A GEOLOGICAL REVIEW OF OLKARIA GEOTHERMAL RESERVOIR BASED ON STRUCTURE

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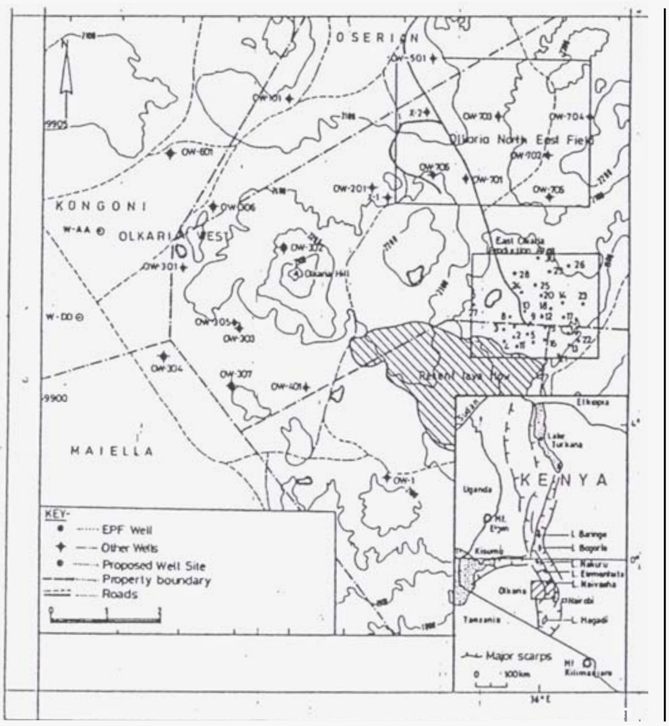
SUMMARY - The geological structure of Olkaria is known to be the main controller of fluid movement in the geothermal reservoir. However, the detailed structure has been elusive due to the substantial cover of the surface geology by ashes, pumice and other pyroclastic deposits from recent volcanic eruptions. The upflowing movement of the deep geothermal fluids in the field appear to be along the north-east to south-west striking Olkaria fault zone and a couple of the east-west striking faults The other fault structures appear to provide passage to fluids at shallow levels. There appears to be no unique upflow locality in the field. The present reservoir conditions are a result of an interplay of shallow level fluid movement, strongly influenced by the hydrological gradient to the south, the north-south fractures and fluids from depth rising along steeply dipping major fault zones.

1. INTRODUCTION

Olkaria Geothermal area was actively explored for geothermal resource from 1970 until 1973 when the first deep exploration well was drilled to a depth of 1003m in the area. A second exploration well was drilled about 3.5 km to the north of the first well and this time a two-phase hot fluid reservoir was discovered. Using the discovery well (OW-02) information, off-set wells OW-03, OW-4 and OW-05 were drilled within 250m distance of OW-02 (Fig 1).



'Figure 1 - Olkaria geothermal area and location

Subsequent investigations of the area culminated in the commissioning of the first 15 MWe plant in 1981 and two others in 1982 and 1985.

In November 1980, a scientific and technical review meeting (KPC 1981) recommended that an exploration programme be drawn up to investigate other parts of Olkaria area for usable geothermal reserves and initiated the programme by siting four explorations wells that were later drilled as OW-101, OW-201, OW-301 and OW-401. After another meeting in 1984 investigation of Olkaria Northeast confirmed the existence of a geothermal reservoir in the zone and since then, a total of 30 wells have been drilled in the Northeast field (NEF) and steam equivalent to about 74 MWe power worn and ready for the 2 x 32 MWe plant planned in the field for commissioning in 1995/96 fiscal year.

Other additional wells have been drilled in Olkaria East Production Field (EPF) where now a total of 33 wells exist and in West Olkaria zone where 10 wells have now been drilled. Therefore a total of 73 wells exist in the area as a whole. The field is therefore well covered by wells which makes the situation ideal for a study of geological structures.

2. PREVIOUS WORK

Geology of the area including Olkaria has been covered in reports by Thompson and Dodson (1963) and McCall (1967) in both of which the geology and geological structures were discussed. Naylor (1972) was the first worker in the area to document the idea of a ring structure around a big volcanic complex in Olkaria which was supposedly destroyed by an explosive eruption which was accompanied or followed by a collapse. The catastrophic episode was supposedly followed later by peripheral volcanic activities located along the ring fractures. The 0 1 Njorowa Gorge cuts the suggested ring structure from north to south. But domes and cones of pyroclastic ashes, pumiceous fragment and tephra appear to occupy both sides of the gorge and do not appear to give any distinctive ring feature in the area. According to Naylor (1972), the ring structure in Olkaria area pre-dates the north-south tectonic trending pattern in the rift valley zone. The resulting caldera basin formed by the explosive volcanic episodes was then infilled with voluminous lava flows and pumiceous ashes from subsequent volcanic activities. The heat source for the geothermal fluids in the area was therefore considered to be related to the devastated volcano.

Naylor (1972) also attached significant emphasis to the tectonic activities forming the north-south fracture system which he correlated with the formation of the *rift* scarps to the west of Olkaria. The north-south and a WSW-ENE patterns, intersecting in the area between Olkaria Hill and the western scarps wall, were also related to the suggested ring structure.

With respect to the effect of structure on reservoir rocks, Naylor (1972) suggested that most faults and fractures had high to vertical dips. Only the 0 1 Butot fault was suggested to have been reactivated resulting in the effusion of the 0 1 Butot pumiceous rhyolite lava flow to the south of the Olkaria East Production Field.

3. GEOLOGICAL STRUCTURE

The geological structure of Olkaria area has to be viewed in the light of the whole Eastern *Africa* rift system. This major tectonic feature has had a good number coverage by many prominent workers during the last three or more decades. Broadly speaking, the Kenya zone of the great rift valley system crosses from north to south what been called "the Kenya Dome" (Baker, 1971). The geological feature *can* be reviewed in a number of ways.

3.1 Current Overview

The region of the rift including Olkaria may be understood better by looking at the topography of the rift floor from north to south. The land surface falls southwards towards Lake Magadi near the Tanzanian border and to the north towards Ethiopia, with Olkaria-Eburru part including Lake Naivasha, being the highest in elevation above the mean sea level. The present geological structure of Olkaria area (Muchemi, 1992) shows three distinctive trends (Fig. 2). There are also a number of arcuate *scarps* that have been interpreted as remnant of a caldera wall of a big volcanic complex in the area (Naylor, 1972 and Muchemi, 1992). While agreeing to the caldera ring idea for Olkaria volcanic complex, Mungania (1992) proposed a strong argument for a dominantly north-south geological structure as observed in the field by Odongo (1982) and emphasized by the occurrence of rhyolitic lava bodies along north-south aligned fissures. The bodies include obsidian *rich* pumiceous rhyolites and comendite dykes. The comendite bodies as seen in parts of the field were emplaced within beds of pyroclastic deposits and re-worked volcanoclastic sediments. At several localities in the 0 1 Njorowa Gorge, the rising viscous comendite lava bodies formed either vertical plugs transgressing the overlying pyroclastic and volcanoclastic beds or mushroom topped lava bodies near the surface.

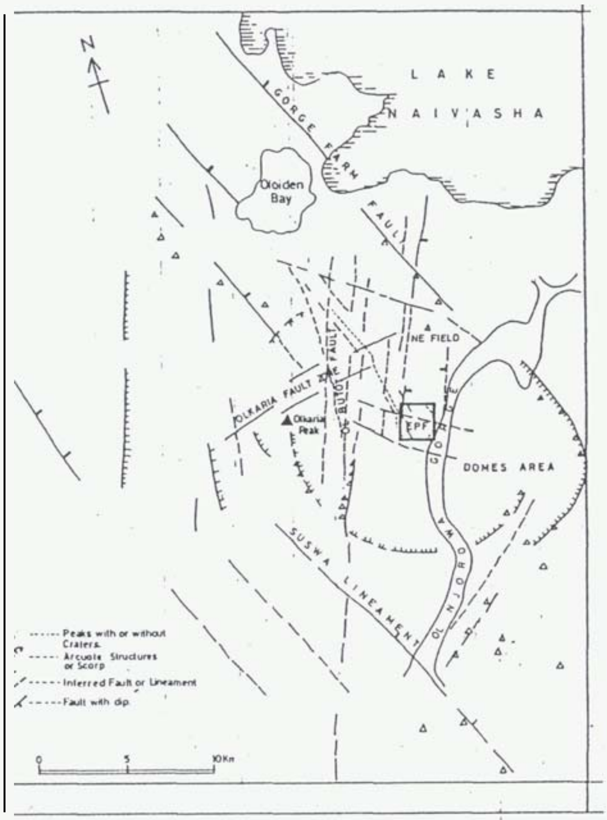


Figure 2 - Structual map showing *ring* structures

It is believed that some of the dome-shaped hills to the east of Olkaria East Field have cores made up of such volcanic lava materials. The observed features about the domes is that only a small number of them *can* be directly related to a volcanic vent with a clearly defined crater (Fig. 3).

The implication is that the bulk of the domes are possibly residual piles of a huge ash-fall that has been washed away by erosion, leaving behind the dome-shaped hills. It is therefore believed that the distinctive three directional trends of structures in Olkaria is of more significance for field development studies than the *ring* structure.

The landsat image of the area between Lakes Magadi and Naivasha shows very strong open fissure pattern trending north-south in the rift floor. The flanks are featuring clearly due to the well developed rift scarps accompanied by abrupt change of vegetation from forests in the flanks to semi-arid vegetation in the rift floor. The obvious truncation of the basement structure by the rift system appear where both the basement rocks and the Tertiany volcanics come together as in the southwest part of the area. Another structural feature in the area is the prominent major lineaments or faults that trend northwest-southeast. The one forming the Nguruman Escarpment, west of Lake Magadi continues past Narok town to the west of Mau Escarpment where it is covered by Terticany volcanics, with most of its length marking the boundary between basement rocks and the young volcanics. The western finger of lake Magadi falls on one of the faults.

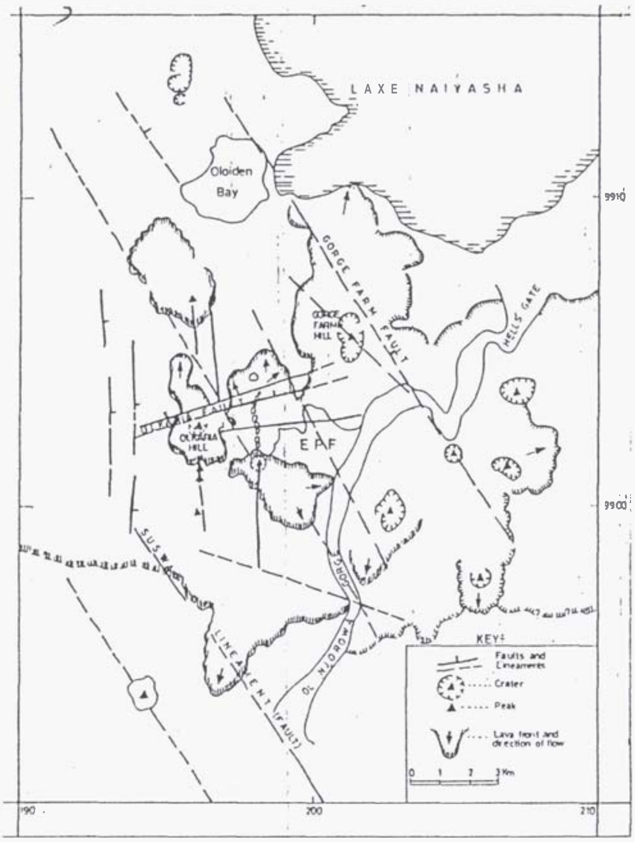


Figure 3 - Olkaria area volcanic centre showing the main structures

In the **Lake** Naivasha-Suswa zone of the area, the scarps forming the Mau in the west and the eastern scarp past Naivasha town also trend in the same direction. Of interest to those concerned with the Olkaria geothermal resource is the Suswa lineament (fault). This structure passes to the west of Olkaria Hill into the western rift flank **and** runs south-easterly, truncating the northeast edge **of** the Suswa caldera and emerging to the southeast of the volcano as a *scarp* ***surface.*** The lineament cuts the 0 1 Njorowa Gorge at the southern end. The structures are cleaner in the smaller area image centred over Olkaria field (Fig. **4).**

The effect of **faulting** *on* the main physical features appear to be visible in some parts of the field and not in all. The intersection between the north-south and southeast-northwest trending structural pattern becomes obvious. However, the ring structure that may indicate the existence of a caldera basin is not discernible on the basis of surface geology.

The latest volcanic activity in the area was marked by multivent eruptions of viscious rhyolitic lavas and associated pyroclastics scattered all over the field. Some of the centres like Olkaria became strong enough to develop substantial cones and can be related to **fissures** that are still fairly visible. **A** group of explosion vents along **a north-south** fissure in the central **zone** extruded highly pumiceous rhyolite lava and in one of them enough lava was produced to form a sizeable flow body **of** obsidian and pumiceous rhyolite. **If** the source of the lava in the whole area was a **single** magma **body,** then the volume **of** the magma chamber must have been substantial because **it** appears to have reached the **surface** level **in a** wide area of ***the*** field.

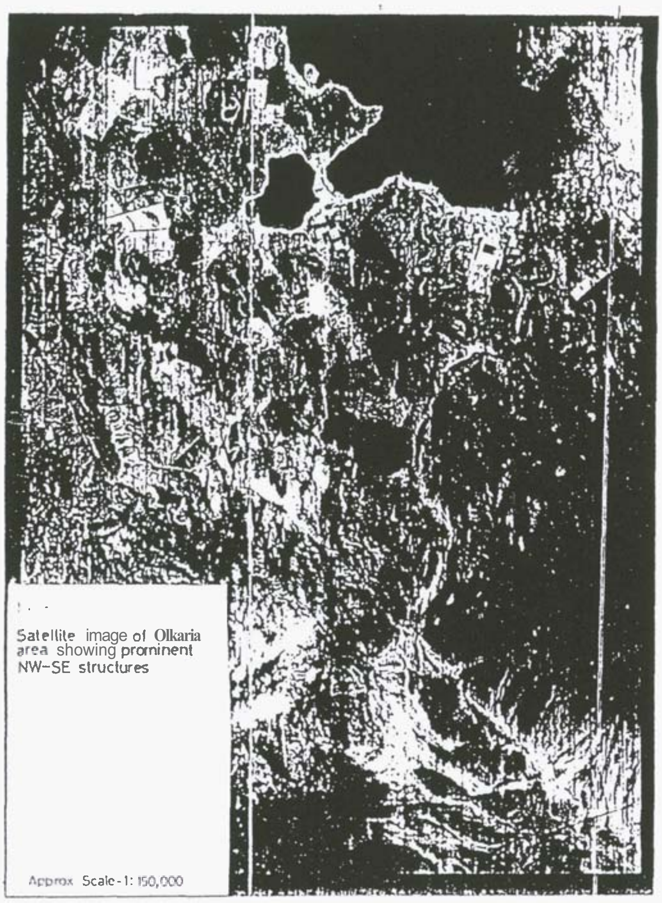


Figure 4 - Satellite image **of** Olkaria area showmg prominent **NW-SE** structures

3.2 Detailed Structure

Most of the strong lineaments trending NNE-SSE, and NW-SE directions that appear in the regional scale become very difficult to define or map on localized scale. However, the **north-south** trending fissuring and faulting pattern remains. In addition a structural grain trending between Northeast to South-west and eastwest becomes prominent, with **Olkaria** fault being the most conspicuous in the area. **A** second major fault **runs** from Olkaria Hill eastwards to end **up** below the younger lava flow east of 0 1 Njorowa **Gorge.** There **is** a fairly clear indication that faults and fractures control the bulk of fluid movement and permeability properties of the reservoir rocks in Olkaria.

It has been established at Olkaria that most of **the** large producing wells of the North-east fields are influenced by Olkaria fault and similar structures. Big producers in the field by Olkaria standards includes wells OW-701, OW-**707,** OW-709, **OW-714,** OW-718 and OW-717 (Fig. *5)* in the northeast. **In** the East Production Field **(EPF)** big producers like **OW-30** and **OW-32** are believed to be tapping fluids from **a** major fault running across the northern part of the field from east to west and dipping to the south steeply.

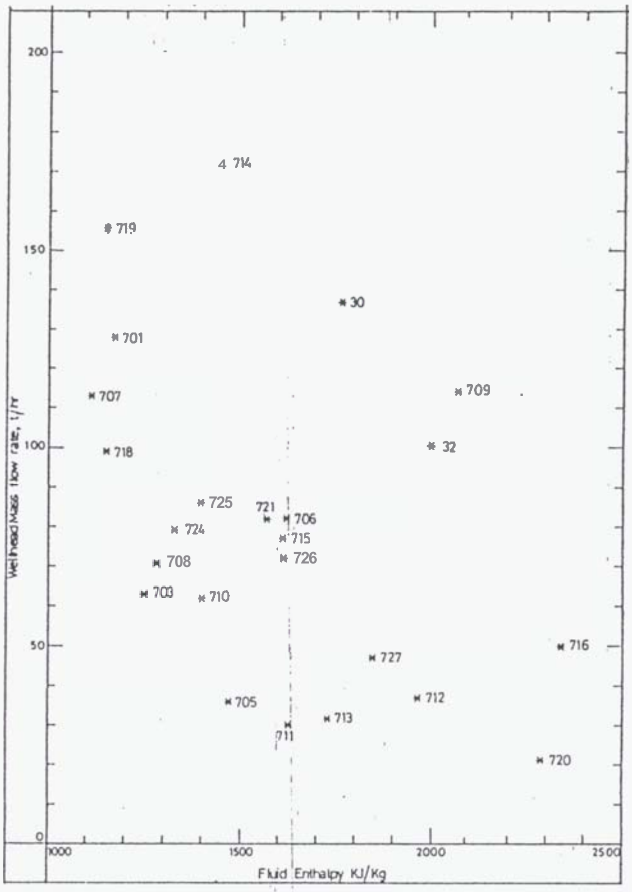


Figure 5 - Mass flow rate and fluid enthalpy for NE field wells

4. LITHOLOGY AND RESERVOIR TEMPERATURES

The E-W section (Fig. 6) brings about a rather complicated correlation model of the reservoir rocks which are all of volcanic **origin.** The section is from well OW-201 in the west of the area to well **OW-704** in the east. The complication of the field geology becomes obvious from the correlation of 'the well lithologies. The interpreted temperature contours show an obvious high in the central zone of the field with significant drop to both the east and west. The temperature rise has been related to the hot fluids within Olkaria fault zone. The upflow appears to be invaded by cooler fluids from both west and east sides of the field. When viewed at different levels of the field, the pattern appear to change drastically. **At** about 1000m elevation, the bulk of the reservoir formation **is** below 260°C over the field.

The reservoir temperatures show a' distinct rise in the field as a whole, dropping significantly to the west and east. The temperature in the field is due to uprising hot geothermal fluid along Olkaria fault zone. However, the lateral movement of the hot fluid is controlled by the north-south striking fractures and north-east to south-west trenching structures. there is also the interference with the upflow by cooler recharging water at shallow levels and a hydrological southerly groundwater movement.

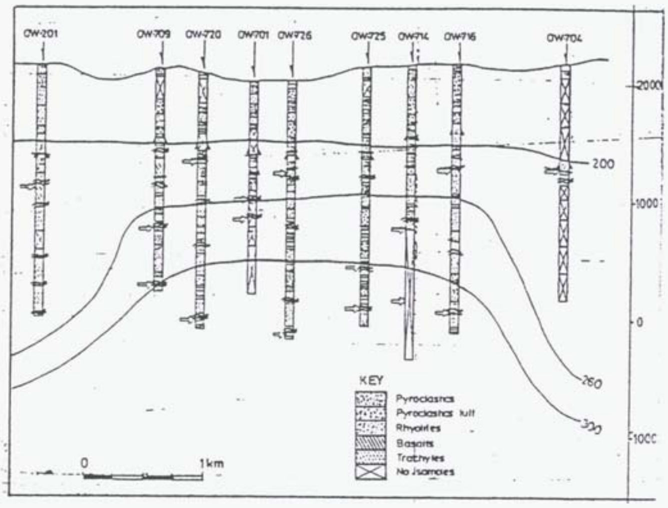


Figure 6 - E-W section with well lithology and measured temperatures

At about 1000m elevation, the inflows from both the west and north have strong impacts in the reservoir. At about 750m elevation the effect of inflows from both the north and west is becoming less prominent.

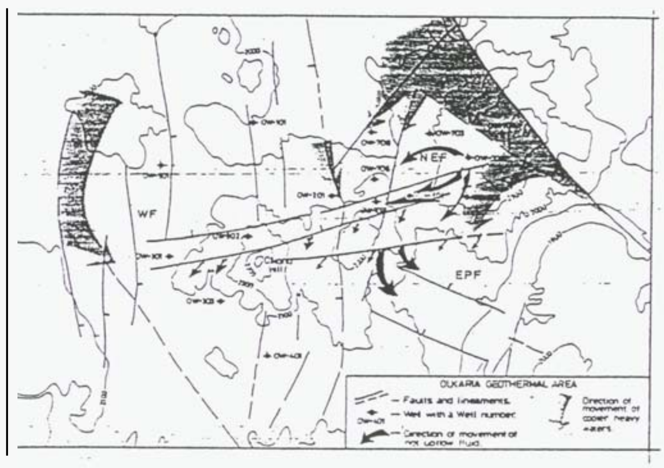


Figure 7 - Structure **of** Olkaria area and ground fluid movement

At **300** m elevation, the temperature is elevated **all** over the field and the effect of shallow inflows becomes virtually non-significant. The effect of the cooler denser water overlying a reasonably hot lower reservoir fluid has resulted in an interplay that features as strong surges in wells close to the fronts of the inflows. The surging conditions of wells OW-703, OW-708 and OW-724 are examples of well sited in the mixed fluid zones of the field. Well OW-04 in the East Production Field also characterize the zone of the field where more dense cooler water encroaches the field which is fairly hot at lower depths. The cooler water is believed to be moving along northwest to southeast striking faults running across the EPF. The whole structurally controlled fluid movement in Olkaria area (Fig 7) is also influenced by the southerly direct groundwater flow and reservoir temperatures.

5. CONCLUSION

Olkaria area geological structure has a significant control over the geothermal reservoir conditions of the field. The movement of hot geothermal fluids from depth are mainly confined to major high angle fault zones in the area, particularly the Olkaria fault zone. However, there is a marked inflow of cooler water at comparatively shallow depths which masks the effect of the upflow of the deep hot fluids. The inflow is strong from the north, northeast and the west. The interplay of the hot solutions at depth and the comparatively denser, cooler groundwater at shallow levels leads to the characteristics surging conditions of some wells at Olkaria. The surging wells are mostly located on the peripheral zones of the drilled part of Olkaria.

7. REFERENCES

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