

GEOLOGICAL CONTROL ON THE RESERVOIR CHARACTERISTICS OF OLKARIA WEST GEOTHERMAL FIELD, KENYA.

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ABSTRACT

The reservoir of the West Olkaria Geothermal Field is hosted within tuffs and the reservoir fluid is characterized by higher concentrations of reservoir CO_2 (10,000-100,000 mg/kg) but lower chloride concentrations of about 200 mg/kg than the East and North East Fields. The West Field is in the outflow and main recharge area of the Olkaria geothermal system.

Permeability is generally low in the West Field and its distribution is strongly controlled by the structures. Fault zones show higher permeability with wells drilled within the structures having larger total mass outputs. However, N-S and NW-SE faults are mainly channels for cold water downflow into the reservoir. Well feeder zones occur mostly at the lava-tuff contacts; within fractured lava flows and at the contacts of intrusives and host rocks.

INTRODUCTION

The Olkaria Geothermal area is located at about $0^\circ 54'S$ and $36^\circ 20'E$ in the Central Rift Valley of Kenya at an elevation of about 2000 m.a.s.l.. The Geothermal area has an aerial extent of more than 100 km^2 and has been divided into four fields for ease of development and management, namely; East, North-East, Central and West Fields (Figure 1). The East Field has been generating electricity since 1981 with an installed capacity of 45 MW_e . Production drilling has been completed in the NE Field for a 64 MW_e power plant that is expected to be operational by 1996.

The Central and West Fields are still under exploration and eight wells have been drilled in the West Field and two in the Central Field. Out of the eight wells drilled in the West Field, only five could sustain discharge, namely; OW-301, OW-306, OW-305, OW-304D and OW-401. Well OW-304D discharged for 168 days before ceasing production due to calcite scaling. Well OW-307 discharged low enthalpy fluid on vertical discharge test only while well OW-601 could not discharge due to very low permeability but the bottomhole temperature is more than 294°C .

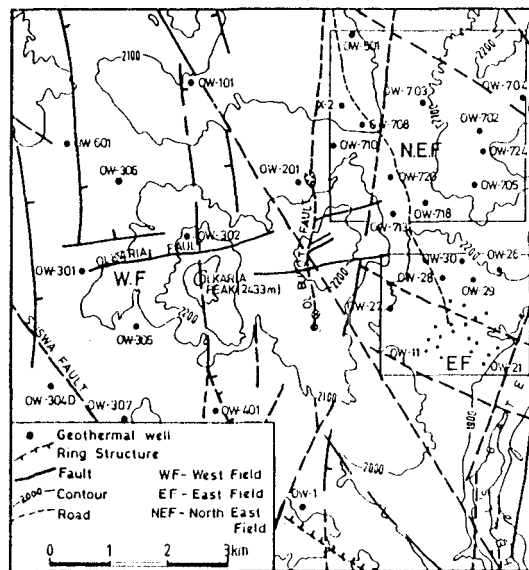


Figure 1. Structural Map of Olkaria Geothermal Field showing well sites

GEOLOGY

The geology of the Olkaria Geothermal area generally shows a division into two based on lithostratigraphy, namely; eastern and western. The eastern section includes; the East, North-East and Central Fields while the western sector has only the West Field. The dividing line between the two sectors is along the N-S Olkaria Fracture (Fault) that passes through the Olkaria hill (Figure 1).

A caldera association has been suggested for the Olkaria geothermal system with the main western collapse margin possibly passing through Olkaria hill but some other workers put it further to the west. Olkaria geothermal system is closely associated with Quaternary volcanism and surface geology is dominated by unconsolidated ashes and comenditic rhyolites, some of which form domes.

The field, being close to the western rift scarps, has major normal east dipping faults that are characterized by N-S and NW-SE trends. Some of these faults are still active and reach the deep levels to tap magma, eg., Ololbutot lava flow. Other

structures also occur, for instance, the Olkaria fault that traverses the Olkaria geothermal area in an ENE-WSW trend is the most important.

The subsurface geology of the Western sector is dominated by semi-welded thick tuffaceous rocks and minor trachytes, rhyolites and basalts. The zone above about 1600 m.a.s.l. is composed of rhyolites, trachytes and unwelded tuffs. Ashes occur on the surface but are underlain by rhyolitic lavas and trachytes. The zone at about 1600 m.a.s.l. is interpreted to be a major *disconformity* in the whole of Olkaria geothermal area and the rocks above it are considered to be of Quaternary age while those below are of Tertiary age. In the eastern fields, the upper zone is underlain by basaltic lava flows that are considered the cap-rock to the geothermal system but none has been identified in the West Field.

Tuff is the main rock in the zone below 1600 m.a.s.l. but rhyolites, trachytes, minor basalts and trachy-basalts occur. The tuff is the main reservoir rock for the West Field while the zone above 1600 m.a.s.l., that is largely composed of rhyolites, tuffs and trachytes is cased off in most wells. Dioritic intrusives have been intersected by some wells drilled close to known fault zones. By comparison, the East, North-East and Central fields have the reservoir within trachytes (Figure 2).

GEOCHEMISTRY

Most wells in the West Field show different reservoir fluid characteristics from those in the East and North-East Fields (Table 2). These characteristics include high reservoir CO₂ content (10,000 - 100,000 mg/kg) but low Cl values (≤ 300 mg/kg) implying that the reservoir is of bicarbonate type. By comparison, the fluid chemistry in the North-East and East Fields have chloride and reservoir CO₂ concentrations of more than 300 mg/kg and less than 1000 mg/kg respectively.

A plot on the Cl-SO₄-HCO₃ diagram (Figure 3) indicates that the fluid in West Field is largely of bicarbonate composition except for well OW-401 which is of mixed chloride-bicarbonate and OW-305 that is of chloride composition. Interpretation of the deep fluid chemistry based on chloride - enthalpy diagram (Figure 4) indicates that there is variable degree of mixing of the reservoir fluid westward with well OW-304D, having chloride concentration of less than 70 mg/kg, being the most diluted. The diluent is both steam heated and cool ground waters.

Hydrothermal mineralogy indicates an abundance of calcite in the reservoir and it occurs in veins where it is the last phase of deposition. The other secondary minerals in the reservoir include; illite, chlorite, vermiculite, gypsum/anhydrite and rarely epidote. On the whole, the mineralogy indicates less than neutral pH conditions in the reservoir.

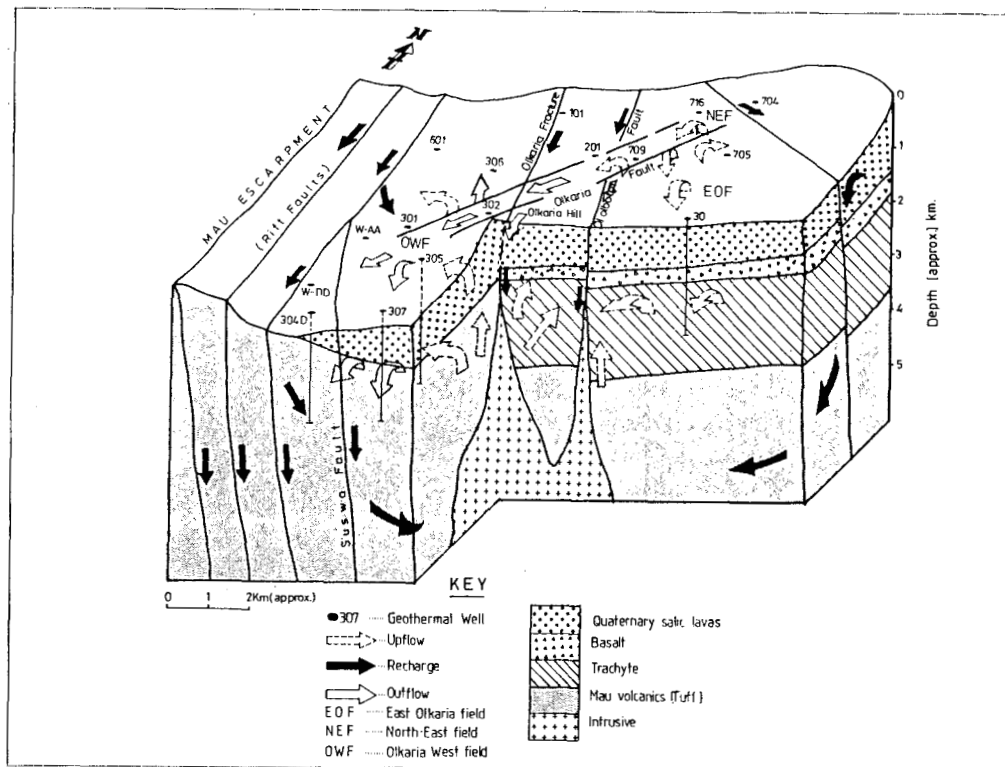


Figure 2. Structure and fluid flow patterns in Olkaria Geothermal Field.

TABLE 1 TOTAL DISCHARGE CHEMISTRY FOR OLKARIA WEST WELLS (mg/kg)

| WELL | Li | Na | K | Mg | Ca | F | Cl | SO ₄ | SiO ₂ | B | CO ₂ | H ₂ S |
|--------|-----|------|-----|------|-----|----|-----|-----------------|------------------|------|-----------------|------------------|
| OW-101 | 2.2 | 498 | 84 | 0.12 | - | 20 | 233 | 9 | 452 | 8.1 | 13364 | 18 |
| | 0.4 | 474 | 82 | 0.06 | 0.6 | 19 | 214 | 8 | 465 | - | 9074 | 23 |
| OW-201 | 0.7 | 255 | 27 | - | - | 22 | 260 | 15 | 189 | - | 915 | 50 |
| | 0.7 | 641 | 63 | 0.06 | 0.5 | 61 | 599 | 30 | 373 | - | 864 | 21 |
| OW-301 | 2.4 | 923 | 138 | 0.23 | 1.5 | 42 | 102 | 93 | 333 | - | 24742 | 50 |
| | 1.4 | 1090 | 129 | 0.11 | 0.6 | 65 | 175 | 53 | 333 | 10.2 | 19064 | 1140 |
| OW-304 | 0.9 | 1339 | 84 | 0.00 | 0.0 | - | 57 | 113 | 280 | 2.0 | 111520 | 23 |
| | 0.9 | 255 | 42 | 0.00 | 1.4 | 38 | 49 | 101 | 262 | 3.9 | 26581 | 9 |
| OW-305 | 1.6 | 324 | 63 | 0.00 | 0.0 | 32 | 386 | 19 | 471 | 1.4 | 2186 | 91 |
| | 1.4 | 379 | 71 | 0.00 | 0.0 | 30 | 392 | 40 | 483 | 1.6 | 2414 | 89 |
| OW-306 | 0.8 | 782 | 89 | 0.00 | 0.0 | - | 174 | 69 | 442 | 3.8 | 13504 | 108 |
| | 0.9 | 503 | 21 | 0.00 | 0.1 | 29 | 184 | - | 433 | 4.3 | 14517 | 16 |
| OW-307 | 1.6 | 684 | 57 | 0.00 | 0.0 | - | 84 | 155 | 159 | 3.5 | 1028 | 0 |
| OW-401 | 0.8 | 418 | 59 | 0.15 | 0.8 | 14 | 343 | 12 | 385 | - | 1972 | 12 |
| | 0.7 | 419 | 61 | 0.03 | 0.3 | 12 | 360 | 12 | 408 | - | 2181 | 10 |

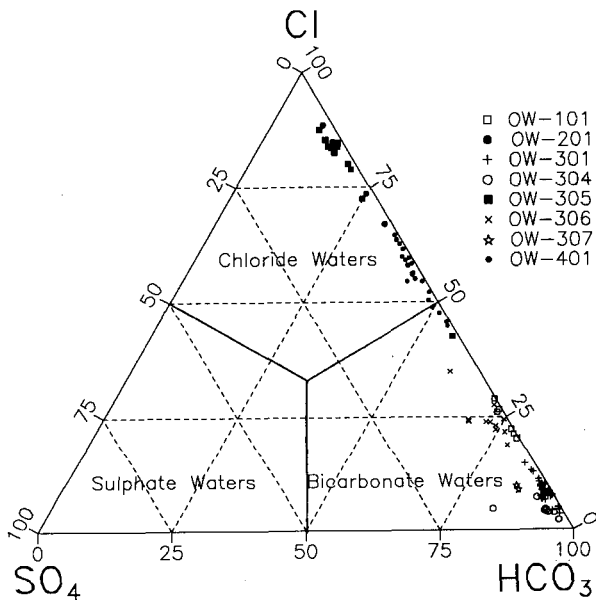


Figure 3. Ternary Diagram of Cl-SO₄-HCO₃

HYDROGEOLOGY

Hydrological structure of the Olkaria geothermal system is controlled by the following: Mau catchment area to the west; Lake Naivasha at about 5 km to the north and fault structures. The Mau escarpment is considered to be the main recharge area for the geothermal system and the recharge paths are the NW-SE, east dipping rift faults (Figure 2). N-S faults are common in the axial region of the rift and in the Olkaria area, they channel cool waters into the system (Ogoso-Odongo, 1986). Stable isotope

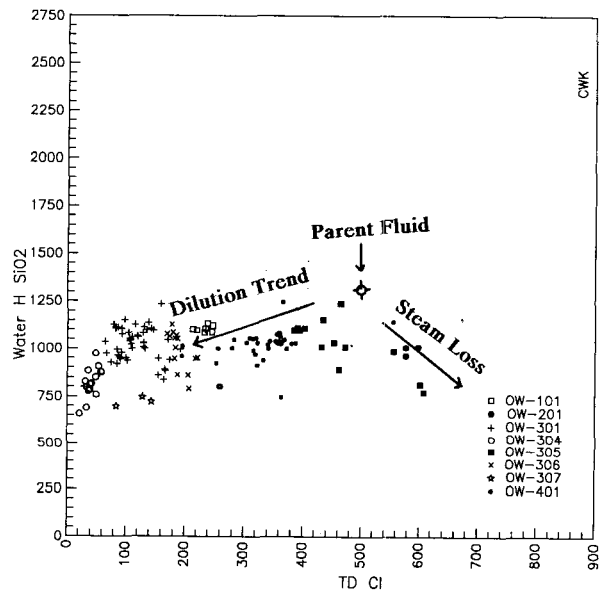


Figure 4. Chloride - Enthalpy Diagram

studies of the Lake Naivasha water and some geothermal wells drilled close to the N-S faults / fractures indicate comparable isotopic composition between the two waters (Ojiambo and Lyons, 1993) and this shows that the hydrologic gradient in the area is southward and that the N-S faults are important in the transmission of cold water.

The ENE-WSW trending Olkaria fault is considered the most important structure in the whole of Olkaria geothermal area in terms of resource exploitation. The fault zone transects the North-East, Central and West Fields. The upflow of the North-East Field has

been associated with the structure (Ambusso and Ouma, 1991) and it is also possible that the structure could be channeling the outflow westward and hence the high concentration of CO₂ in the West Field. It is also possible that some CO₂ could be of deep magmatic source discharging through the deep seated rift faults. Such discharges occur in many places along the major rift faults.

Permeability, as indicated by water loss test and heating profiles, is generally low in the West Field and this is due to the abundance of tuffs as the reservoir rock. Though tuffs have good primary permeability, this is often reduced on alteration to clays.

Most important permeability intersected by wells is associated with lithostratigraphic contacts between lavas and tuffs. The lava units are also better transmitters of fluid than tuffs and this can be related to their brittle nature that allows for open fractures that are not possible with tuffs. Some permeability is also associated with dykes as in well OW-304D but in this part of the field, they channel cool fluids into the reservoir (Figure 5).

DISCUSSION

The Olkaria West Field is largely located within an outflow structure of a system located under Olkaria hill and possibly further to the east. This is shown by the high bicarbonate and low chloride content of the reservoir fluid encountered by most of the wells, except OW-305. Clay analysis of samples from well OW-304D shows that the well has some cold feed zones at depths below 1200 m.a.s.l. (Figure 5). Inter-planar spacing (d) value of more than 16 Å indicate the presence of hydrothermal smectite that is stable at temperatures less than 150 °C thus the coincident zones in the well are interpreted to be cool inflow points. Correlation with lithology in well OW-304D

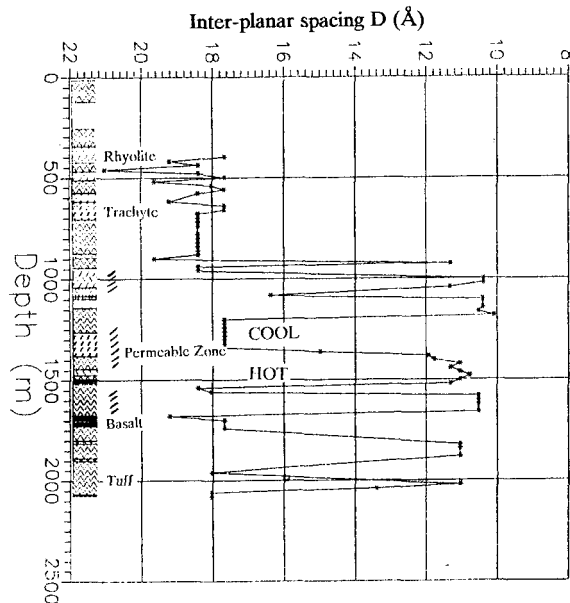


Figure 5. Clay data analysis of well OW-304D

shows that most of the cool inflow points coincide with trachy-basaltic layers which are interpreted to be dioritic intrusives that were injected through N-S faults. Downhole temperature profiles, however, do not show the cool (150 °C) fluid inflow zones in form of temperature inversion (Figure 6). This can be attributed to the fact that these zones may not be the main producers. The well is therefore, considered to define a SW boundary to the system and is possibly within the recharge area. The northern boundary of the system is still uncertain since high temperatures occur in well OW-601 though the well is non-productive.

The other boundaries of the field are defined by downhole temperature inversions that have been observed in some wells, namely; OW-307, OW-401 and OW-302. The southern extent is defined by wells OW-401 and OW-307 while wells OW-302 marks an eastern boundary. Wells OW-401, OW-101 and OW-302 were drilled within a N-S fault zone and the lower temperatures observed are possibly due to cold water movement through the fault. The importance of fault permeability is indicated by higher total mass output in wells drilled within known fault zones (Figure 1 and Table 2).

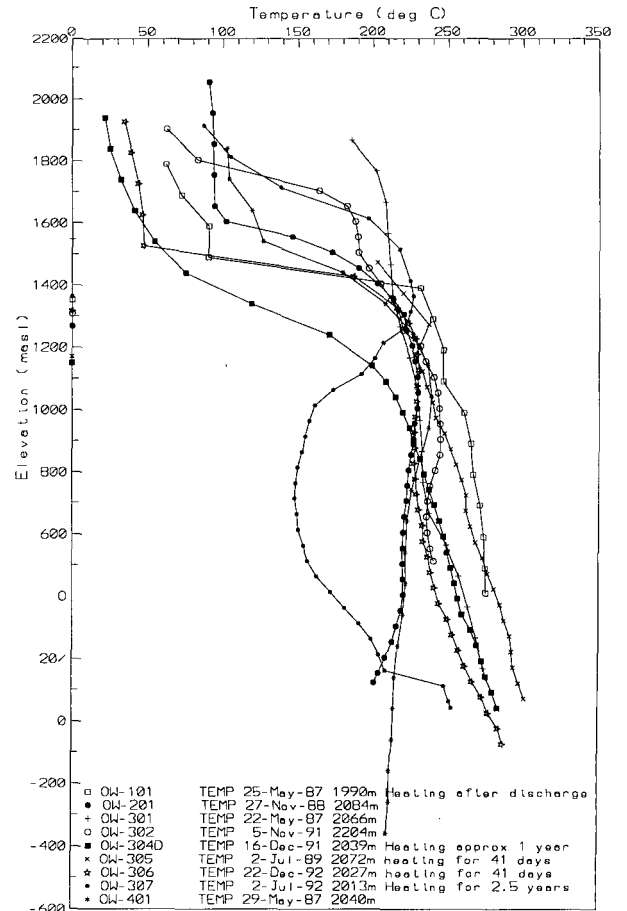


Figure 6. Temperature profiles of Olkaria West wells

Table 2. Summary of the Well Properties
(After Ouma, 1993)

| Well | KH dm | Injct. kg/s/ba | Enthal kJ/kg | Mass kg/s | Power (MW _e) |
|------|----------|-------------------|-----------------|--------------|-----------------------------|
| 101 | 5.0 | 5.0 | 1060 | 16.0 | 1.2 |
| 201 | 3.1 | 1.7 | 1050 | 35.0 | 1.5 |
| 301 | 4.2 | 4.4 | 1600 | 27.9 | 5.0 |
| 302 | 4.4 | 1.9 | 1140 | - | - |
| 305 | 2.2 | 7.8 | 2085 | 5.8 | 1.7 |
| 306 | - | - | 1037 | 12.9 | 1.2 |
| 307 | - | - | - | - | - |
| 401 | 2.8 | 0.9 | 1030 | 21.0 | 1.6 |
| 601 | - | - | - | - | - |
| 304D | - | - | - | - | - |

The resource area in the West Field is about 6 km², however, its exploitation will require some techniques of handling calcite scaling in the wellbore and reservoir. Using estimates of power generation of 11 MW_e/km² obtained by reservoir simulation studies of the East Field (Bodvarsson and Pruess, 1988), about 66 MW_e can be produced from the field for 25 years. However, the high CO₂ concentration may hinder its realization due to calcite scaling that is expected to occur both in the reservoir and bore of most wells.

CONCLUSIONS

1. Most areas of the west field are in an outflow structure and calcite scaling is expected to occur both in the reservoir and well bore.
2. The western sector of the field is in the main recharge area of the Olkaria geothermal system.
3. Permeability is associated with lithostratigraphic contacts, fractured lava units and fault zones.
4. About 66 MW_e can be generated for 25 years in the field.

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