SURFACE EXPLORATION OF DOMES AREA: AN EXTENSION OF OLKARIA GEOTHERMAL FIELD

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SUMMARY- The surface exploration of the Domes area indicates that surface manifestations, geophysical structure, fluid flow patterns and the expected output of the wells are controlled by the geological and tectonic evolution of this area. The intersections of NW, N, NE, and EW structures define an area of about 25 Km^2 which is estimated to have reservoir temperatures in excess of 240°C below 800 m.a.s.l. The deep water dominated reservoir is expected to be within fractured trachytes. Recent volcanic activity and highly differentiated pyroclastic products are evidence of a magmatic body providing the heat source. However, the form and geometry of this body are speculative.

1. INTRODUCTION

Domes area lies immediately to the east of the Olkaria Geothermal field which is within the Olkaria volcanic complex in central sector of the Kenyan Rift Valley (Fig. 1). The volcanic complex covers an area of about 240 Km^2 and is marked by several Quaternary volcanoes and volcanic centres. The field is further divided into Olkaria East, North-East, and West (Fig. 2) Olkaria East Field has been under exploitation since 1981 with an installed capacity of 45 MWe. The North-East Field is under production drilling for a 64 MWe power station while the western field is earmarked for appraisal for a further 4 * 32 MWe power plants.

Surface investigations of the Domes area which included detailed geological mapping, resistivity soundings, and geochemical sampling of surface manifestations were carried out with a view of establishing the existence of a viable resource. The surface exploration was carried to evaluate the geothermal potential in relationship to the subsurface structures and the surface manifestations. The geochemical data is was limited to the Ol'Njorowa Gorge and the Ololbutot fault zone where fumaroles occur in abundance. This is because the Domes area has no geothermal manifestations except on the lava domes where some altered grounds occur.

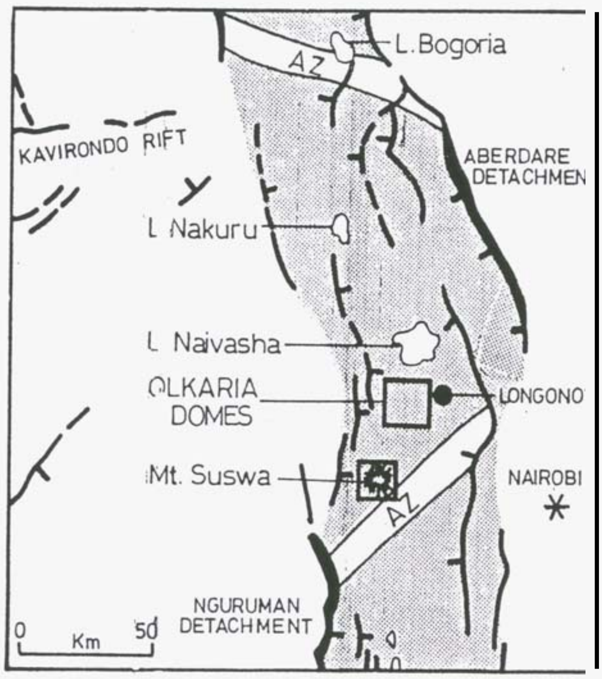

Figure 1- Location of Olkaria - Domes Area within the central part of the Kenyan Rift Valley

2. GEOLOGICAL SETTING.

The volcanic activity in this area has progressed from Miocene to the present with eruption of rocks ranging from intermediate to acid with minor basic eruptions. Major volcanic and fissure controlled eruptions characterised by caldera collapse phases have resulted in uneven surface covered by fresh lava rocks and pyroclastics. Some of the volcanic centres are aligned on an arcuate structure that suggests that the Olkaria complex is a remnant of an older caldera (Naylor, 1972; Virkir, 1985; and B.G.S, 1990). The surface outcrops mainly comprise alkali rhyolitelava flows, pyroclastic deposits, some trachytic and basaltic flows. Pyroclastic deposits comprise compacted and reworked beds and pumice rich deposits which are very thick on the Domes.

Some lava dykes of thickness 6 m have been observed to cut across the pyroclastics a **NS** direction. Fumaroles and hydrothermal alteration of pyroclastics are usually found in areas where the lava dykes reach the surface indicating structural control. The difference in the volcanic succession between Olkaria East and West implies a structural boundary probably formed by a narrow horst structure along the Ololbutot fault. This means that the local geological setting of ***Olkaria*** may not necessarily extend to the Domes area. The Ol'Njorowa Gorge is probably an important structural feature that separates the Olkana East Field **from** the Domes prospect.

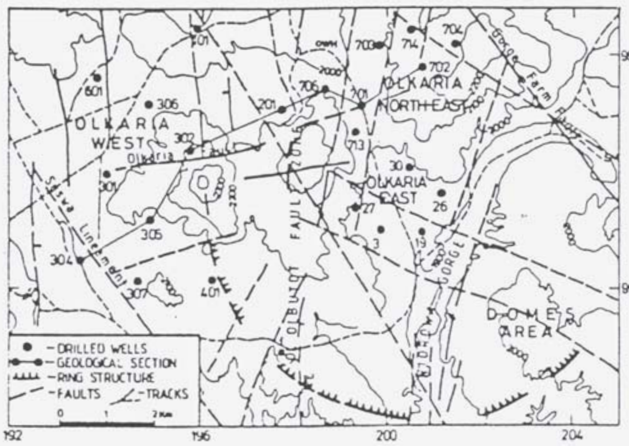

Figure 2- Location of the Geothermal Fields in Olkaria - Domes Area.

3. STRUCTURES.

The most common geological structures are normal faults, fissures, explosive craters, lava issue centres and caldera collapse. Few classical faults are observed on the surface over the domes region but evidence of concealed faults and fissure systems may be reconstructed from the volcanic activity to mark the approximate location of the structures. The lava issue centres in the form of domes, explosive craters, plugs and linear fissures form three NS active volcanic zones (Fig. **3)** characterised by fresh alkali rhyolitic lavas. Another possibly older active zone forms a ring pattern to the south and south east. These zones are interpreted as the major reactivated structures associated with the transmission of magmatic material and geothermal manifestations. Tensional fissures observed in the pyroclastics imply recent tectonic reactivation in the active zones. The Olkaria complex has an **ESE** major axis postulated to coincide with a regional structure with the same trend associated with old basement shear or transcurrent faulting induced by differential lithospheric spreading of the crust. This **ESE** structure extends to the eastern and western escarpments coinciding with a hydrogeological barrier between Lake Naivasha basin and the Akira plains. This barrier acts as a divide such that shallow water wells drilled to the south encounter steam thus indicating a southward gradient.

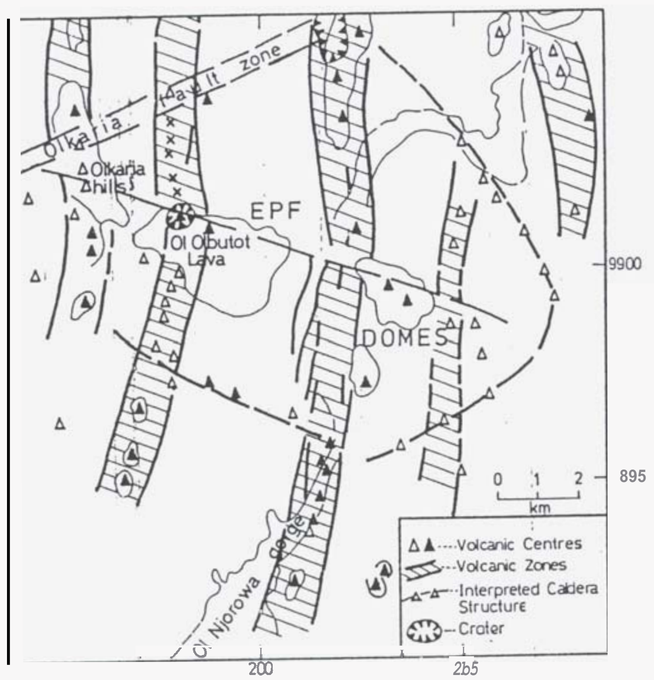

Figure 3- Location of active volcanic zones.

4. DOWN HOLE GEOLOGY.

The neighbouring Olkaria is an extensively drilled feild from which some inference about the down hole geology of the Domes can be obtained From the deep wells drilled in the Olkaria area stratigraphic models have been constructed by correlation of the subsurface lithologies obtained from cores and rock and cuttings (Omenda, 1990; Muchemi, 1992). The volcanic rock formation for Olkaria East and North East are similar to drilled depths of 2000 m. However, there are fewer Occurrences of trachytic and basaltic formations in Olkaria West (Fig. **4)** probably indicating that this area is within a graben that may have existed during the formation of Pliocene plateau lavas. The differences in the two areas probably indicates the importance of linear structures in the control of the local geological setting. If this argument is extended into the Domes area then there may be a slight variation in the localised subsurface geology due to the presence of active volcanic zones that may contribute to differences in the volcanic episodes.

5. VOLCANOLOGY.

Volcanology aims at evaluating factors that may help in understanding the origin and evolution of volcanic eruptions related to the geothermal potential. Regional geology and theoretical considerations on the evolution of magmatic bodies have been studied by various authors including Baker et.al; 1987; and **BGS,** 1990.

The eruptive material covering Olkaria volcanic complex area is characterised by acid pyroclastics and alkali rich lavas to an elevation of about 1400 m.a.s.l which is indicative of explosive volcanism. The high incompatible trace elements concentrations imply that the volcanic

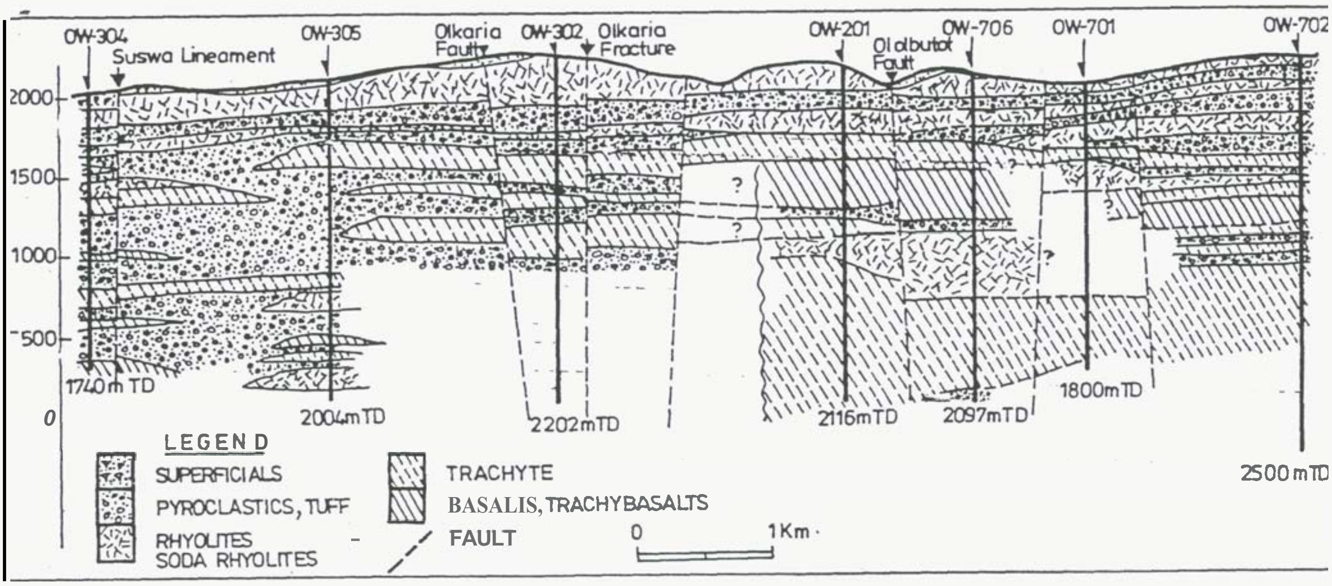

Figure 4- Geological section across Olkaria West and North East Fields

activity tapped the upper parts of a highly fractionated magma reservoir rich in volatiles. This is further supported by the presence of gas charged magmatic products like pumice and features of explosive volcanism like craters and caldera. Xenoliths of syenite in pyroclastics within the Domes and Longonot areas imply a possible cold or cooling upper part of a magma body which is interpreted to be shallower towards Longonot. The zone between 1400 and 1000 m.a.s.l is dominated by thin basaltic and pyroclastics flows indicating quiet fissure eruptions and a period of strombolean type volcanism. Below 1000 m.a.s.l trachytic lava dominate with associated pyroclastics and basalts. The trachytes are further divided into two types. The first is a quartz-rich porphyritic type that extends to an elevation of 500 m.a.s.l and may represent the remnant of the Olkaria mountain shield Iavas. The second is a fine grained type having flow texture may indicate low viscosity associated with Pliocene plateau lavas (Fig. 5). Starting from these plateau lavas, the following volcanological history may be adapted:

(i) The old Pliocene volcanic terrain covered by flood volcanics is characteristic by block faulting associated with extensional tectonics.

(ii) The Plio-Pleistocene shield volcano was built upon the shield quartz-trachyte lavas. The volcano then collapsed and formed a cauldron floor at about 1000 - 1200 m.a.s.l. and due the emptying of the volatile rich parts, of the magma chamber during the explosive caldera collapse phase, more basic magma erupted effusively into the cauldron floor.

(iii) Reactivation of N-S faults during Pleistocene caused further explosive withdrawal of magma from a deep differentiated salic magma chamber.

This phase may have been contemporaneous with activity in Longonot. Withdrawal of lavas through **N-S** fissure system continued till recently (Ololbutot 120 yrs ago).

6. GEOPHYSICAL STRUCTURE

Most of the previous Geophysical studies have been concentrated within the Olkaria East and West regions where exploration and production **drilling** has taken place. Domes area exploration programmes have been limited by poor accessibility due to difficult terrain and wild animals. Previous resistivity surveys have been carried out by Furgerson, 1972; Bhogal, 1980; Mwangi, 1986; Geotermica Italiana, 1990; Onacha, 1989; and Dimitrios, 1989. Dimitrios (1989) using a 2-D MT model suggested the presence of a 20 **km** wide and 25 km thick resistive block of 50 Ωm at 1 km depth that extends from central Olkaria to Longonot. The deduction however was based on very limited data. Geotermica Italiana (1990) carried out Schlumberger and MT studies and constructed maps and geoelectric sections with emphasis on the "resistive basement". The results showed that resistivity values of the basement have a wide variation and no attempt was made to evaluate the significance of the variations in terms of target areas.

The available gravity data has been very difficult to interpret in terms of localised anomalies for geothermal exploration. This problem is compounded by the lack of understanding of the regional gravity field. However, aeromagnetic data over the Rift Valley indicate that the Olkaria - Domes area has a **NW-SE** trending positive anomaly which may be attributed to a normally magnetised body controlled by **NW-SE** trending linear structures.

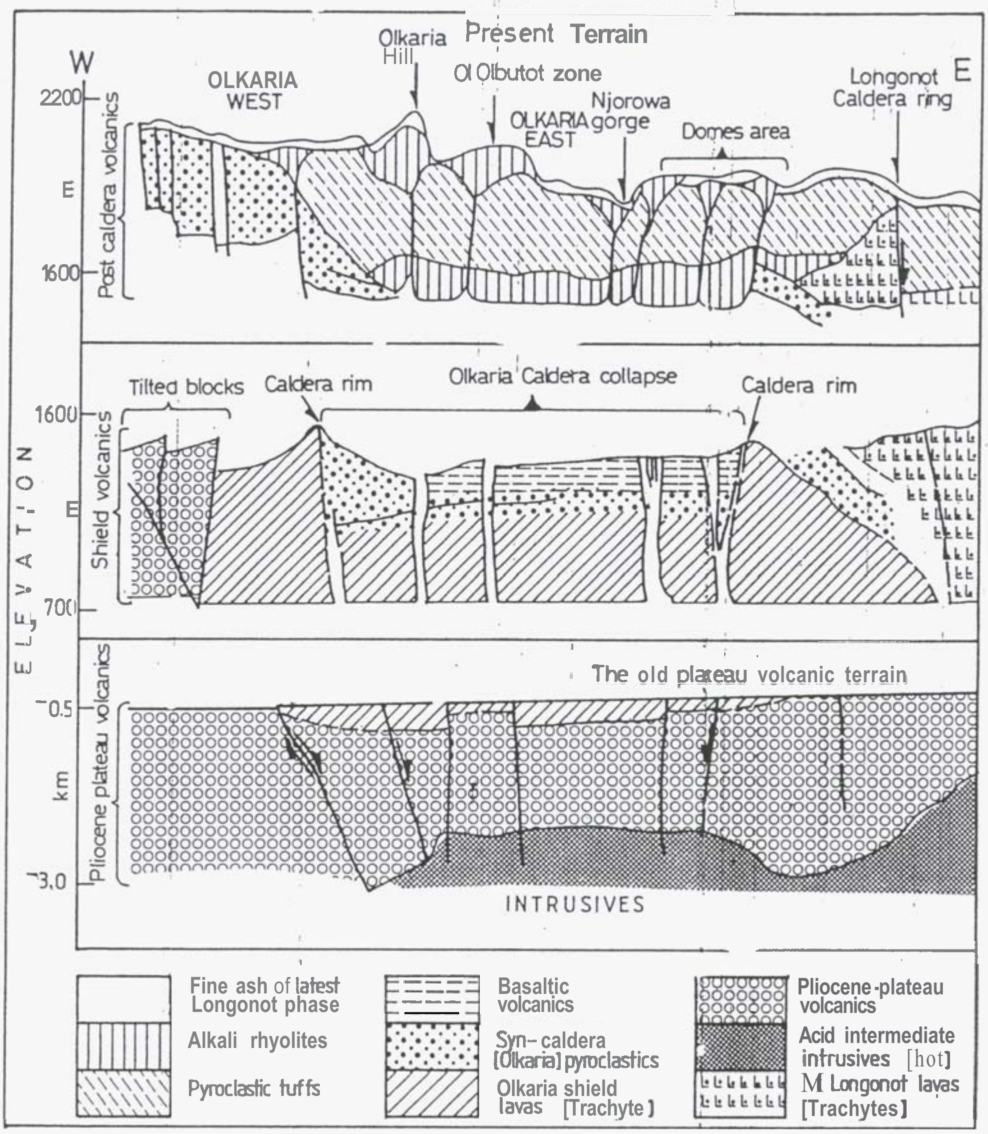

Figure 5- Volcanological model of Olkaria - Domes area.

The structure in the Domes area has been deduced mainly from the interpretation of 74 DC schlumberger soundings, carried out in sub-parallel directions to the structural trends to minimise effects due to lateral discontinuities. The apparent resistivity obtained depends on the azimuths of the soundings indicating that the resistivity distribution is at least 2-D. The 1-D interpretation indicates that, the surface layer has very high resistivity (>100 Qm) with a big variation in thickness (10 - 400 m). This layer is thickest around the topographic high grounds and very thin in the Ol'Njorowa Gorge - Olkaria area. Two anomalies (<30 Ωm) separated by intermediate resistivity (30 - 100 Ωm) are found within the Olkaria East-Domes area and the Longonot caldera. The Olkaria-East Domes anomaly is found between the Ololbutot fracture zone and the eastern part of the proposed ring structure and is characterised by a surficial (200 - 500 m) conductive layer 'separated from a deeper low resistivity by a layer of intermediate resistivity. The deeper low resistivity is associated with a deep hot water dominated reservoir. The resolution of this deeper layer is poor and a 2-D interpretation would give a better picture.

The areal distribution of the resistivity shows patterns that vary significantly with depth. The resistivity at 1800 m.a.s.l shows two distinct anomalies (< 30 Qm). The Olkaria - Domes anomaly encloses a very low resistivity area (< 5 Qm) covering most of the Olkaria East Production Field and extending into the Domes. The southern extension of this anomaly lies between the Ol'Njorowa Gorge and the Ololbutot fault volcanic zones. The Longonot caldera anomaly extends in an E-W direction and is separated from the Olkaria anomaly by intermediate to high resistivity (30 - 100 Qm). The shape of the anomalies probably is related to hydrothermal alterations influenced by injection of fluids along NW, NE and EW linear structures.

The resistivity pattern between 1400 and 1600 m.a.s.l indicates a strong influence of **EW** trending linear structure (Fig. *6)* through the Olkaria East Production Field and Akira ranch which lies to east of Domes. This probably represents flow of geothermal fluids in an **EW** direction. The **proposed** ring structure **does** not play **any** significant role in the resistivity distribution at shallow depths. The resistivity anomaly above 1400 m.a.s.l may be due to alteration of post caldera evolved acid volcanics.

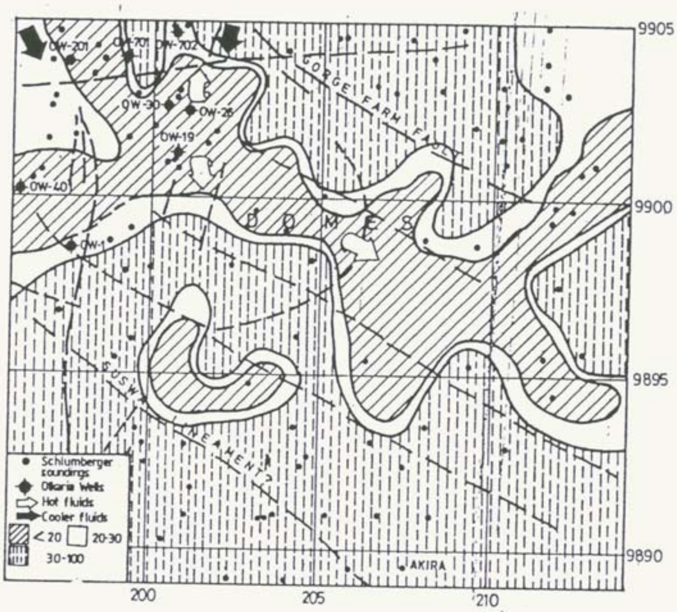

Figure 6- Resistivity distribution in the Olkaria - Domes Area at 1600 m.a.s.l.

The resistivity distribution between 1200 and 600 m.a.s.l shows that the very low resistivity (<20 Ωm) area is confined to the south by the proposed ring structure which probably coincides with a **NW-SE** trending fault. The anomaly is also strongly influenced by NW and NE trending linear structures. The Olkaria, Ololbutot and the **NW-SE** faults like the Gorge Farm fault have a strong influence on the resistivity pattern. The Akira ranch anomaly has a NE trend. The low resistivity anomaly at the mouth of Ol'Njorowa Gorge is found at the intersection of the Suswa lineament and the Ol'Njorowa Gorge volcanic zone. By comparison with the drilled areas of Olkaria, the <30 Ωm anomaly at 800 m.a.s.l (Fig. 7) probably represents an area of reservoir temperatures in excess of 240°C and enhanced vertical permeability.

Some of the available MT data although limited in interpretation due to static shifts also indicates that the low resistivity occurs in narrow linear trends which sometimes coincides with mapped fault zones. The anomalous areas show evidence of a deep conductive layer (**4 - 6** km). However, the resistivity distribution below 600 m.a.s.l is poorly resolved

7. DISCUSSION

The integrated evaluation of surface exploration data indicates that the distribution of surface manifestations follow geological and structural features related to recent volcanic activities like dykes, volcanic centres and N-S volcanotectonic active zones. This distribution of manifestations limits the contribution of geochemistry as a tool of evaluating the geothermal resource in areas capped by pyroclastic deposits.

The geothermal potential and reservoir characteristics are mainly influenced by secondary permeability

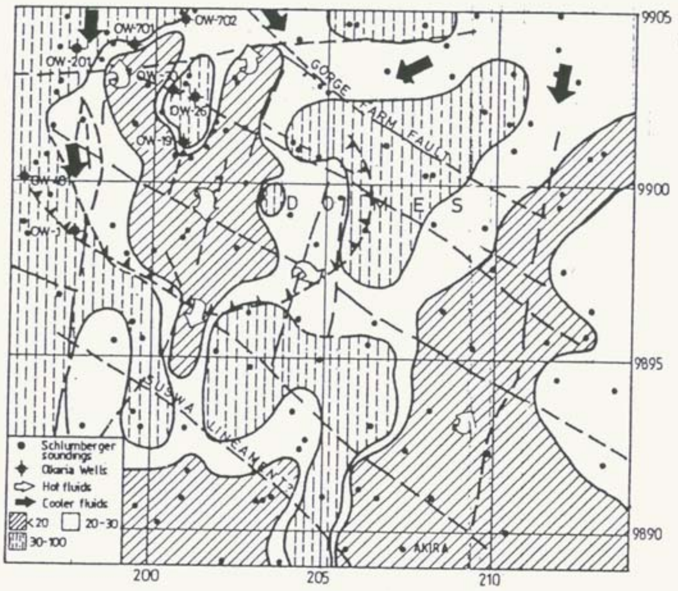

Figure 7- Resistivity distribution in the Olkaria - Domes Area at 800 m.a.s.l.

controlled by geological and tectonic episodes within the Olkaria volcanic complex. The linear nature of the geophysical anomalies including gravity, magnetics and resistivity reinforces the interpretation **of** NW, N, **NE** and oblique **EW** structures controlling the properties of the geothermal fields. The most important areas of enhanced secondary permeability may be found at intersections of faults such that the upflow zones may be visualised to be spread in several places within the geothermal prospects. The distribution of the narrow upflow zones and decrease in bulk permeability with depth may probably account for the big variation in the output of production wells.

Horizontal fluid flow is limited to permeable layers which occur at the contacts of lava flows especially between 1600 and 1000 m.a.s.l. From the resistivity pattern, the overall hot fluid flow seems to be in the **NW-SE** direction. The low resistivity anomaly at 800 m.a.s.l may represent an area of temperature in excess of 240° C below this elevation.

The reservoir is probably within trachytes corresponding to mountain building shield lavas and Pliocene plateau volcanics. Since the trachytes are essentially non porous, the main reservoir is probably controlled by fractures which have been rejuvenated during recent volcanic and tectonic activities.

The Ololbutot fault zone, Ol'Njorowa Gorge, and Gorge Farm fault are probably important channels of cooler fluid **inflow** in the area. The Ololbutot fault zone controls the extension **of** the deep low resistivity to the west while the Gorge Farm Fault controls the extension to the north. The areas with resistivity of **30 - 100 Ωm** at depth below 800 m.a.s.l. seem **to** indicate **an** incursion of cooler fluids of temperature less **than** 240 **°C** as indicated by wells OW- 201, 401, and 704. By extrapolation, such areas may include the zone between Domes and Longonot caldera.

The recent volcanic activity, for instance along the Ololbutot fault and the presence of extensive highly differentiated pyroclastic products, may either indicate a large evolving magmatic body or reactivation of fractures and faults causing enhanced heat flow and vertical permeability. The presence of major fault zones within the Olkaria - Domes area may also indicate that the region lies on the fringe of a large magmatic body whose form and geometry are speculative. However, the evidence of caldera collapse imply an initially centralised and extensive magma chamber.

From the analysis of the resistivity patterns, the best targets for further geothermal exploration are areas with near surface low resistivity due alteration of pyroclastics by steam condensate; a resistive middle layer and a conductive deeper layer **(30 Ωm)**. It is worth noting that the resistivity below 800 m.a.s.l. as determined from Schlumberger soundings tends to be homogeneous partly due to poor resolution.

8. CONCLUSION

The integrated interpretation has identified an area of about 25 Km^2 further sub-divided into five zones (Fig. 7) that are considered as the best targets for geothermal potential appraisal by slim 500 m deep temperature gradient wells. The boundaries of the anomalous areas have not been defined conclusively but they seem to be strongly controlled by NW, N, NE and **E-W** oblique structures that may also act as channels of both hot and cooler fluids. The intersections of structures probably form upflow zones due to enhanced vertical permeability. The areas with intermediate to **'high** resistivity (30 - 100 Ωm) below 800 m.a.s.l. are indicative of both low permeability and incursion **of** cooler fluids.

9. ACKNOWLEDGEMENTS

The authors are grateful to the Kenya Power Company for providing the funds for the projects and permission to publish this paper.

10. REFERENCES

B.G.S. (1990). ***Geological, Volcanological and hydrogeological controls on the occurrences of geothermal activity in the area surrounding L. Naivasha, Kenya.***

Baker, **B.H.,** Mitchell, **J.G.** and Williams, **L.A.J.** (1987) Stratigraphy geochronology and volcano tectonic evolution of the **Kedong-Naivasha-Kinangop** region, Gregory Rift Valley, Kenya. ***Jnl.Geol. Soc.*** *London.*

Bhogal, P.S. (1980). ***Electrical resistivity method of geophysical prospecting and its application in the Rift Valley of Kenya.*** Phd Thesis, University of Nairobi.

Dimitrios, G. (1989). ***Magnetotelluric studies in Geothermal Areas of Greece and Kenya.*** Phd Thesis, University of Edinburgh.

Furgerson, **R.B.** (1972). ***Electrical Resistivity survey of the Olkaria prospect, Kenya.*** Unpublished UNDP/EAPL Geothermal project report.

Geotermica Italiana Srl. (1989). ***Supplement of surface investigations within the caldera of Longonot and Suswa volcanoes Vol.1*** A UN/DTCD and MERD report.

Muchemi, G.G. (1992). ***Geology*** of ***Olkaria North East Field.*** **KPC** report.

Mwangi, M.N., (1986). ***Interpretation of additional sounding data at Olkaria, Kenya.*** KPC Geothermal project report No. GP/OW/010.

Naylor, **W.I.** (1972). ***Geology of Eburru and Olkaria geothermal prospects.*** UNDP/EAPL geothermal exploration report.

Omenda, P.A. (1990). ***Geology of Olkaria West Field.*** **KPC** unpublished report.

Onacha, **S.A.** (1989). ***An Electrical Resistivity study of the area between Mt. Suswa and the Olkaria Geothermal Field, Kenya.*** MSc Thesis University of Nairobi.

Virkir Consulting Group, (1980). ***Geothermal development at Olkaria.*** Report prepared for KPC.