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THE FLUID CHARACTERISTICS OF THREE EXPLORATION WELLS DRILLED AT OLKARIA-DOMES FIELD, KENYA

Opondo Kizito Maloba.
Kenya Electricity Generating Company,
P.O. Box 785, Naivasha, 20117, Kenya
E-mail: kopondo@kengen.co.ke

ABSTRACT

Exploration drilling in Olkaria-Domes Field began in 1998 and three wells were drilled to completion. These were wells OW-901, OW-902 and OW-903. A mixed type sodium bicarbonate - chloride- sulphate water with dilute chloride concentration (chloride ~178-280 ppm) was discharged. The pH of fluids discharged tended to alkali (8.68 to 10.69) as sampled at atmospheric pressure. Carbon dioxide gas concentration in steam on average was high relative to that of the Olkaria East Field. A less mineralised water component is thought to exist in this field due to the wells being shallowly cased. Solute geothermometry offer a good estimate of temperatures where dilute fluids inflow into the wells between 1000m to 1200m. Gas geothermometry approximate to the deep temperature in the reservoir though these were less than measured temperatures at well bottom. Down hole temperatures ranged from ~240 ^{0} C to ~ 340 ^{0} C were encountered in the three wells. The well fluids have low to medium enthalpy.

INTRODUCTION

Olkaria-Domes Field is located within the Greater Olkaria Geothermal Area and lies to the west of Longonot Volcano. The Greater Olkaria Geothermal Area consists of seven sectors namely, Olkaria North East, Olkaria East, Olkaria Central, Olkaria South West, Olkaria North West, Olkaria South East and Olkaria-Domes. Olkaria- Domes is the latest of these sectors to be explored by deep drilling. Three deep exploration wells were drilled between 1998 and 1999. Drilling slipped for eight years due to short falls in funding, but this resumed in June 2007. Since some additional wels have been drilled but yet to be discharge tested. Olkaria East and Olkaria North East are fully developed with installed capacities of 45 MWe and 70 MWe. Olkaria South West has a 12 MWe binary plant operated by Orpower4inc and construction is underway for an additional 36MWe. A smaller binary plant of ~ 4 MWe is operated by Oserian Development Company (ODC). Olkaria-Domes Field lies to the east of the Olkaria East Field.

The fields in the Greater Olkaria Geothermal Area are shown in Figure 1.

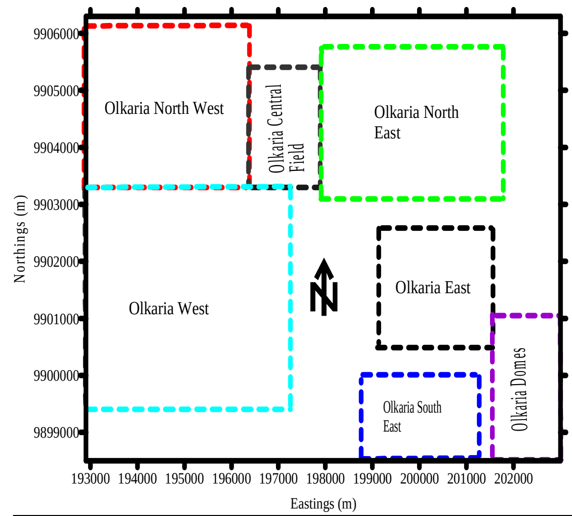

Figure1. Geothermal Fields in the Greater Olkaria Geothermal Area

The Olkaria –Domes Field comprises of the area immediately to the east of the Olkaria East Field. It is bound approximately by the Hell's Gate National Park– Ol' Njorowa gorge to the west and a ring of domes to the north and south (Mungania 1999). Most of the Olkaria Domes Field lies within the less than 20 Ωm apparent resistivity zone that covers the central and western portions of the Olkaria –Domes prospect. The rest of the field lies within the 30 Ωm apparent resistivity (Onacha 1993).

Three exploration wells were sited in the Olkaria –Domes Field which were drilled to depths varying from 1900m to 2200m vertical depth. These were named as wells OW-901, OW-902, and OW-903. These wells were sited to investigate the easterly, southerly and westerly extents of the reservoir and the structures that provide fluid flow into the field. Discharge tests were conducted and the fluids characterised. The wells discharged medium to low enthalpy fluids. These were a mixed sodium bicarbonate – chloride –sulphate water type with very dilute chloride concentrations ranging from 178 to 280 ppm. A dilute fluid exists between 1000m to 1200m.

Previous work.

A lot of work on surface geoscientific studies has been done in the Greater Olkaria Volcanic Area. Detailed geological and geochemical work was conducted in the area by different workers (Naylor, 1972, Clarke et al, 1990 , Muna, 1992 and Mungania, 1992). Detailed surface exploration with emphasis in the Olkaria-Domes field was conducted in the period 1992 to 1993 for geophysical, geological and geochemical surveys. This led to the development of a basic working model that resulted in recommendations to drill three wells.

Exploration drilling started in June 1998 through June 1999 and three wells drilled to completion. These were discharge tested to assess the field's power potential and characterise the fluids before appraisal drilling could commence. The three wells were well OW-901, OW-902 and OW-903. Hydrothermal mineral assemblages encountered in these wells indicated temperatures in excess of 300 ^{0}C around wells OW-901 and OW-903. This was in agreement with measured temperatures at bottom hole.

Geological setting.

The Olkaria-Domes Field is part of the Greater Olkaria Geothermal Area. The surface geology in Olkaria –Domes Field has been described by (Naylor, 1972., Clarke et al, 1990 and Mungania, 1992). This is dominated by the occurrence of thick pumice lapilli and ash deposits, which overlie comendite lava flows. The pyroclastic ash deposits are well layered and vary from weakly to highly weathered often imparting a brownish colour to the deposits (Omenda, 1999). Comendite is exposed in a few locations a long lava fronts and along the Ol'Njorowa gorge. Lava domes covered by pyroclastic deposits are common in the area. Most of them lie in an arcuate trend subscribing to what is known as the ring structure. The presence of the ring of domes has been used to suggest the presence of a buried caldera (Naylor, 1972, Clarke et al, 1990 Mungania, 1992)

The subsurface geology in Olkaria-Domes was described from drill cutings. The rocks comprise of unconsolidated pyroclastics, alkali ryholite lavas with intercalations of tuffs, basalts interstratified with trachytes and synetitic intrusives at the bottom of the wells (Lagat,1999; Mungania,1999; Omenda,1999). A generalised NW-SE geological cross-section through Olkaria East Field and Olkaria -Domes Field is shown in Figure 2.

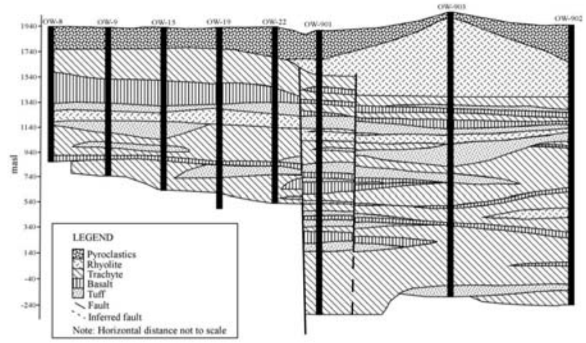

Figure 2: Generalised geological cross section through Olkaria East and Olkaria Domes Fields

GEOCHEMICAL CHARACTERISTICS OF WELL WATERS

Water composition

Typical fluid chemistry of the three exploration wells in Olkaria-Domes is shown in Table1:

Water composition for wells OW-901, OW-902 and OW-903 (in ppm) (Karingithi, 2002)

	OW-901	OW-902	OW-903
pH	9.8	9.55	9.43
Na	506	448	493
K	57	41	47
Mg	0.03	0.05	0.04
Ca	0.72	1.31	0.71
Li	2.4	1.3	1.7
Al	0.68	2.12	1.22
Fe	0.03	0.08	0.02
B	2.4	1.5	1.1
SiO_2	529	477	443
CO_2	566	434	634
SO_4	124	100	103
Cl	280	212	178
H_2S	1.83	2	3.51
F	80	52	46

Water discharged from the Olkaria–Domes wells is mixed sodium bicarbonate – chloride –sulphate type in the alkali pH range. The relative chloride, sulphate and bicarbonate content of water types is shown in Figure 3.

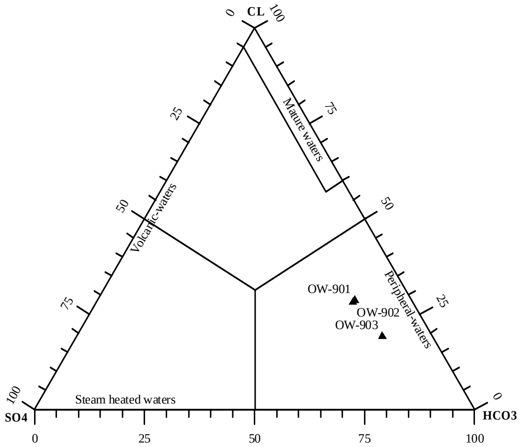

Figure 3: Relative Cl, SO_4 and HCO_3 contents of thermal fluids from wells in Olkaria -Domes

Water from the three wells has very low chloride and relatively higher bicarbonate content. The water types plot in the intermediate region of the peripheral water along the Cl-HCO_3 axis. This could suggest that the waters are formed by near surface dilution of meteoric water with the absorption of carbon dioxide gas. Low chloride alkali sodium bicarbonate–sulphate water could be found on the margins of a typical alkali chloride reservoir. These are formed when steam condenses on contact with cold meteoric water. Such processes occurring near the surface could produce the waters of the wells drilled in Olkaria- Domes.

A plot of Cl-Li-B from the waters are shown in Figure 4.

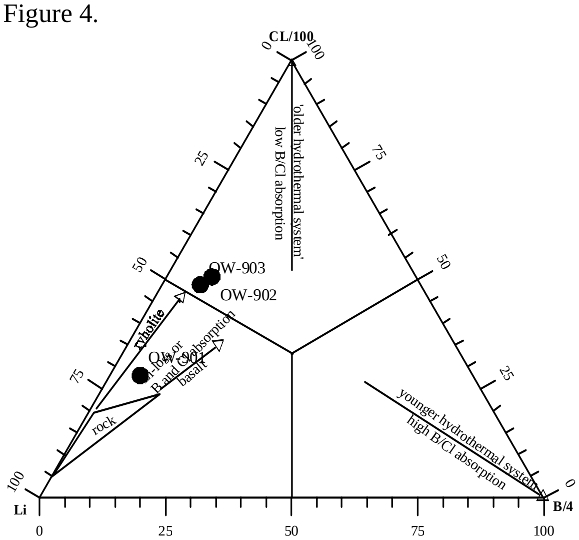

Figure 4: Relative Cl/100, Li, and B/4 contents in thermal waters from Olkaria Domes wells.

Fluids with a similar origin the Cl and B ratio is generally constant though the elements may be affected by dilution and evaporation (Ellis and Mahon, 1977). A decrease in the boron values could also be attributed to boron uptake by clays. Boron and chloride levels in the well fluids was fairly low suggesting possible dilution of the deep reservoir water by water low in solute content or preferential uptake of boron by clays. Occurrence of clay minerals is reported by (Mungania, 1999). Lithium is the least affected by secondary processes.

Older hydrothermal systems are relatively depleted in boron. The fluid discharges from wells OW-901, OW-902 and OW-903 plot in the intermediate region along the Li-Cl axis and cluster around the same point. B/Cl ratios are in the intermediate region and could suggest the absorption of low B/Cl magmatic vapours. Discharges from the Olkaria -Domes wells show comparatively low lithium content. These would suggest that the interaction of the fluids with rocks in Olkaria-Domes is less intense at the temperatures of the reservoir.

To further clarify the subsurface conditions in Olkaria-Domes the composition of well water was plotted on the trilinear plot of Na-K-Mg diagram (Giggenbach, 1988) Figure 5.

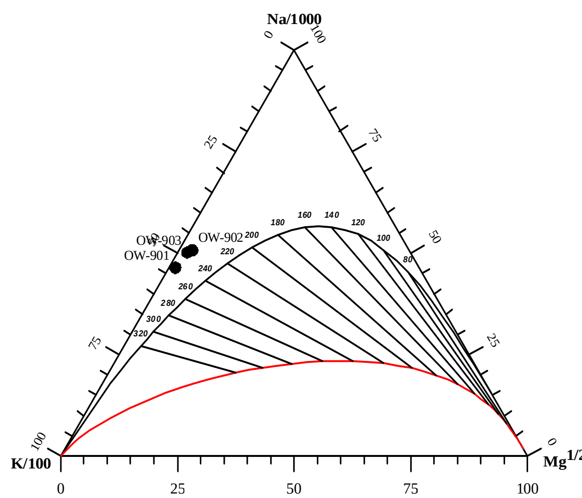

Figure 5: Evaluation of Na-K-Mg contents for wells in Olkaria Domes

This was used to evaluate the waters from the exploration wells in Olkaria-Domes Field to have equilibrated with hydrothermal minerals as well as estimating the equilibration temperatures of tNa-K and tK-Mg. A few samples of wells OW-901, OW-902 and OW-903 fall in the area of partially equilibrated water. Estimated NaK temperatures from the plot range between ~ 200 ˚ C and 240 ˚ C for wells OW-902, OW-901 and OW-903 fluids respectively. This could suggest some significant contribution from meteoric water input.

Gas chemistry

The gas composition of the discharges from wells OW-901, OW-902, OW-903 is shown in Table 1.

Table 2. Gas composition of fluids from wells in Olkaria-Domes (mmoles/100 moles of steam) (Olkaria geochemistry data base).

	CO_2	H_2S	H_2	CH_4	N_2
OW-901	176	18.4	5	0.4	4
OW-902	587	1.1		2.4	31
OW-903	534	4.4	1	4.2	47

The wells discharged fluids that had slightly high gas concentrations in steam. The carbon dioxide gas concentration shows variations in the well fluids. The concentrations vary from 587 mmoles/100 moles of steam in well OW-902 and 176 mmoles/100moles for well OW-901 while well OW-903 was ~ 534 mmoles/100moles of steam. Carbon dioxide carbon dioxide rich waters are produced for the most part by active metamorphism where carbon dioxide is released due to reactions between carbonates and silicates (Arnorsson and Barnes, 1983). Magma intrusive bodies may constitute the source of carbon dioxide in some areas. Hydrogen sulphide and hydrogen gas contents of the three wells was relatively low. These gases are probably depleted by reactions with the colder diluting water as steam ascends to the surface.

Nitrogen gas concentrations in the steam was high on average for all the three wells and showed the highest values in well OW-903 of 47 mmoles/100 moles of steam. In geothermal fluids nitrogen gas often originates from meteoric water saturated with air or breakdown of ammonia. The high values of nitrogen gas would suggest a significant contribution of cold meteoric water to the discharge of these wells. Well OW-901 fluids exhibited relatively lower molecular gas ratios of CO_2/H_2S, CO_2/H_2 compared to wells OW-902 and OW-903. The lowest gas ratios of CO_2/H_2S and CO_2/H_2 and the highest ratios of H_2/CH_4 often indicate fluids that are close to the upflow or have the most direct route to the surface. These ratios are also indicative of proximity to an underlying hot water source. Table 3 below shows molecular gas ratios of CO_2/H_2S, CO_2/H_2 and H_2/CH_4 for wells OW-901, OW-902 and OW-903.

Table 3: Molecular Gas Ratios for Olkaria-Domes wells

	CO_2/H_2S	CO_2/H_2	H_2/CH_4
OW-901	18.6	47.4	0.62
OW-902	528.8		
OW-903	121.4	29.62	0.22

The highest H_2/CH_4 ratio was for well OW-901 fluids and this could indicate the upflow of the reservoir could be around this well.

MEASURED AND GEOTHERMOMETRIC TEMPERATURE DSITRRIBUTION

Temperature profiles for the three drilled in wells in the Olkaria-Domes field are shown in Figure 6

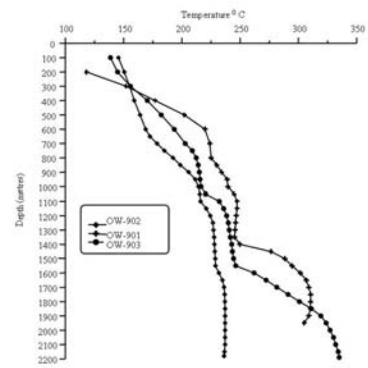

Figure 6: Temperature Profiles for wells OW-901, OW-902 and OW-903 (Ouma, 1999)

The bottom hole temperatures in the three exploration wells were very high except for well OW-902. The highest bottom hole temperatures are recorded in wells OW-901 and OW-903 while well OW-902 recorded lower temperatures. These temperatures range from 338 ^{0} C to 343 ^{0} C in wells OW-901 and OW-903 respectively. Well OW-902 recorded the lower temperatures at bottom hole ~ of 240 ^{0} C.

The solute geothermometric temperatures (Arnórsson, 2000a) calculated using the computer code WATCH for species components indicated lower temperatures than those measured at the well bottom for the three wells. For quartz temeprature, these ranged between 228 ^{0} C, 223 ^{0} C and 218 ^{0} C for wells OW-901, OW-902 and OW-903 respectively. For NaK temperatures, these ranged between 213 ^{0} C, 193 ^{0} C, 193 ^{0} C respectively for OW-901, OW-902 and OW-903 respectively. The solute equilibration temperatures compare closely with the measured temperatures of the three wells at depths between 1000m and 1200m which is thought to be the major feeder zone (acquifer) to all the three wells.

DISCUSSION

Olkaria–Domes well fluids fall in the alkali pH range and are mixed sodium bicarbonate -chloride-sulphate water type and have very low chloride content ranging from 178 ppm in well OW-903 to 280 ppm in well OW-901 as sampled at atmospheric pressure. This could suggest that the well waters could have formed by absorption of carbon dioxide gas from ascending steam into near surface waters of meteoric origin. Boron and chloride levels in the well waters were fairly low suggesting possible dilution of the deep reservoir water or preferential uptake of boron by clay minerals. In Olkaria- Domes the waters have comparatively low lithium content. These could indicate less intense water-rock interaction at reservoir temperatures.

Gas composition in the steam was slightly higher. High Carbon dioxide gas concentration were observed in wells OW-903 and OW-901 and lower concentration in well OW-902. Measured The measured temperatures of wells OW-901 and OW-903 are higher than that of well OW-902 and this would suggest that wells OW-901 and OW-903 would be closer to magma intrusive bodies. Hydrogen sulphide and hydrogen gas contents of fluids of the three wells was relatively low and could have been depleted by reactions with the cold diluting fluid or the wall rocks as steam ascends to the surface. Nitrogen gas concentrations was elevated on average for all the three wells and showed the highest values in well OW-903 and lower values in well OW-901. High nitrogen gas concentration in geothermal fluids often originate from meteoric water saturated with air or breakdown of ammonia and this suggest a significant contribution of cold meteoric water to the discharge of these wells. Molecular gas ratios of CO_2/H_2S, CO_2/H_2 for well OW-901 were relatively lower than for wells OW-902 and OW-903 suggesting well OW-901 could be closest to the upflow or closest to the underlying hot water source. Similarly, the H_2/CH_4 ratio is highest in this well which is consistent with upflow systems.

Temperature estimates from the Na-K-Mg trilinear plot (Giggenbach, 1988) indicate that Na/K temperatures are highest in well OW-901 and OW-903 while it is lower in OW-902. The solute geothermometric temperatures of quartz and indicated lower temperatures than those measured at the well bottom. Solute geothermometers compared closely y with the measured temperatures of the three wells at depths between 1000m and 1200m which is thought to be the major feeder zone. Solute geothermometry temperatures coupled with measured temperatures from temperature profiles and water chemistry suggest the water feeding these wells is a mixed water of a shallow origin. This could suggest the existence of a reservoir of shallow fluids in the upper parts of the field. The highest bottom hole temperatures were recorded in wells OW-901 and OW-903 while well OW-902 recorded lower temperatures.

CONCLUSIONS

- Olkaria–Domes wells produced mixed sodium-bicarbonate – sulphate water type low in chloride content.
- Carbon dioxide and nitrogen gas concentration is relatively high in the fluids.
- Gas ratios of CO_2/H_2S, CO_2/H_2 and H_2/CH_4 suggest the upflow fluids could be around well OW-901.
- Solute geothermometry temperatures of quartz and NaK indicate low temperatures which coincide with occurence of cold water feeders into the wells. Gas geothermometry temperatures approximate to measured temperatures at bottom hole.

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