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**KenGen**

Kenya Electricity Generating Co., Ltd.

## **STATUS OF GEOTHERMAL EXPLORATION IN KENYA AND FUTURE PLANS FOR ITS DEVELOPMENT**

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### **ABSTRACT**

The high temperature geothermal prospects in Kenya are located within and are associated with the development of the Kenya Rift. Kenya Rift is a continental scale volcano-tectonic feature that stretches from northern to southern Africa. Development of the Rift started during the Oligocene (30million years ago) and activity has continued to recent times. The last 2 million years saw the development of large shield volcanoes within the axis of the rift. These centres are the most important geothermal prospects within the rift. Association between rifting and most of the occurrences of geothermal energy is mainly due to shallow magma chambers underneath the young volcanoes within the rift axis.

KenGen in collaboration with the Ministry of Energy of the Government of Kenya has undertaken detailed surface studies of most of the prospects in the central sector of the rift which comprises Suswa, Longonot, Olkaria, Eburru, Menengai, Lakes Bogoria and Baringo, Korosi and Paka volcanic fields. Electric power is currently being generated at Olkaria with 130MWe installed while exploration drilling has been undertaken at Eburru and a 2.5MWe pilot plant is planned for development by KenGen and commissioning by 2009. Common methods that have been used by KenGen during exploration expeditions include geology (lithology, geochronology, structures); geophysics (seismic, gravity, magnetic, and resistivity); geochemistry (fluid and thermometry), heat flow and environmental baseline assessments. The results indicate that large geothermal resource exists under the Kenya Rift which estimates put at more than 3,000 MW.

### **1. INTRODUCTION**

Geothermal is an indigenous and abundantly occurring resource in Kenya. Exploitation of Kenya's geothermal resources has environmental and social advantages over the other major sources of electricity generation options available for the country. Geothermal is the least cost source of electric power for base load in Kenya (Acres, 1987, 1994; 1997; KPLC, 1998, 2000). Currently, 128 MW<sub>e</sub> of the installed interconnected generation of 1100MW<sub>e</sub> is generated from geothermal sources at Olkaria. Geothermal is expected to contribute additional 700MW<sub>e</sub> over the next 20 years. Current estimates indicate that generation potential of the Kenya Rift could exceed 3,000MW if both high and low temperature resources are considered.

## 2. GEOLOGICAL SETTING

Kenya rift is part of the eastern arm of the East African rift system. The segment referred to as the Kenya rift extends from Lake Turkana in the north to northern Tanzania near Lake Natron (Fig. 1). In this sector of the rift system, the activity began about 30 million years ago in the Lake Turkana area and then migrated southward being more intense about 14 million years ago.

Formation of the graben structure started about 5 million years ago and was followed by fissure eruptions in the axis of the rift to form flood lavas by about 2 to 1 million years ago. During the last 2 million years ago, volcanic activities became more intense within the axis of the rift. During this time, large shield volcanoes, most of which are geothermal prospects, developed in the axis of the rift. The volcanoes include Suswa, Longonot, Olkaria, Eburru, Menengai, Korosi, Paka, Silali, Emuruangogolak, and Barrier Complex.

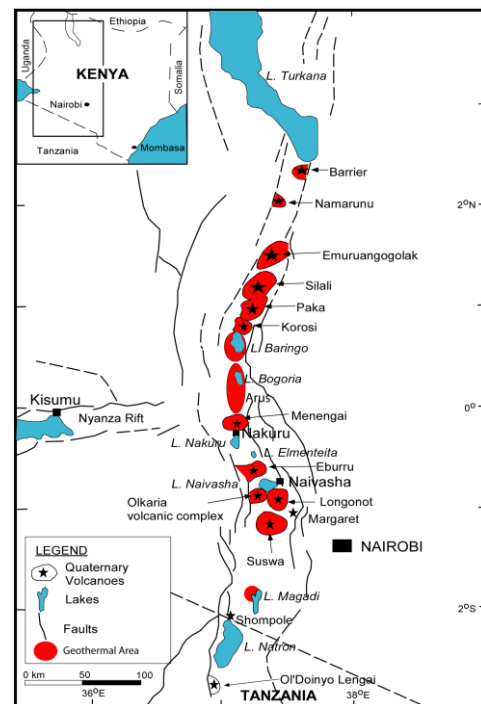


FIGURE 1: Map of the Kenya Rift showing the geothermal prospects

## 3. GEOTHERMAL DEVELOPMENT

Exploration for geothermal energy in Kenya started in the 1960's with surface exploration that culminated in two geothermal wells being drilled at Olkaria. In early 1970's more geological and geophysical work was carried out between Lake Bogoria and Olkaria. This survey identified several areas suitable for geothermal prospecting and by 1973, drilling of deep exploratory wells commenced and was funded by UNDP. Additional wells were thereafter, drilled to prove enough steam for the generation of electricity and in June 1981, the first 15 MW<sub>e</sub> generating unit was commissioned. The second 15 MW<sub>e</sub> unit was commissioned in November 1982 and the third unit in March 1985 which increased the total generation to 45 MW<sub>e</sub>. This was the first geothermal power station in Africa and is owned and operated by KenGen.

In 2003, KenGen commissioned a 2x35MW Olkaria II power plant in the Northeast field. An IPP is generating 12 MW<sub>e</sub> and has plans to increase capacity to 48 MW<sub>e</sub> by 2009 in the Olkaria West field. However, the proven geothermal resource at the greater Olkaria geothermal field is more than 400 MWe.

KenGen and Ministry of Energy (GoK) have continued to explore for geothermal energy in the Kenya rift. British Geological Survey and the government of Kenya have carried out some studies in the Lake Magadi area (Allen et al., 1992), the area around Lake Naivasha including Longonot, Olkaria, Eburru, and Badlands (Clarke et al., 1990), and in the north rift (Dunkley et al., 1993). Geotermica Italiana also did some work in Longonot and Suswa calderas and also described geo-volcanological features important in geothermal exploration at Menengai (Geotermica Italiana Srl, 1987a, 1987b, and 1988).

## 4. GEOTHERMAL PROSPECTS

### 4.1 Eburru

Eburru volcanic complex is located to the north of Olkaria. KenGen carried out detailed surface studies between 1987-1990 that culminated in the drilling of six exploration wells in Eburru between

1989 and 1991. Further infill MT surveys done in 2006 revealed that the Eburru field can support up to 50-60MW<sub>e</sub> (Figure 3). The results from the exploration wells indicate that the field had experienced temperatures of over 300°C possibly due to localized intrusive.

Discharge fluid chemistry from the wells indicates that the reservoir is non-boiling with high salinity brine and a high amount of non condensable gases (NCG). Despite the almost similar geology, the chloride level of EW-I (956 to 1976 ppm) is higher than the Olkaria average. As compared to Olkaria, the reservoir permeability is moderate (KPC, 1990).

The maximum discharge temperature was 285°C and the total output from the two wells that discharged (EW-1 & EW-6) is 29 MWt (Ofwona, 1996). The estimated power potential of the field based on the data from the wells is about 50-60 MWe (Wameyo, 2006; Mburu, 2006; Omenda et al, 2000) and conceptualized as in Figure 4. The area has a fairly well established infrastructure and for this reason a 2.5 MWe binary pilot plant is planned for commissioning in 2009. Additional studies will also be done to refine the field model prior to commissioning of the plant.

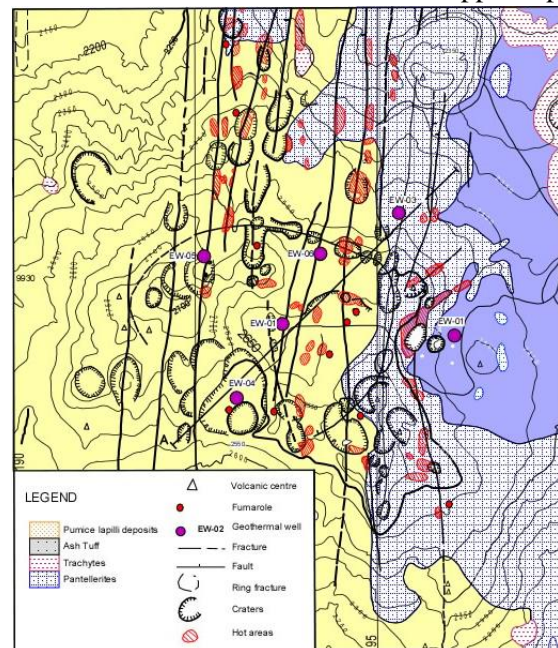


FIGURE 2: Geological map of Eburru Geothermal Field (Omenda and Karingithi, 1993)

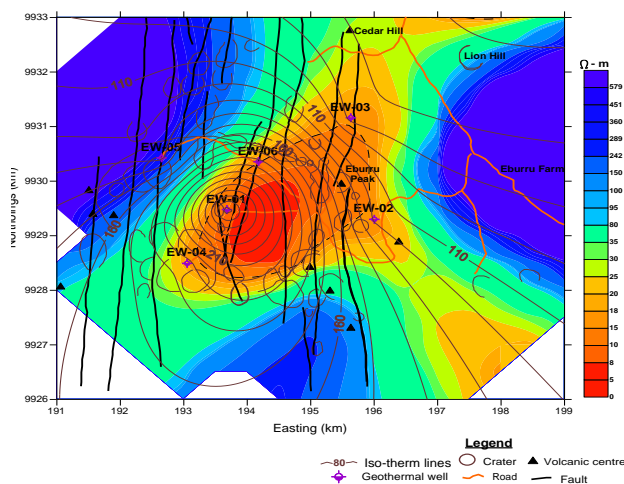


FIGURE 3: MT Resistivity distribution at 500 m a.s.l. (Wameyo, 2006)

#### 4.2 Menengai volcano

Menengai is a major Quaternary caldera volcano located within the axis of the central segment of the Kenya Rift. The volcano is located within an area characterized by a complex tectonic activity characterized by confluence of two tectono-volcanic axes (Molo and the Solai). The volcano has been active since about 0.8 Ma to present. The volcano is built of Trachyte lavas and associated intermediate pyroclastics. Most of the pyroclastics activity accompanied caldera collapse. Post caldera

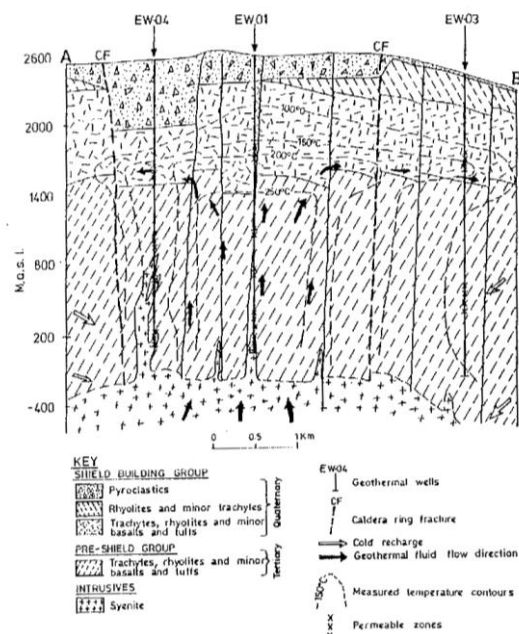


FIGURE 4: Conceptual model of the Eburru Geothermal system (Omenda and Karingithi, 1993)

activity (<0.1 Ma) mainly centred on the caldera floor with eruption of thick piles of trachyte lavas from various centres (Figure 5).

MT resistivity distribution at 2km b.s.l. shows a conductive body of less than 50hm-m centred in the western caldera floor “lobe” and a smaller anomaly at the centre of the caldera (Figure 6). Seismology indicates seismic wave attenuation at 7-8km depths underneath Menengai caldera and Ol’banita, respectively suggesting the presence of magma bodies, which could be heat sources. Vp/Vs ratios of 1.6-1.7 suggest steam-dominated reservoir (Simiyu, 2003). Gravity modelling also shows the presence of dense bodies at about 4 km depth under the caldera floor.

Heat loss survey indicates that the prospect loses about 3,536 MWt naturally to the atmosphere with 2440 MWt being the convective component (Ofwona, 2004). Fumaroles are scarce in the prospect with the few strong ones occurring within the caldera floor. Fumaroles steam compositions have low contents of reactive gases (CO<sub>2</sub>, H<sub>2</sub>S, H<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>). Gas geothermometry based on H<sub>2</sub>S and CO<sub>2</sub> indicates that the reservoir temperatures are greater than 250°C.

The mapped potential area in Menengai is about 40 Km<sup>2</sup> translating to over 720 MWe of electric power when conversion rate of 15MW per square kilometre is used (Figure 6 and 7). The reservoir rocks are expected to be trachyte as at Olkaria and therefore comparable permeability is postulated. Whereas Olkaria system has several discrete hot magmatic intrusions which are considered heat sources, Menengai has a centralized body under the caldera (Figure 7).

Environmental baseline studies conducted indicate that minimal impacts would occur from proposed drilling activities and future development of the resource (Mungania et al, 2004). Existing infrastructure also favour development of this resource. If developed, the resulting hot water could be used by the various Agro based industries which are close to the resource in Nakuru town. KenGen plans to undertake drilling of three exploratory in the prospect in 2008 and envisions power plant construction in the very near future.

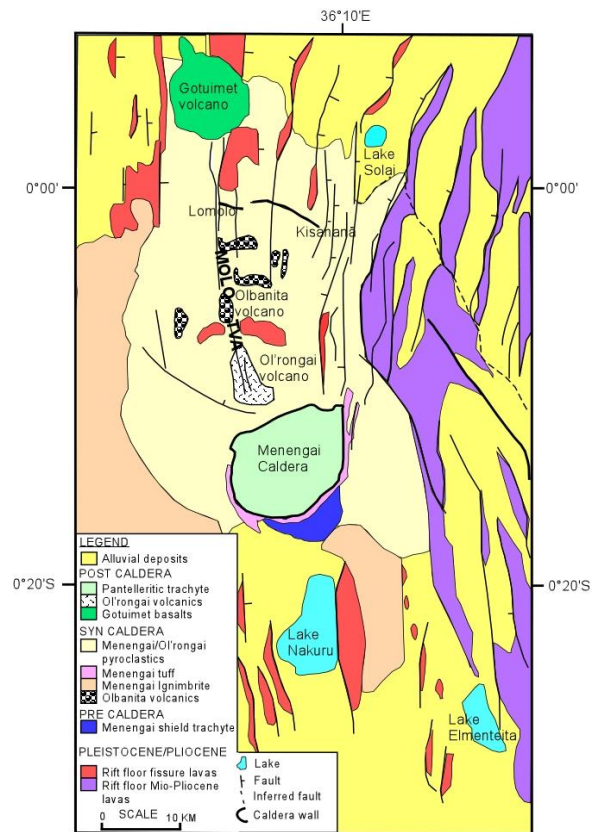


FIGURE 5: Geological map of Menengai caldera volcano

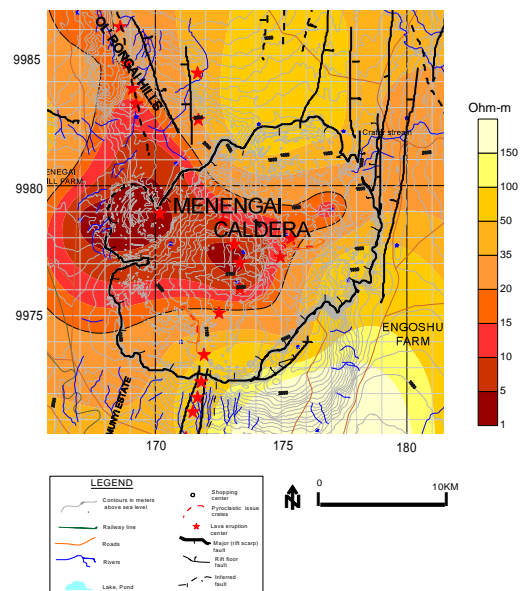


FIGURE 6: MT resistivity plot of Menengai at 2000mbsl

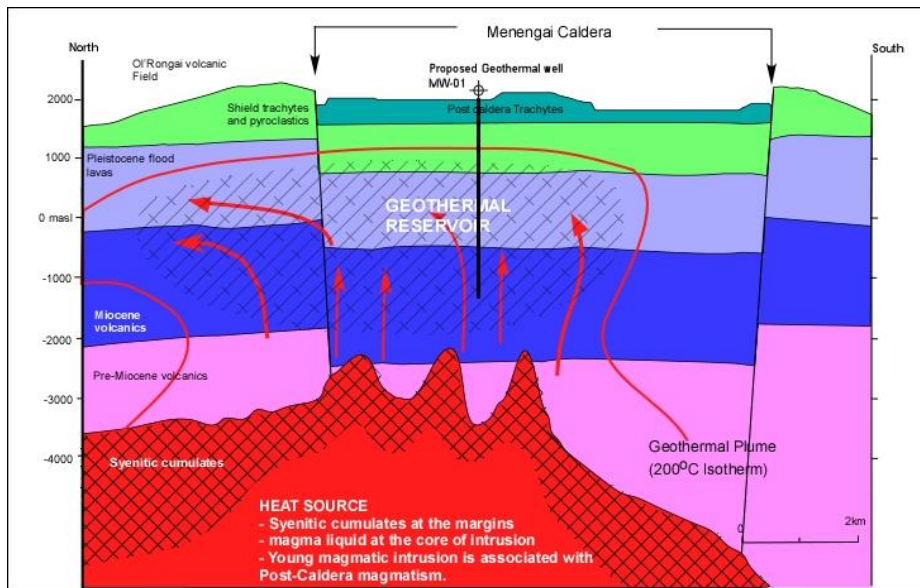


FIGURE 7: Geothermal model of Menengai volcano

**4.3 Longonot volcano**

Longonot is a large caldera volcano within the floor of the southern Kenya Rift adjacent to Olkaria Geothermal field (Figure 1). The volcano comprises of a large trachyte caldera of about 11 km in diameter and a resurgent activity on the caldera floor that formed a central volcano with a crater at the summit. The caldera floor is filled, to a large extent, by trachytic ashes from the central volcano.

The youngest activity (<300 yrs BP) at Longonot was of mixed Trachyte-basalt composition and erupted within the crater floor and on the northern flank of the central volcano (Figure 8).

Geothermal surface manifestations are mainly fumaroles and hot grounds within the central crater. The geochemical survey revealed high radon and CO<sub>2</sub> gas discharges. Gas geothermometry also indicate that geothermal reservoir temperatures could exceed 300 °C (KenGen, 1998).

MT resistivity distribution at 2km b.s.l. shows a conductive body of <11ohm m in the southern slopes of the young central volcano and extending beyond the caldera boundary. It is postulated that the body could be of magmatic type and thus possibly the resource heat source (Figure 9). Preliminary results of micro seismic investigations show correspondence between seismics and MT. Shear wave splitting anisotropy directions were evidenced in the data suggesting fault control in the movement of pressurized fluids in the near subsurface (Onacha, 2006).

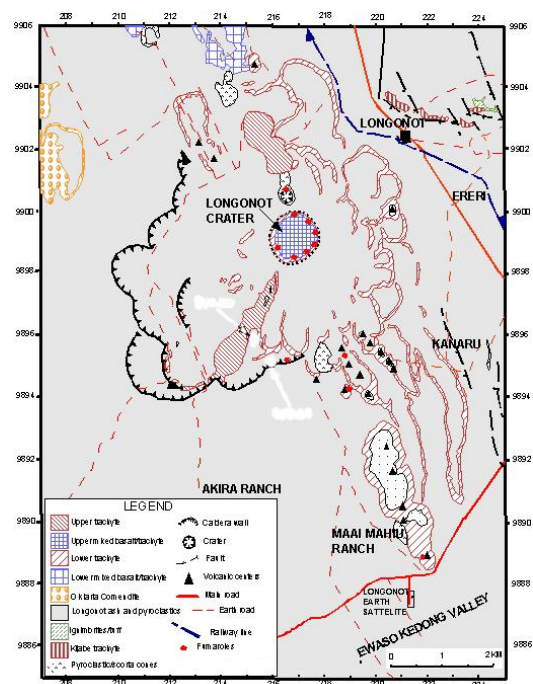


FIGURE 8: Geological map of Longonot Geothermal area

Combined MT, gravity and seismics indicate that the heat source is at 6 km deep with the shallowest portion directly under the central volcano. Conceptual model indicates that the main upflow for the system is to the immediate south of the central crater extending beyond the SE margin of the caldera wall. The fluid then outflows southward (Figure 10). Recharge for the system is probably from the rift shoulders and also axially. The heat source for the main system is associated with the resurgent activity, which developed the central shield volcano within the caldera. The model indicates that a high temperature geothermal system >250°C is expected to exist under Longonot. KenGen plans to drill three exploratory deep wells in the prospect in 2008.

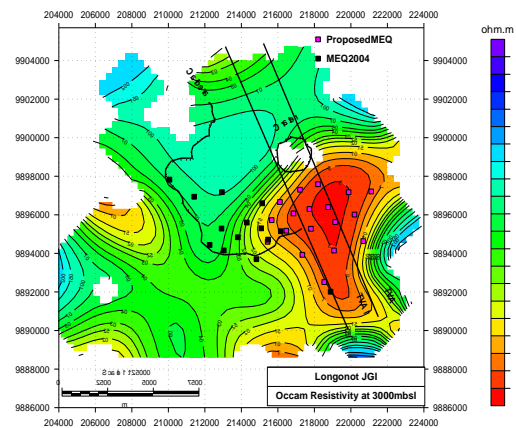


FIGURE 9: MT resistivity map of Longonot (Onacha, 2006)

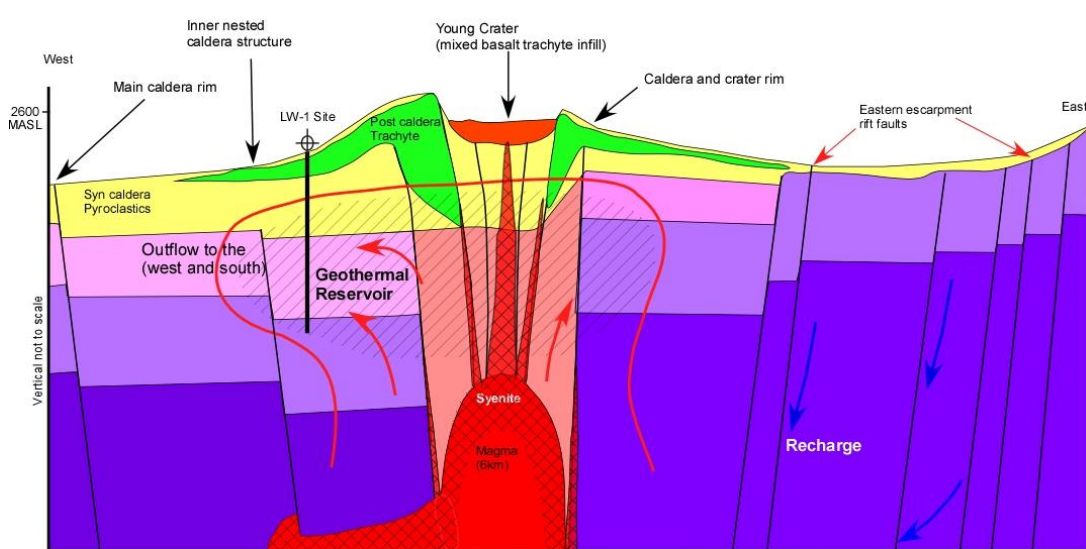


FIGURE 10: Geothermal model of Longonot Volcano

4.4 Suswa

Suswa is the southernmost of a series of Quaternary caldera volcano in the Kenya rift. The volcano has two nested calderas: outer and inner with diameters of 10 and 4 km, respectively (Figure 11). Volcanism at Suswa that comprised trachytes and phonolites started about late Pleistocene and continued to less than 1,000 years ago (Omenda, 1997).

Results from detailed surface studies done by KenGen in suggest reservoir temperatures of 250°C based on gas geothermometry. Seismic and gravity studies show that the heat source under the caldera is at about 6-8 km deep with a NE-SW bias. Resistivity (MT) at 500 m b.s.l. indicates a low (15-20 ohm m) anomaly under the island block and extending to the north out of the inner caldera (Figure 12).

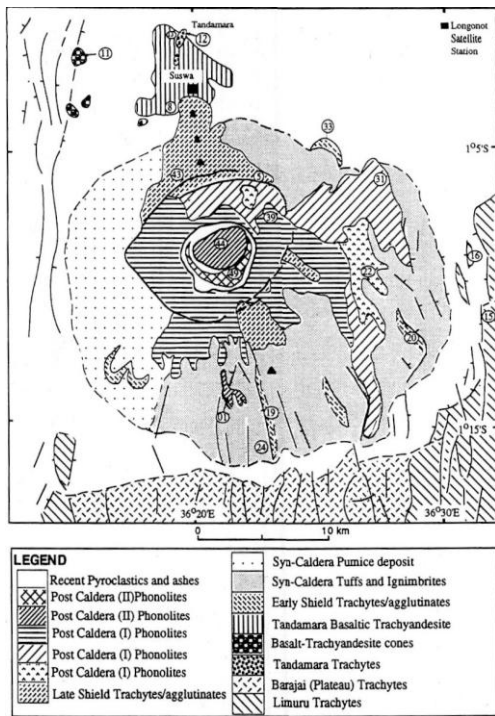


FIGURE 11: Geological map of Suswa volcano

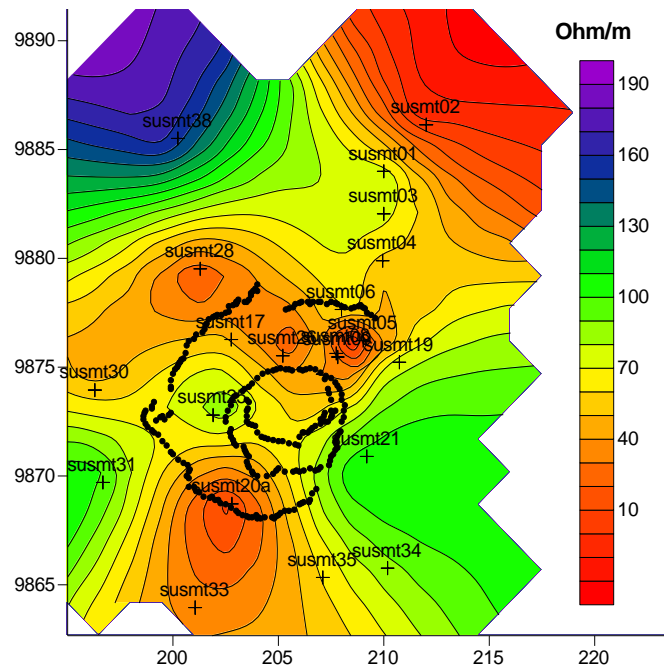


FIGURE 12: MT plot for Suswa at 500 m b.s.l.

Conceptual model indicates that heat source for Suswa is a magmatic body centred under Ol Doi Nyoke volcano (Figure 13). The body is at a depth of more than 6-8 km and could be the heat source of the geothermal system. The geothermal system must have attained temperatures of more than 250°C as seen from the presence of hydrothermal epidote within the lithics. Gas geothermometry indicate that gases sampled in the prospect originated from sources having temperatures of more than 250°C. The prospect has a fairly good recharge from both the west and east rift escarpments. However, the water table in the rift floor is deep, probably more than 300 m, due to intense faulting of the pre-Suswa formations. Drilling of exploratory wells in the prospect is planned after Menengai and Longonot.

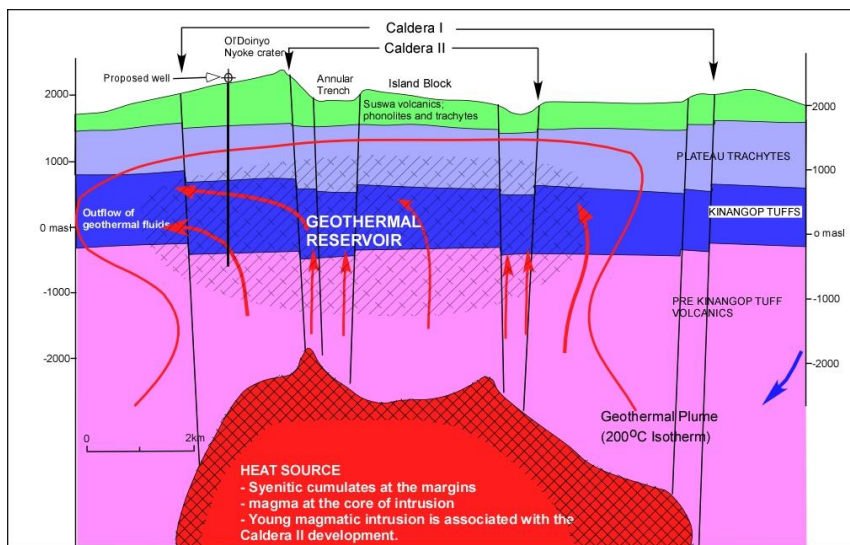


FIGURE 13: Geothermal model of Suswa volcano

**4.5 Lake Bogoria and Arus**

Arus – Lake Bogoria prospect is the area surrounding Lake Bogoria and extending about 50 km southward and westward (Figure 1). The upper Plio-Pleistocene volcanism of the rift floor in the area between Arus and Lake Bogoria is characterized by large volumes of evolved lavas that consist mostly of peralkaline trachyte, trachyphonolite and phonolite (Figure 14). Small outcrops of basaltic lavas occur in isolated areas within the prospect. The northern sector south of Lake Baringo is, however, dominated by fluvial and alluvial deposits. There are no Quaternary central volcanoes in the prospect.

The geothermal manifestations occurring in the prospect include fumaroles, hot and steaming grounds, anomalous boreholes, hot springs, steam jets, altered grounds, sulphur, calcite and travertine deposits. Most of these manifestations occur along the shore of Lake Bogoria and at the Arus springs (Figure 15).

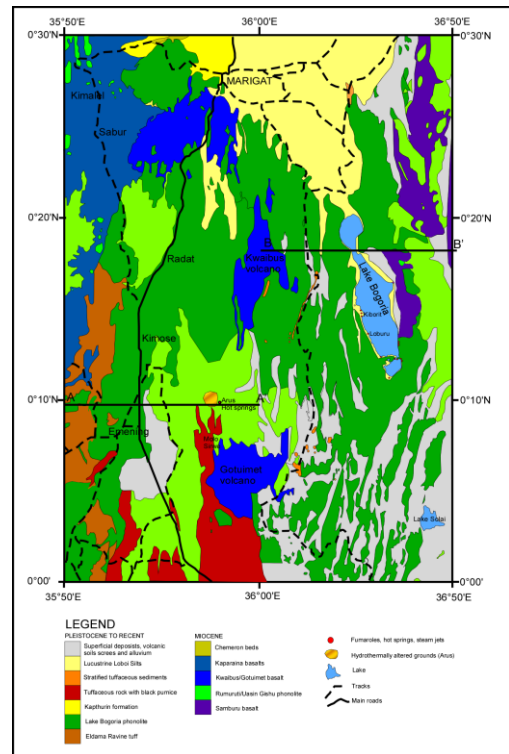


FIGURE 14: Geological map of the Lake Bogoria – Arus prospect

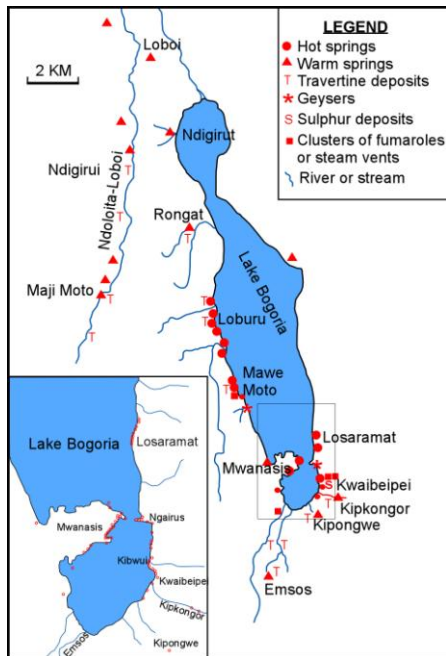


FIGURE 15: Locations of fumaroles and hot springs in the Lake Bogoria area.

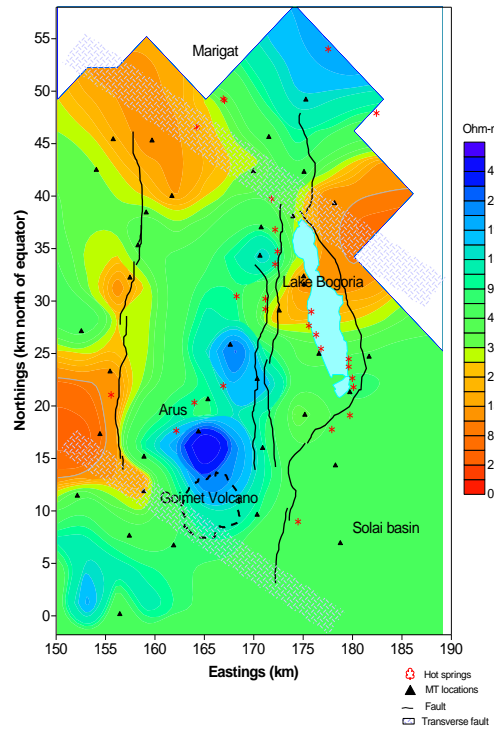


FIGURE 16: Arus-Bogoria MT resistivity distribution at 2,000 m b.s.l.



Fluid geothermometry indicates intermediate subsurface temperatures of more than 145-245°C for the Lake Bogoria springs while those at Arus are at 170-192°C. The low resistivity bodies (< 10 ohm-meter) occur mainly along and at the intersection of major faults and transverse zones (Figure 16). These intersection zones may be forming weak regions through which magmatic materials find their way to the shallow sub-surface. However, the resistivity data has not defined clear geothermal reservoirs in the field.

The geothermal reservoirs in this field, therefore, could be assumed to follow the fault plane model where discrete small reservoirs are located along fault zones (Figure 17).

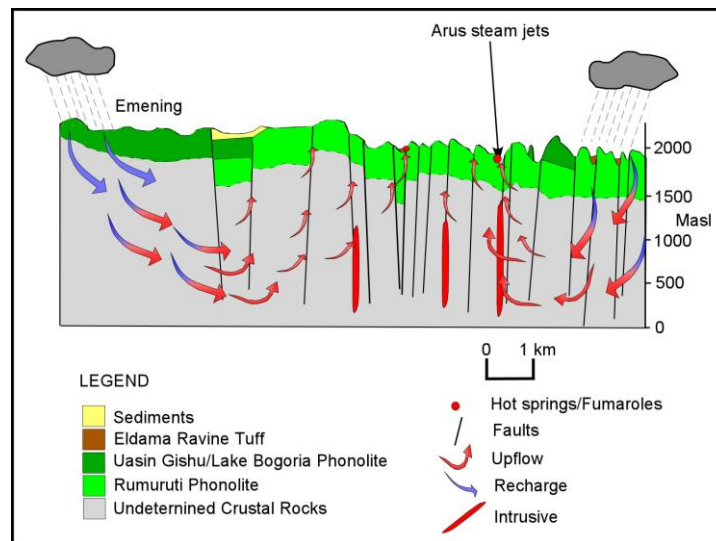


FIGURE 17: Regional geothermal model of Arus-Bogoria geothermal prospect

#### 4.6 Lake Baringo

Lake Baringo geothermal prospect is in the northern part of the Kenyan rift and covers the area around Lake Baringo. Surface manifestations include fumaroles, hot springs, thermally altered hot grounds and anomalous ground water boreholes. The geology of the area is characterized by trachyte and trachy-phonolite to the east and west while basalts occur to the north and alluvial deposits to the south. Olkokwe Island in Lake Baringo is the only Quaternary volcanic complex which is associated with volcanic activity at Korosi to the north

Fumaroles and hot springs occur on Olkokwe Island while weak fumarolic areas occur in the western zone along fractures/faults. Gas geothermometry indicates reservoir temperatures of more than 120-200°C in the west near Chepkoiyo well and more than 170°C in the Olkokwe Island system.

Resistivity indicates potential occurrences of fault controlled, discrete reservoirs in areas west of the Lake, SE and north (Figure 18). Since a large portion of the prospect is not associated with a centralized Quaternary volcano, it

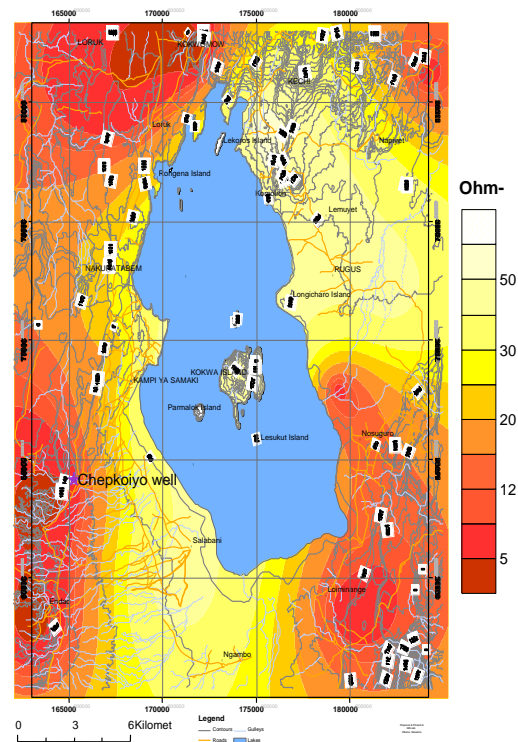


FIGURE 18: Resistivity at sea level at Lake Baringo prospect

is postulated that the heat sources are probably deep dike swarms along the faults. It can be concluded from the available information that the resource at Lake Baringo is low to intermediate temperature suitable for direct uses.

**4.7 Korosi volcano**

Korosi volcano is located in the north rift Valley and neighbours Lake Baringo to the south and Paka volcano to the north. KenGen and the Ministry of Energy undertook detailed surface studies in the prospect in 2005. The area is strongly faulted by a system of NNE trending faults, which extends northwards onto the flanks of Paka volcano (Figure 19). The latest volcanic activity associated with Korosi was of basaltic composition and occurred a few hundred years ago while the last trachytic volcanism occurred about 100ka.

Surface geothermal manifestations include hot steaming grounds and fumaroles. Surface temperatures ranging between 90 – 95°C have been recorded.

The MT resistivity map at 1500 m b.s.l. shows low resistivity below the Korosi massif but is well defined in resistivity map at 4000 m b.s.l. (Figure 20). The MT plot shows a well defined <10Ωm low resistivity below the Korosi Massif. The low resistivity below the massif is interpreted to mark the top of the heat source for the geothermal system.

Gas chemistry of five samples from Korosi using H<sub>2</sub>S Gas geothermometry function indicates that temperatures of more than 250°C exist in the reservoir under the volcano. Conceptual model indicates that a viable geothermal system exists under the Korosi massif with the upflow within the micro-graben and outflow largely to the north.

**4.8 Chepchuk volcanic field**

The Chepchuk area was covered during the studies at Korosi which was done by KenGen and the Ministry of Energy in year 2005. The geology of Chepchuk is characterized by faulted Plio Pleistocene flood trachytes and younger basaltic flows occupying micro-grabens. The area is heavily faulted with half of the Chepchuk volcanic complex down faulted westward. It is postulated that the old Chepchuk volcano could be the dominant source but with contribution from Paka volcanic area. It is estimated that the resource is of intermediate temperature.

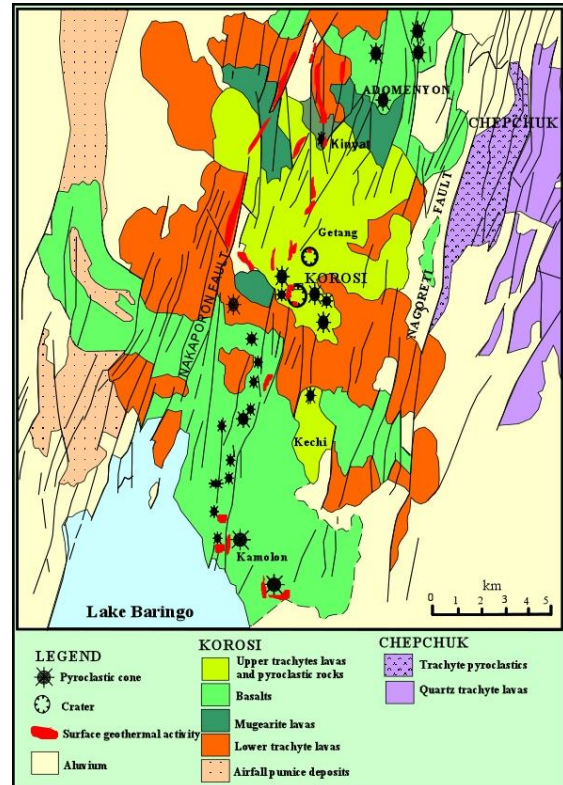


FIGURE 19: Geological map of Korosi volcano

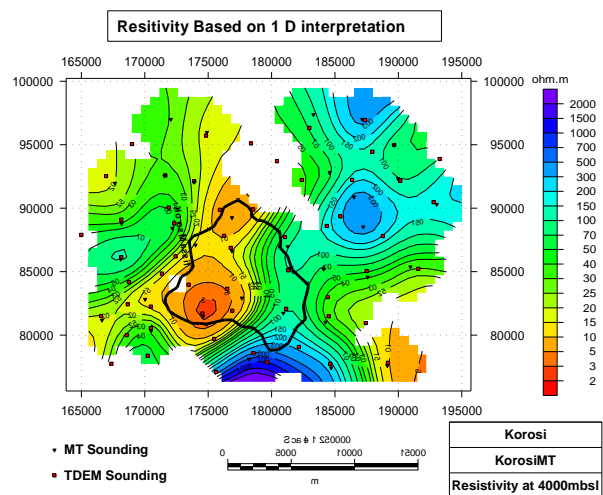


FIGURE 20: Resistivity distributions at 4000 m b.s.l. in Korosi area

### 4.9 Paka volcano

Detailed surface studies of Paka volcano was undertaken in 2006/7. Paka is a relatively small shield volcano constructed largely by trachyte lavas and pyroclastic deposits and located just to the north of Korosi volcanic complex (Figure 21). Volcanic activity commenced by 390 ka (Trachytes) and continued to within 10 ka (basalts).

The structure of Paka is dominated by a broad zone of normal faulting 7.5 km wide graben bound by the eastern and the western fault boundaries respectively. This zone shows a right stepping en echelon arrangement along the volcano and forms one of the regional fault pattern, which extends southwards to Chepchuk and northwards into the southern flanks of Silali.

Surface geothermal activity is widely developed at Paka particularly within the summit craters and the northern flanks where fumaroles at  $>97^{\circ}\text{C}$  are common. Sulphur crystals are common for the fumaroles within the craters. Gas geothermometry of fluids from Paka indicate the reservoir system to be at more than  $250^{\circ}\text{C}$ .

MT resistivity at Paka prospect shows conductive bodies under the massif and on the eastern side at foot of fault scarp. The latter is not considered to be of geothermal interest (Figure 21). The anomaly under Paka volcano could be imaging hot rocks. Seismic studies indicate shallow events directly under Paka suggesting that a hot body exists below about 2.5 – 5km depth. Heat loss studies of Paka volcano revealed that a total heat loss of  $2,855 \text{ MW}_t$  occurs within the prospect with a convective component of  $10 \text{ MW}_t$ . Most of the heat is lost within the Paka craters area.

Conceptual model developed for Paka indicates that the system is closely associated with the magmatic intrusion under the volcano. The model indicates that the low resistivity imaged by MT at the foot of the eastern scarps may not be of geothermal significance but further studies are required to characterize the anomaly. The potential area is expected to be small and restricted to the massif.

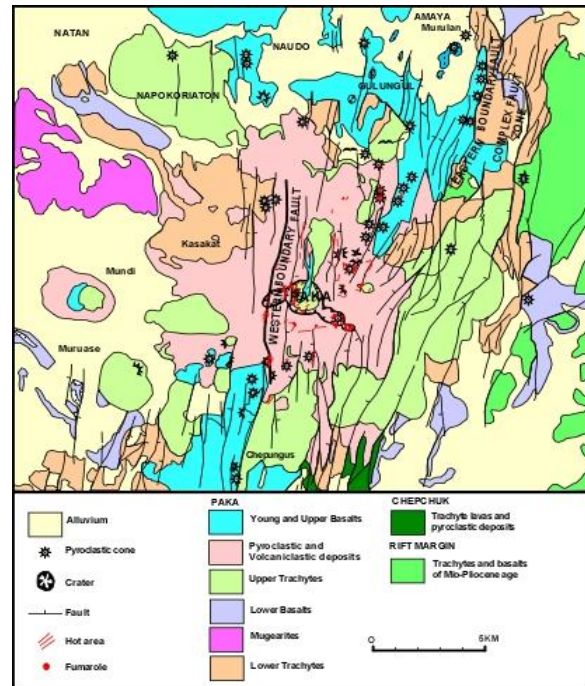


FIGURE 21: Geological map of Paka volcano

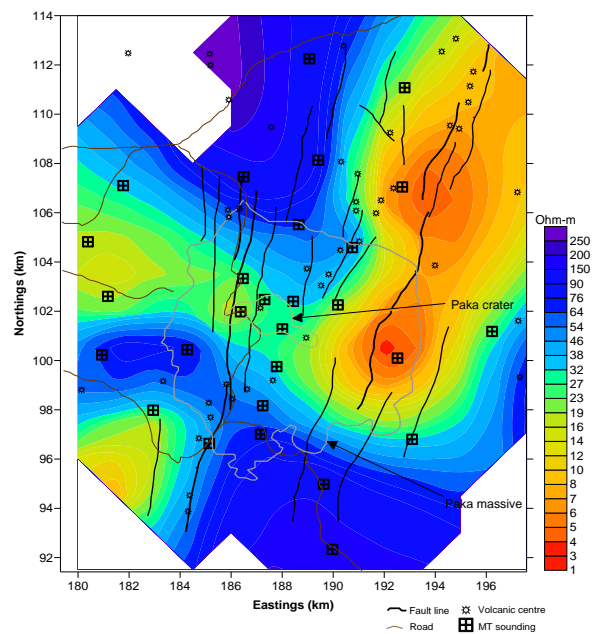


FIGURE 21: MT resistivity plot at 3000mbsl

The potential area is expected to be small and restricted to the massif.

## 5. OTHER GEOTHERMAL PROSPECTS

The other potential geothermal prospects within the Kenya rift that have not been studied in details include Lake Magadi, Silali, Emuruangogolak, and Namarunu and Barrier volcanic complex. KenGen and Magadi Soda Company are currently working on a possibility of carrying out detailed studies of the prospect with a view to exploiting the resource for use at the soda mining activity. Preliminary information indicates that the Lake Magadi system could be of intermediate temperatures (Allen et al., 1989).

Since northern prospects are still magmatically active (Dunkley et al., 1993), it is postulated that high temperature geothermal systems could exist under the volcanoes. KenGen has plans to undertake detailed studies at Silali in 2007/2008 followed by the studies at the other centres in the subsequent years. Previous studies coupled with the existence of hot springs discharging over 1000 l/s at Silali, young Trachyte eruptions and high geothermometric temperatures (>250°C) gives Silali high priority over the other un explored fields in the north rift.

## ACKNOWLEDGMENTS

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