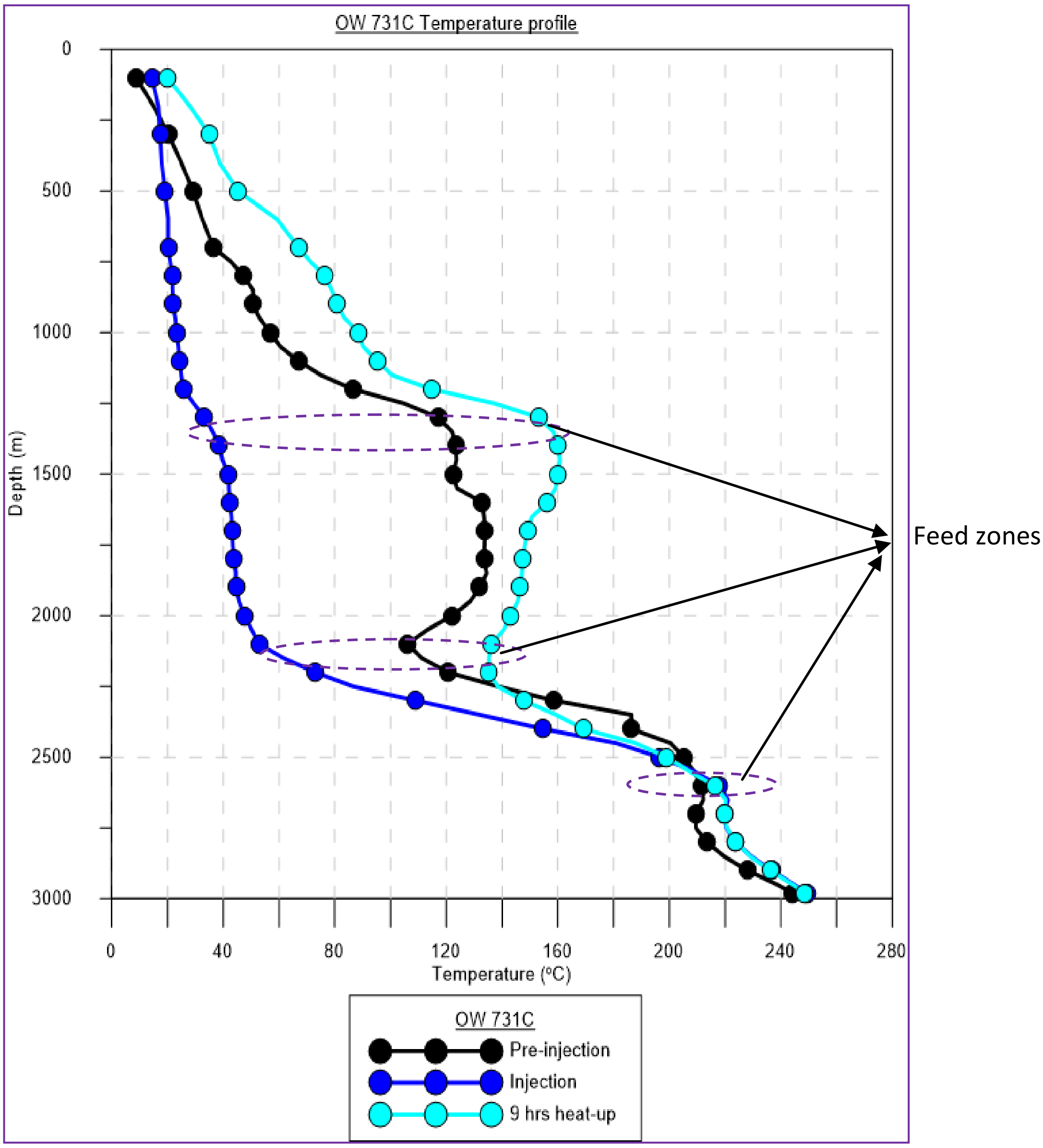


**Figure 9:** Heating profiles and feed zones of OW 731C

The temperature observed to increase to about 160°C at around 900 m from the surface then suffer reduction to 220°C at the bottom (Figure 10).

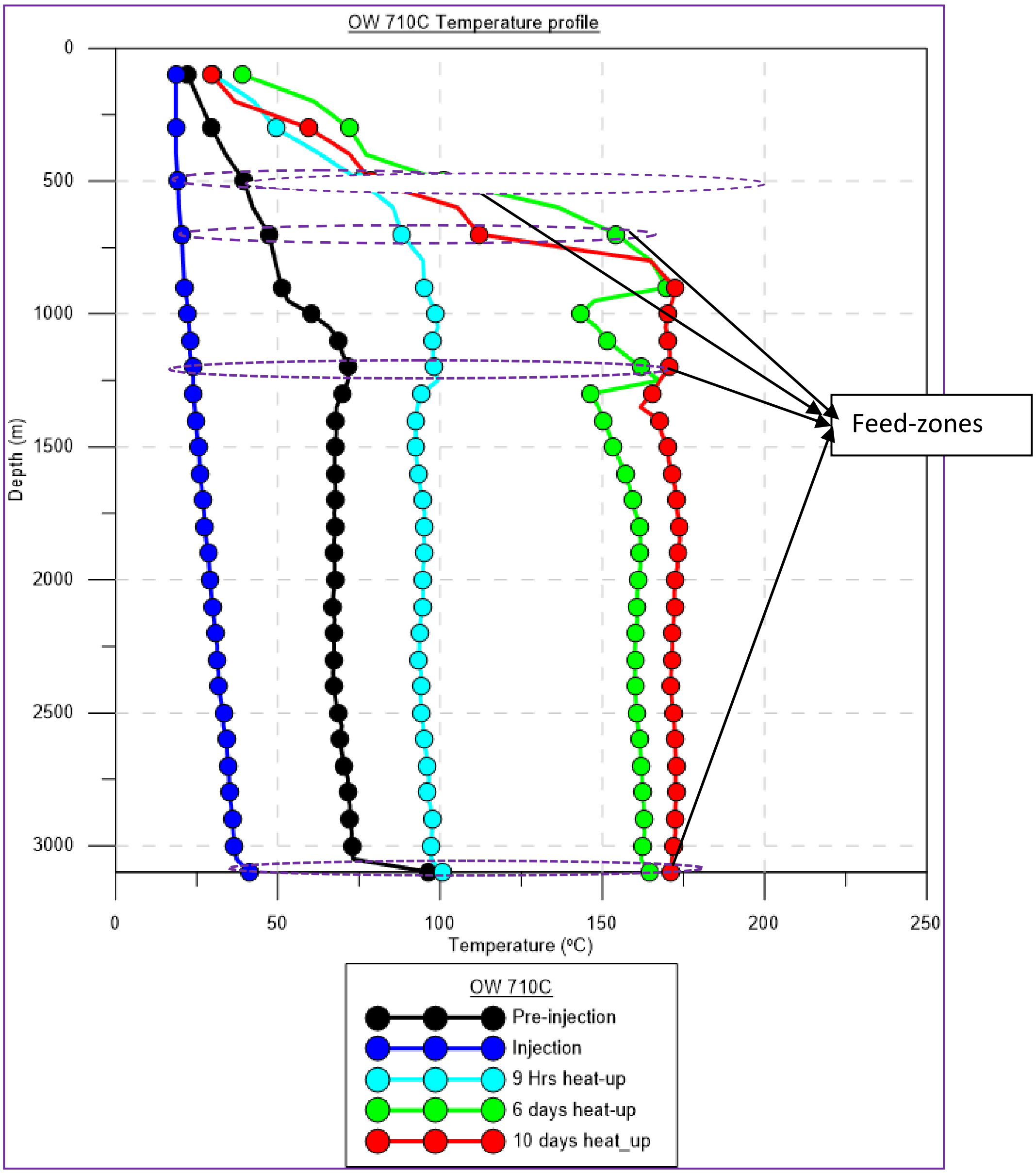


**Figure 10:** Heating profiles and feed zones of OW 710C

The OW 710C is located at the down flow on the thermal model, which means the Ololbutot fault allows cold fluid into the system at the depths of 900 m and 1100 m noted by temperature reversal. The feed zones near the casing shoe seem to dominate the temperature recovery with the deeper ones remaining quenched.

Well OW 39B is a productive well with 4 MWe, from the temperature logs minor feed zones are interacted at 600 m, 1100 m, 2500 m and 2750 m. Thedeepest feed zone which is associated with faults in the well is at 2750 m which is cooling faster and temperature reversal is noted Figure 11. The Ololbutot fault affecting the well by infiltrating cold fluid in the system.

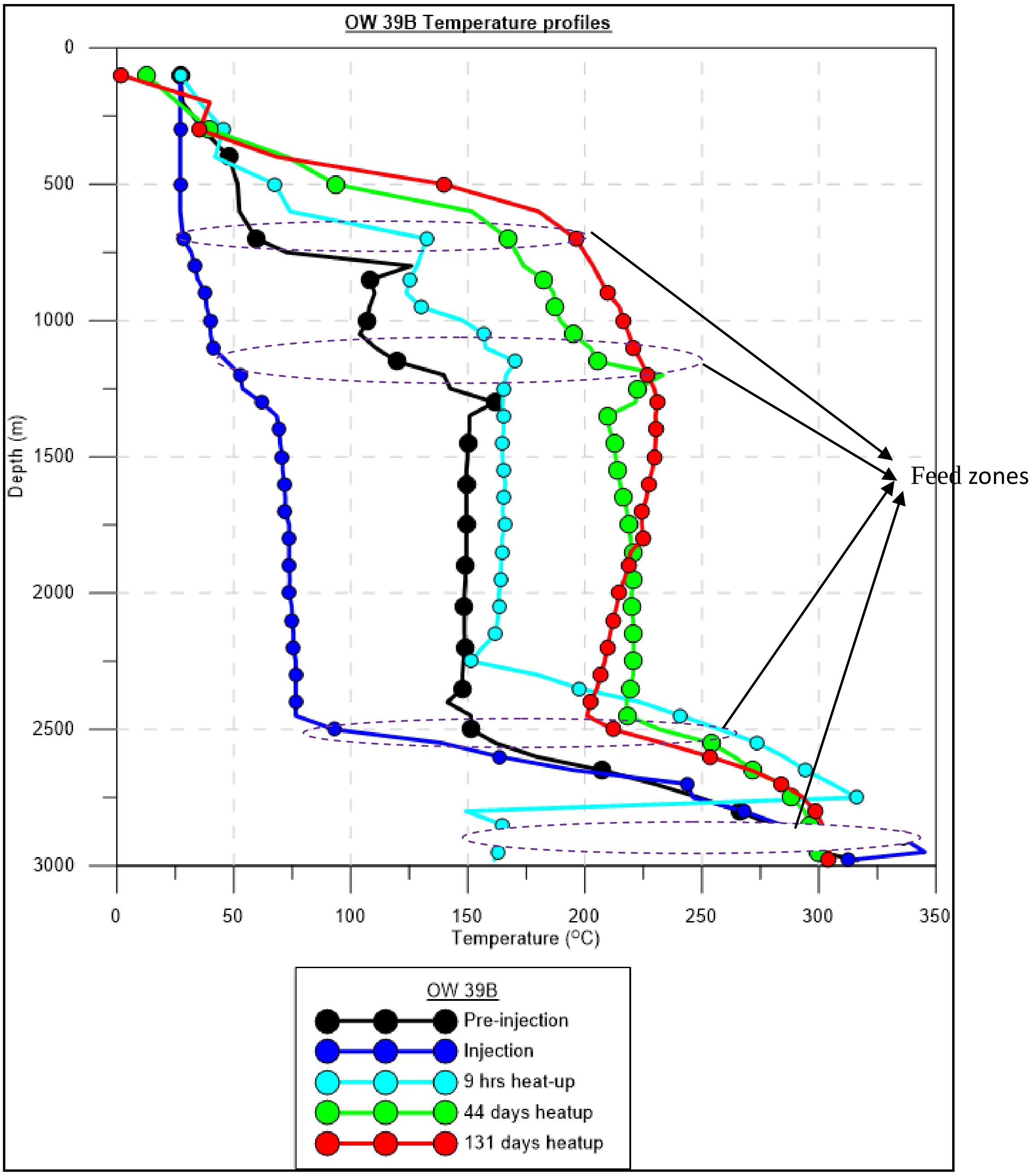


**Figure 11:** Heating profiles and feed zones in purple dotted color for OW 39B

Temperature profile indicate there is an increase in temperature up to a maximum temperature of 250$^{O}$C, feed zones associated with structures are at 1300 m, 2100m, and 2600 m Figure 12.

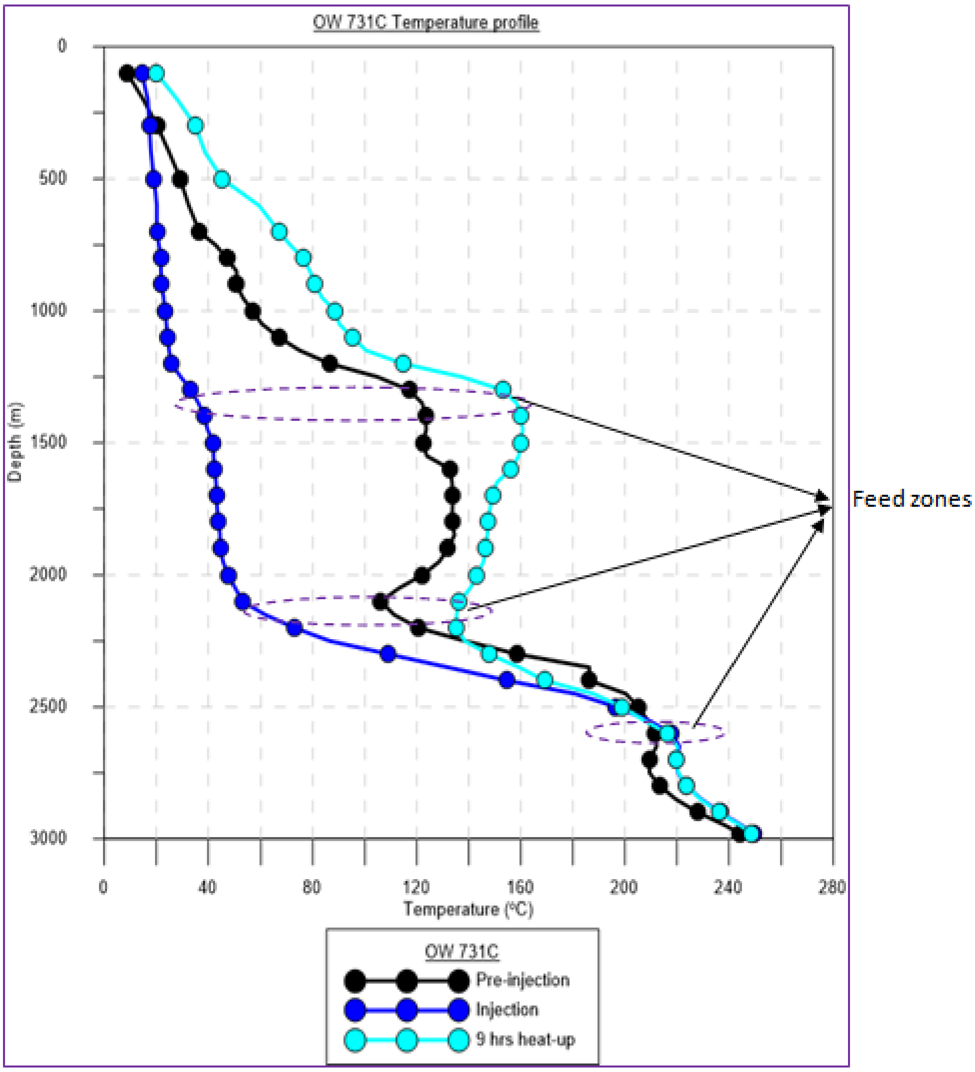


**Figure 12:** Heating profiles and feed zones of OW 731C

The temperature observed to increase to about 160°C at around 1000 m from the surface then suffer reduction to 220°C at the bottom (Figure 13).

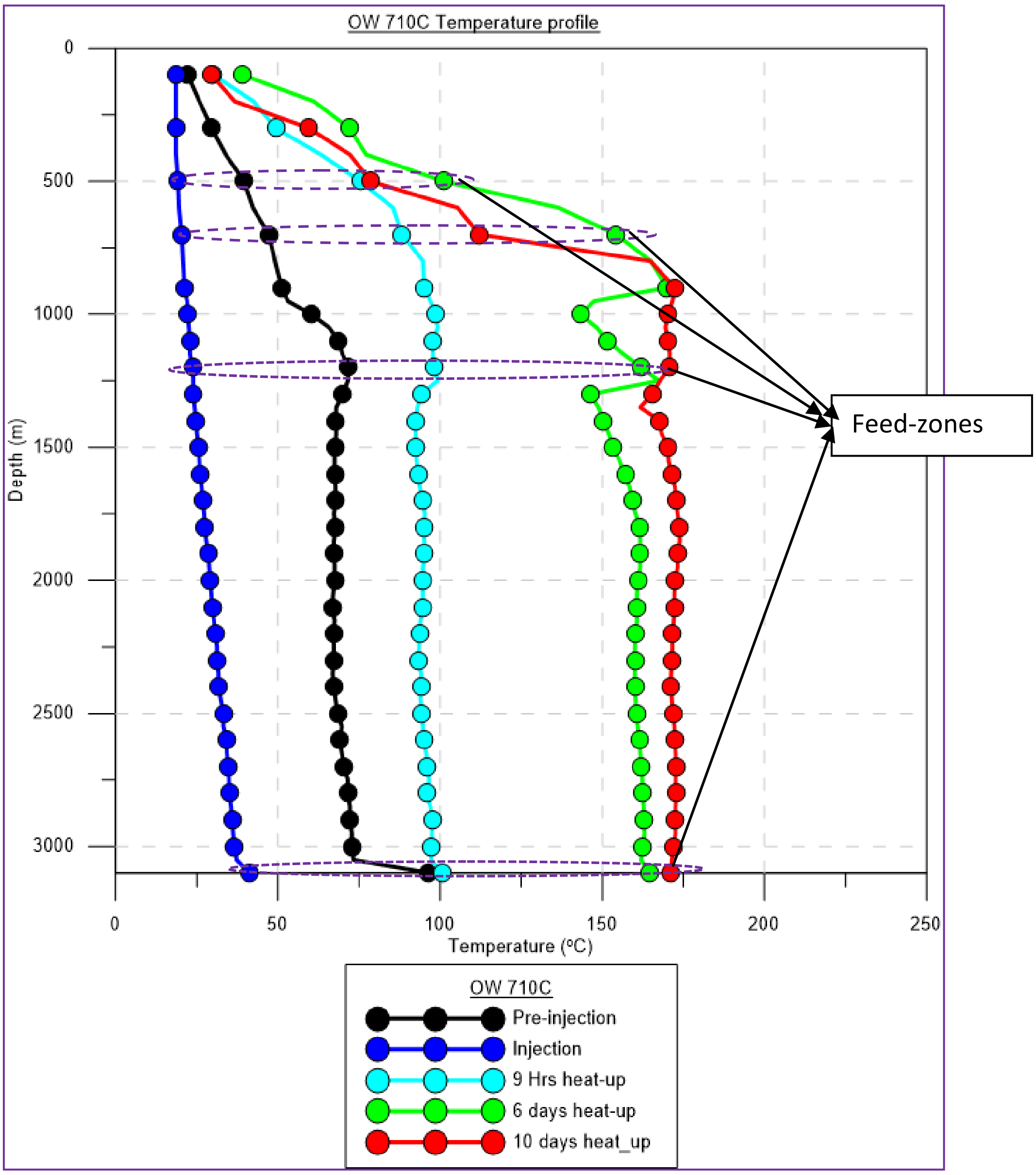


**Figure 13:** Heating profiles and feed zones of OW 710C

The OW 710C is located at the down flow on the thermal model, which means the Ololbutot fault allows cold fluid into the system at the depths of 500 m, 700 m, 1100 m and 3053m. The feed zones near the casing shoe seem to dominate the temperature recovery with the deeper ones remaining quenched.

Well OW 39B is a productive well with 4 MWe, from the temperature logs minor feed zones are interacted at 600 m, 1100 m, 2400 m and 2800 m. Thedeepest feed zone in the well is at 2800 m which is cooling faster and temperature reversal is noted Figure 14. The Ololbutot fault affecting the well by infiltrating cold fluid in the system.

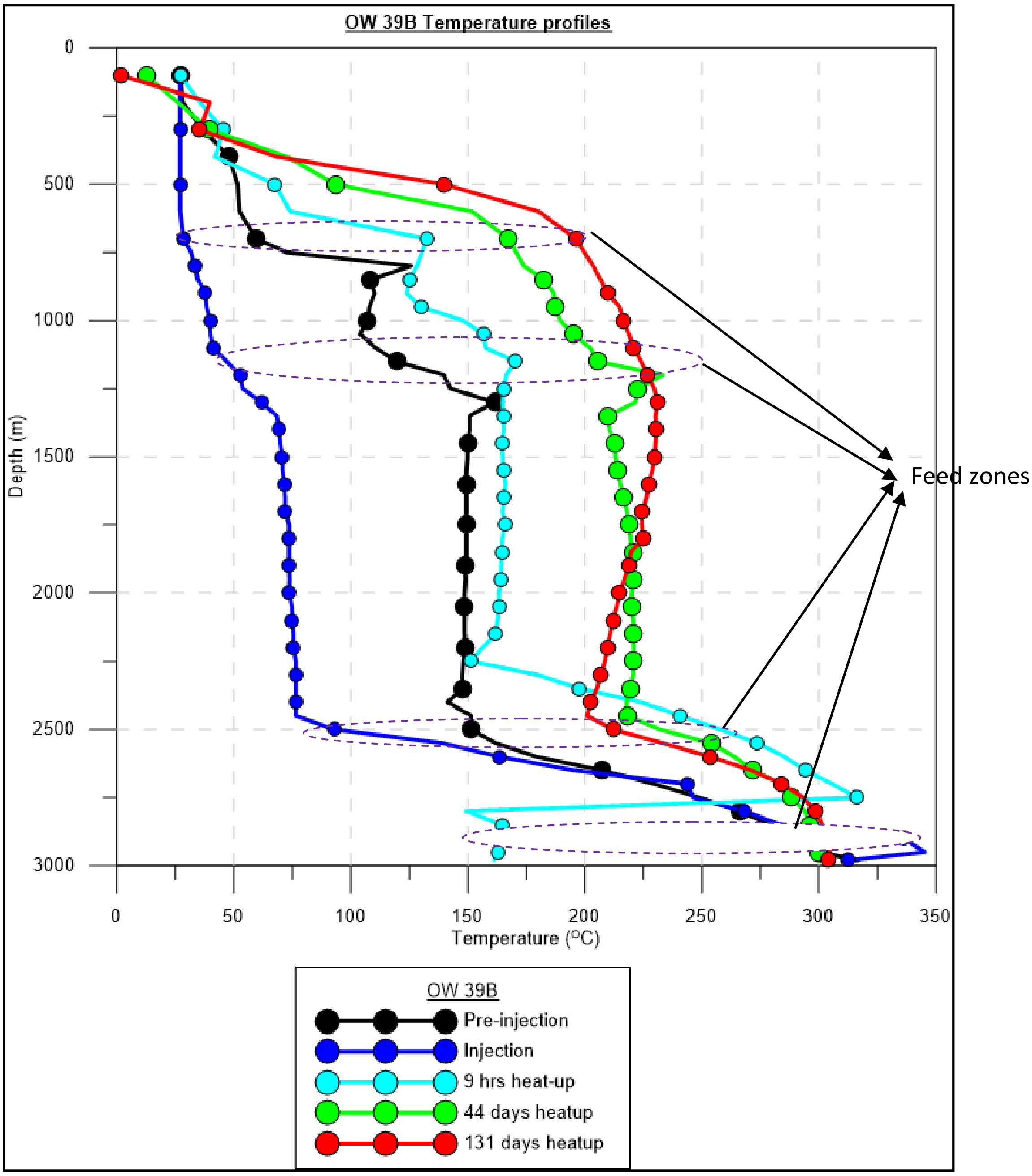


**Figure 14:** Heating profiles for and feed zones in purple dotted color OW 39B

## III. Conclusion

Within the study area up flow zones are OW 924A, OW 923A, OW 914B and OW 39B while the down flow are OW 917A, OW 710C and OW 731C from thermal model that is in agreement with current temperature measurement.

Temperature measured and alteration temperatures show good agreement, indicating highest temperature in excess of 280$^{o}$C at deeper levels.

The depth of feed-zones identified in the study vary from well to well and note that those feed-zone which are associated to loss of circulation at deeper depth tend to have higher temperatures and pressure and are associated with subsurface structures.

Wells located inside the ring structure tend to post expected/moderate production, these are OW 924A, OW 923A, OW 914B while those located at periphery or outside the ring structure OW 917A tend have low production.

Wells intersecting the Ololbutot structure tend to post low production the wells are the OW 710C and OW 39B.

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