ANALYSIS OF WELL TEST DATA FOR OLKARIA WEST AND PRELIMINARY ASSESSMENT OF ITS POWER POTENTIAL

P.A. OUMA

Olkaria Geothermal Project, Kenya Power Company, Naivasha, Kenya

SUMMARY - Analysis of the well test data from ten (10) deep wells completed in Olkaria West is presented. The high temperatures are distributed along the Olkaria fault zone or Olkaria fracture zone. The upflow of the system is suggested to be to the west or North west of OW-301, based on the pressure and temperature contours. Permeability and hence fluid movement is mainly along contact surfaces between pyroclastics and rhyolites, fractures within the rhyolites and along major fault zones such as the ones around OW-301. The output from the wells in Olkaria West is low except for OW-201 and OW-301 but with higher CO_2 content in the discharge fluids than observed in the wells from Olkaria East and North East. The proven resource area covers about $14 km^2$ probably capable of supporting about 150 MWe power production for 25 years. Further drilling is required to establish the extent of the proven resource area to the west and north west of OW-301 and OW-101.

1. INTRODUCTION

Olkaria West geothermal field is one of the three sectors which together form Greater Olkaria geothermal field, located 125 km north west of Nairobi (Fig. 1).

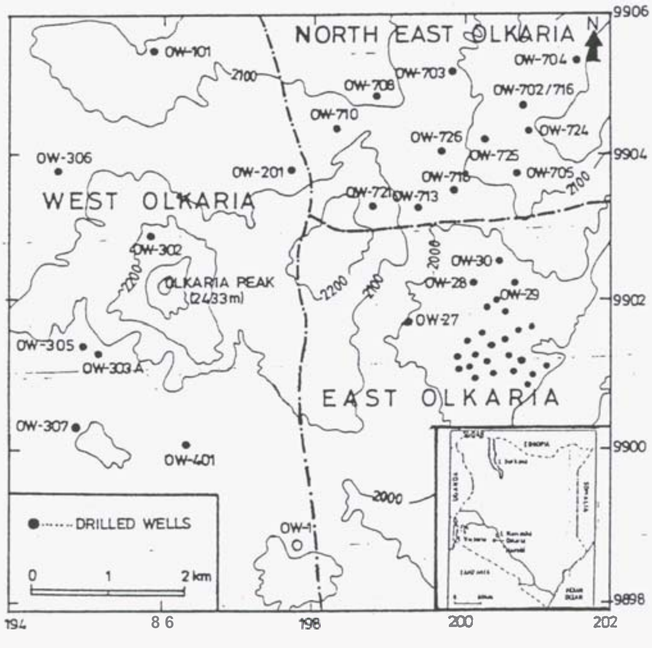

Figure 1 - Location map of Olkaria Geothermal field, Kenya

The other sectors are Olkaria North East and Olkaria East geothermal fields. Olkaria East geothermal field has been producing electrical power since 1981 when the first 15 MW unit started operation. The other two 15 MW units came on line in 1982 and 1985, respectively, bringing the plant capacity to the current level of 45 MW. Olkaria North East geothermal field is currently under development following a successful exploration programme. A total of twenty nine (29) wells have been drilled in this sector and a *64* MW power plant is planned. Exploration drilling in Olkaria West geothermal field started in 1982 with drilling of OW-101 which was completed to 1616m TD. Since then ten (10) wells have been drilled and completed. Eight (8) of these wells have been discharge tested whereas two (2) of them cannot discharge.

This paper looks at the test data from the wells already drilled in this sector with an aim of assessing its power potential. Recommendations are also made on what additional work is required before finalizing the estimate of field size and hence its power potential.

2. GEOLOGICAL SETTING

The Olkaria geothermal field is associated with the Olkaria Volcanic Centre. Olkaria forms one of several major volcanic centres west of lake Naivasha, in the East African Rift Valley. The geothermal reservoir is considered to be bounded by arcuate faults forming a *ring* or a caldera structure (Naylor, 1972). Naylor's interpretation that the Olkaria volcanic centre, and the present geothermal system, are associated with a former caldera has not been universally accepted. From the review of the local geology, **KRTA** could find no substantiating evidence for a caldera structure at Olkaria (**KPC**, 1984). Yet Virkir (**KPC**, 1985) and Woodhall (1987) have supported the caldera theory at Olkaria. Subsurface geology available to date has not confirmed or negated a caldera though indications are strong in that the Olkaria West wells have a different stratigraphy from the eastern wells indicating that the Olkaria West field could be outside the proposed caldera structure (KPC, 1990). The magmatic heat source is represented by intrusions at deep levels inside the ring structure. Faults and fractures are prominent in the area, particularly in Olkaria West. The general trend is **N-S** and E-W but there are also some inferred faults striking almost NW-SE (Fig.2).

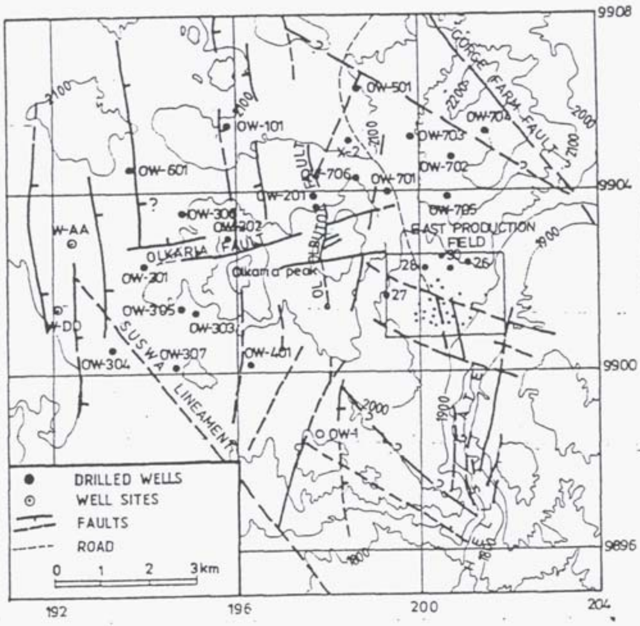

Figure 2 - Structural map showing well localities

3. WELL PROPERTIES

3.1 Well 101

The well was completed to a depth of 1616m. The maximum temperature recorded in this well is 278°C at 1580m. Completion tests, pressure and temperature recovery and flowing temperature/pressure profiles indicate the major permeable zones to be at 632-700m, 800-1050m and below 1500m.

Results of discharge show the average mass output as 15.1 kg/s With enthalpy of 1085 kJ/kg at a WHP of 6.6 bars absolute using a 4" lip pipe.

3.2 Well 201

This well was completed to 2116m. Indicated aquifers from completion tests, losses during drilling and chemical analysis of circulation fluids, are at 960-1000m, 1080-1120m, 1220-1260m, with minor aquifers at 1340-1350m, 1456-1460m, 1600-1700m and at 1900m. This well is located on the Olkaria fault and cuts through fractures in the interval 960 to 1460m.

Temperature recovery shows a maximum of 237°C at 1000m with an average of 225°C at 1200-1800m and a bottom hole temperature of 193°C. The well mass output is 34.2 kg/s at 4.5 bars absolute WHP with average enthalpy of 1085 kJ/kg.

3.3 Well 301

Well 301 was completed to a depth of 1912m. Indicated aquifers are at 520-650m, 900-1000m and 1250-1350m. The pressure pivot point indicates that the major aquifer is at 1200-1300m. The well was located on the Olkaria fault and cuts through a near vertical fracture zone in the interval 520 to 1500m.

Temperature recovery shows a maximum of 300°C at 1895m and an average of 225-235°C over the interval 520-1300m where the highest permeability is encountered. Discharge tests gave an output in excess of 34 kg/s with enthalpy of 1725 kJ/kg at WHP of 6.3 bars absolute.

3.4 Well-302

The well was drilled to 2197m. Intermediate completion tests and heating runs revealed major permeable zone between 1030-1070m with some minor permeability at 1415-1425m and 1680-1710m. The pressure transient tests conducted at well completion indicated transmissivity averaging about 3.3. x $10^{-8}m^3$/Pas. Then injectivity tests yielded a specific capacity of 1.9 kg/s/bar. Well OW-302 could not initiate self discharge and attempts to airlift in order to stimulate the well to discharge failed after pipes were left in the hole. The hole is only clear down to 1700m. After more than two years of shut-in following the discharge attempts peak temperatures of 230°C are measured between 1250-1300m With temperature of 220°C at 1690m.

3.5 Well-304D

OW-304 was renamed OW-304D after it was deviated following drilling problems encountered while drilling OW-304. The well did not intersect the steam zone intersected by OW-301 and OW-303A below about 1550m masl necessitating setting of a deep casing at 885m. However, major permeability and high temperature conditions were encountered below 1000m. Water loss test and heating profiles indicated major permeability at 1250-1450m and 1550-1650m. Minor permeability could also be picked at 900-1050m. The well was deviated from just below the production casing shoe at 921m and then successfully drilled to a total depth of 2099m. The maximum temperature recorded in the well is 289°C at 2050m depth.

OW-304D was capable of initiating self-discharge. However, the discharge from this well had the highest amount of CO_2, in the steam, ever recorded in the entire Olkaria geothermal field (ranging between 10-76% by wt. of the steam). The well collapsed after 168 days of discharge due to scaling. The nature of scaling has not yet been established.

3.6 Well 305

This well was sited only 140m away from OW-303A with the hope of successfully drilling it to 2200m. Down to the level at which OW-303A was abandoned, high temperatures upto 235°C were realised and the permeability was good. However to effectively appraise the area, all the scientific data below the drilled depth was still required together with the well output. The well was sunk to 2004m using aerated mud to drill in the production horizons.

The analysis of pressure transient tests at completion gave transmissivity values which varied between 1.4-3.9 x $10.8m^3$/Pa.s. The skin factor obtained from the infinite acting reservoir type curve matching was +5 suggesting mud damage. Permeability in the well is fairly distributed with major feed zones occurring between 950-1050m, 1250-1450m and 1750-2000m. Temperature recovery trend exposes a cased production aquifer between 600-900m. The highest temperature recorded is 301°C at 2000m. The well develops internal flow while shut in thus preventing full temperature and pressure recoveries.

The output on 3" ϕ pipe was total mass of 6.25 kg/s, steam flow of 4.1 kg/s and weir flow of 1.8 kg/s with an enthalpy of 2035 kJ/kg and WHP of 8.9 bars absolute equivalent to 1.7 MW(e). The output from the well generally improved as the well remained on discharge a phenomenon that could be attributed to mud damage. The well turned out to be a small producer probably due to deep casing or reduced permeability due to mud damage.

3.7 Well-306

The well was drilled to a total depth of 2147m. It had formation collapse problems below the production casing shoe upto 948m and several cement plugs were put between 700m and 948m within the production zone so the permeability within that depth range could have been sealed. From the water loss tests and recovery profiles major permeability was indicated at 700-850m and 1550-1750m depth. The maximum temperature recorded in the well is 289°C at 2150m. The average output at 5 bars absolute is mass of 12.9 kg/s and enthalpy of 1037 kJ/kg equivalent to 1.2 MW(e).

3.8 Well-307

The well was completed to a depth of 1998m. The casing shoe was set at 650m and before setting the production casing temperatures of more than 210°C were measured at 600m.

Completion tests data suggested good permeability and favourable temperatures. The highest temperature recorded is 259°C. Further temperature recovery profiles revealed inverted temperatures. The well could initiate discharge but at very low enthalpy and virtually producing no steam.

3.9 Well 401

This well was completed to a depth of 2505m on 21/4/84. Aquifers were identified at 1000-1200m and 1800-1900m. Pressure pivot point indicates the main active aquifer to be at 1200m, while temperature recovery indicates an aquifer cased off at 800m.

Temperature recovery shows a maximum of 225°C at 800m, and a bottom hole temperature of 208°C with an average of 200-208°C over 900-2000m interval.

Discharge test shows the well has a mass output of 22.8 kg/s at 4.9 bars absolute WHP with enthalpy of 985 kJ/kg.

3.10 Well-601

Well OW-601 was sited to the north western part of Olkaria West field to investigate the possible extension of the high reservoir potential discovered by the drilling of well OW-301. The well was drilled 2000m depth in an area marked by low resistivity anomaly (below 20 Ωm). The completion tests indicated extremely low permeability. Though well OW-601 was drilled close to a fault, the well is impermeable possibly due to sealing by the puggy clays observed (KPC, 1990). The recovery runs indicated high temperatures (maximum stable bottom hole temperature of 304°C) with no inversion. The profile is basically conductive due to the fact that the well did not intersect any permeability. The well cannot discharge.

The properties of Olkaria West wells are summarised in Table 1 below.

Table 1 - Summary Of Well Properties

Well No.	KH Dm	Inj. kg/s/b	Enth. kJ/kg	Mass kg/s	Power MW(e)
101	5.0	5	1060	16.0	1.2
201	2 5	1.7	1050	35.0	1.5
301	4.2	4.4	1600	27.9	5.0
302	4.4	1.9	-	-	
303A	7.8				
304D					
305	2.2	7.8	2085	5.8	1.7
306			1037	12.9	12
307		-	-	-	
401	2.8	.9	1050	21.0	1.6
601			-		

4. TEMPERATURE AND PRESSURE DISTRIBUTION

Figures 3 and 4 show the aerial temperature distribution in the Olkaria West field at 1000 and 500 masl. The temperature maxima at 1000 masl (Fig. 3) occur along a north-south stretching corridor housing OW-101, 301, 302 and OW-305. This suggests a high temperature anomaly along the Okaria fracture zone. Similar contours at 500 masl (Fig. 4) suggest a NE-SW trending high temperature anomaly superimposed on N-S stretching high temperature corridor observed at 1000 masl. The combined effect puts the upflow of the Olkaria west system around OW-301 and OW-305 area. The high temperature anomaly around OW-301 probably extends further to the west. The NE-SW trending signature of the temperature distribution could be associated with the Olkaria fault structure. **This** puts OW-301 at the intersection of the Olkaria fault and the Olkaria fracture zones. The distribution also shows that the area around **OW-101** is underlain **by** a hot reservoir with temperatures in excess **of** 280°C below 500 masl. **A** deep well around **OW-101** area is needed to confirm the **high** temperature projected below 500 masl.

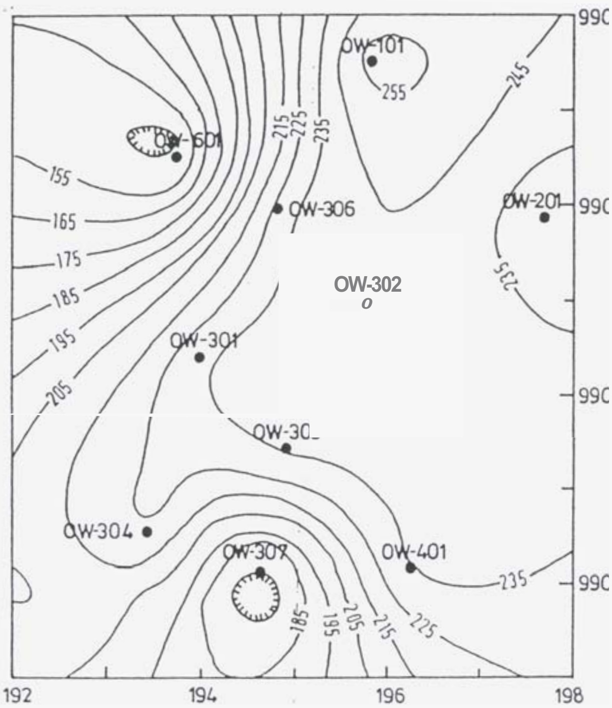

Figure 3 - Temperature Contours at 1000 masl

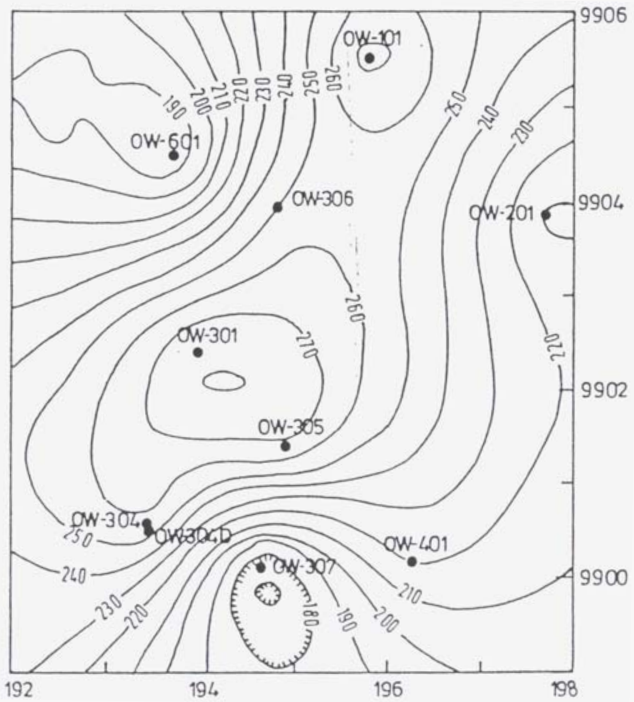

Figure 4 - Temperature Contours at 500 masl

Figures 5 **and 6** show the pressure distribution at 1000 and 500 masl in the Olkaria West field. The general pattern of pressure distribution indicates high pressures around or to the west **of** OW-301.

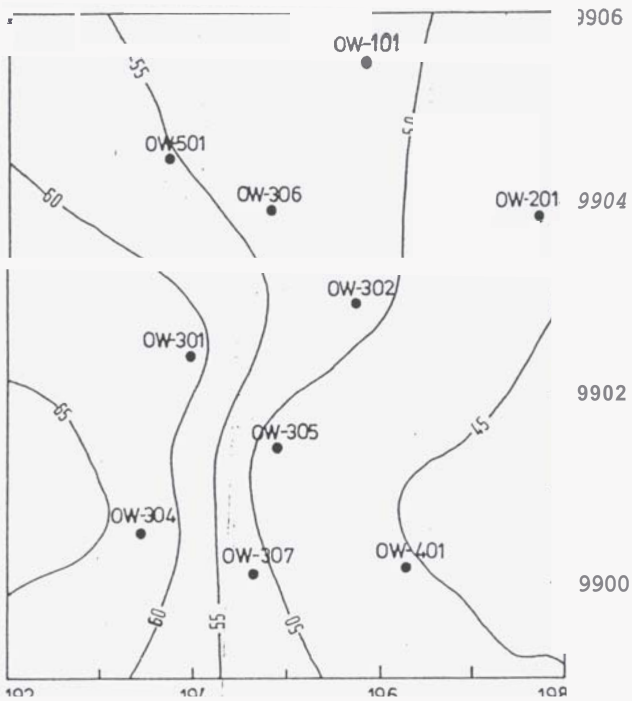

Figure 5 - Pressure Contours at 1000 masl

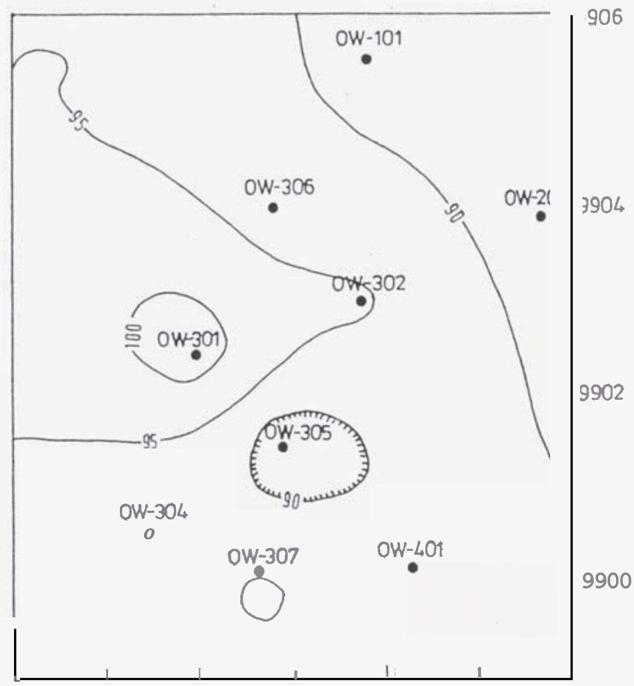

Figure 6 - Pressure Contours at 500 masl

5. LITHOLOGY AND AQUIFERS

By superimposing the well feeder zones unto the geological sections of Olkaria West field it is observed that fluid movement is mainly along contact surfaces between pyroclastics and rhyolites, fractures within rhyolites and **along** major fault zones such as the ones around OW-301 (Fig. 7 and 8).

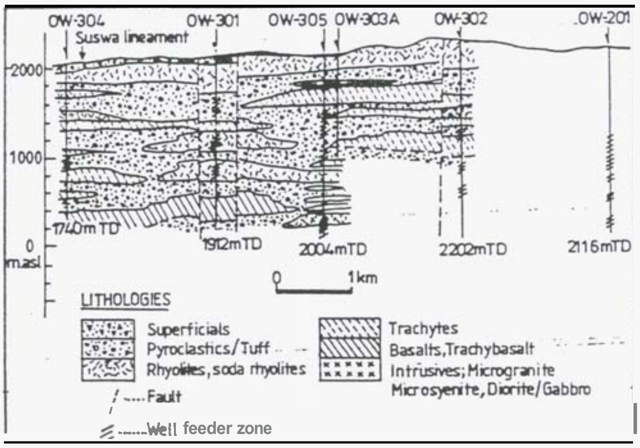

Figure 7 - Aquifers superimposed on geological section through **OW-304, 301, 305, 303A & 302**

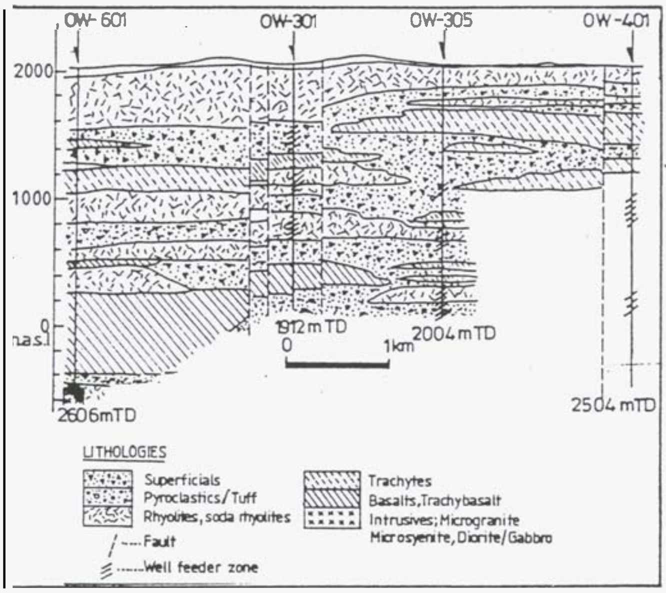

Figure **8** - Aquifers **superimposed** on geological section through **OW-601,301,305 & 401**

6. PROVEN AREA AND POWER POTENTIAL

From the temperature and pressure distribution and from the geophysical data (Fig. **9; KPC, 1990),** the proven area for Olkaria west is centered mainly around **OW-301.** The boundaries for proven area are still unclear to the west or **north** west of **OW-301 and** to the north west of **OW-101.** Thus the potential area in Olkaria west remains quite extensive.

The power potential can broadly be divided into two categories as follows (Fig. **10**):-

a) The definitely proven area, which includes **area** around **OW-301,** OW-305, **OW-306, OW-304D** and **OW-101.** This area covers about **14 km^2,** which at an average productivity of **11** MWe/km^2/25 years, obtained from numerical simulation studies **of Olkaria** East, has a combined potential of 154 MW(e).

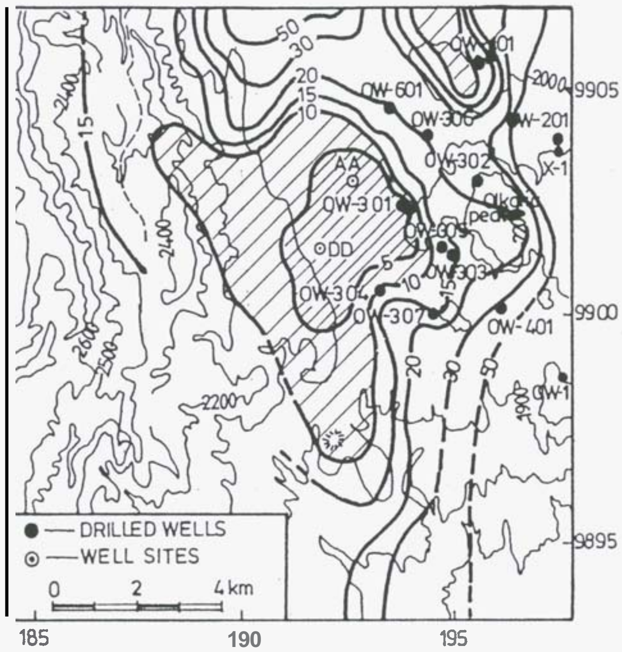

Figure 9 - True resistivity for **1000** masl

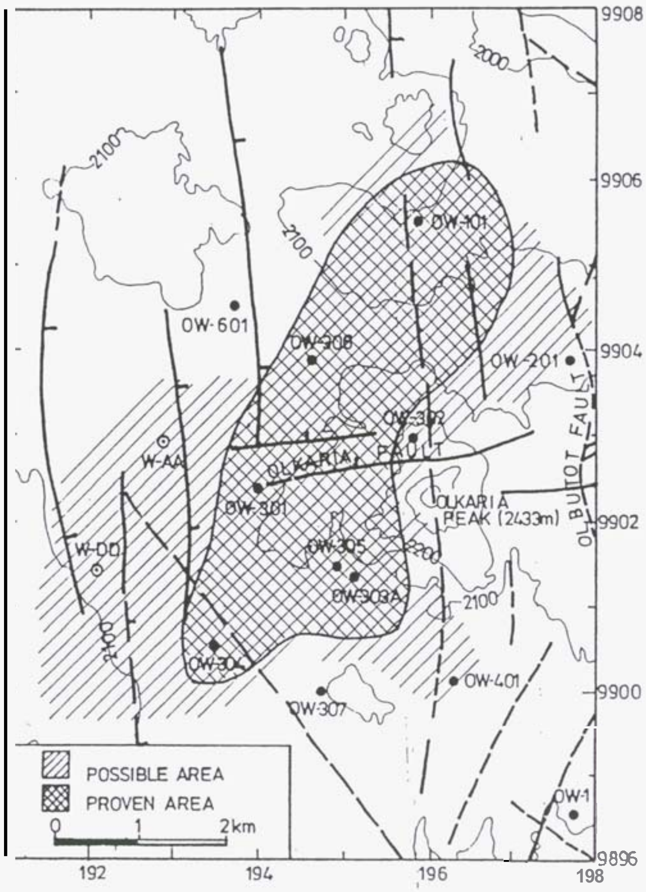

Figure 10 - Proven and Possible Potential Areas

b) The possible area which extends to the north **or** north west of **OW-301** and to the north west of **OW-101.** Therefore the possible area indicates that Olkaria west is capable of **minimum** output of 154 MW(e) and maximum capacity could be much bigger especially if higher average well productivity can be proven by future wells drilled in this area.

7. DISCUSSION

Downhole temperatures and pressures have indicated that basically similar reservoir conditions, to the rest of the Olkaria system, exist in Olkaria west. The pressure transient tests indicate similar permeability parameters as in Olkaria East and North East (kh averages about 2 dm) as indicated in Table **2.**

The outputs from the wells so far drilled are low except for **OW-201** and OW-301. These two wells are located within the Olkaria fault zone with OW-301 probably intersecting the Olkaria fracture zone. Future drilling in the Olkaria west should target the fault zones especially where the location of the fault is also favoured by the temperature contouring projections and low resistivity anomaly (Fig. 9).

The chemistry observed from Olkaria West wells show presence of much higher CO_2 in the discharge fluids than observed in the Olkaria East and North East wells. The level of CO_2 produced from OW-304D was the highest ranging between 10-76% by wt in the steam. This is considered extremely high CO_2 level in the discharge fluid. It is even above the level observed in all the Olkaria west wells (about 2% by wt of the steam). The CO_2 in OW-304D could be originating from some other source which needs to be investigated.

8. CONCLUSIONS

Nearlly all drilled wells in Olkaria West field encounter permeability in the interval 1500-1000 masl where temperature recovery indicate near two-phase conditions. However, some of the wells encounter major permeability in the liquid zone in the range 1100-200 masl. Permeability below 200 masl still needs to be investigated by deep drilling.

Measured injectivity, transmissivity and output characteristics show that the well steam productivity is similar to that of the average Olkaria East and North East field wells. Therefore, the average productivity of 11 MWe/km^2/25 years, obtained from numerical simulation studies of East Olkaria field, is equally applicable here.

From the temperature recovery runs in OW-305, 307 and OW-401 it is observed that the production casing was set deep and in the process cased some possible production horizons. The temperatures also indicate 307, 401, are on outflow features.

Further drilling is required in Olkaria West so as to defiie the Western and Northern boundaries otherwise there is a vast possible potential area which still requires to be proven. Sites AA and DD have been proposed to the North west of **OW-301** and these should be drilled to confirm the extent of the proven resource to the west.

Permeability in the Olkaria West field is possibly effected through contacts between pyroclastics and rhyolites, fractures within rhyolites and due to faulting within major fault zones.

Upflow is probably located to the West/North West of OW-30 1.

9. REFERENCES

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