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Status of Geothermal Exploration in Kenya and Future Plans for Its Development

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ABSTRACT

Kenya is endowed with vast geothermal resource potential along the world Kenya Rift that transects the country from north to south. Exploration reveals that geothermal potential exceeds 7,000 MWe and is capable of meeting all of Kenya's electricity needs over the next 20 years. Out of this potential, only 167 MWe and 18 MWt are being utilized for indirect and direct uses respectively. Kenya Electricity Generating Company Ltd (KenGen) and Geothermal Development Company Ltd (GDC) in collaboration with the Ministry of Energy (MoE) has undertaken detailed surface studies of most of the prospects in the Kenya rift, which comprises Suswa, Longonot, Olkaria, Eburru, Menengai, Lakes Bogoria and Baringo, Korosi and Paka volcanic fields. The Least Cost Power Development Plan (2008-2028) prepared by the Government of Kenya indicates that geothermal plants have the lowest unit cost and therefore suitable for base load and thus, recommended for additional expansion. Electric power demand in Kenya currently stands at over 8% annually. In order to meet the anticipated growth in demand, The Kenya Government through the newly formed utility (GDC) has embarked on an ambitious generation expansion plan to install additional 1500 MWe and 4000 MWe of electric power by the year 2018 and 2030 from geothermal sources respectively. The planned geothermal developments require over 1000 wells to be drilled and about 30 large power stations of about 140 MWe each to be built at a total cost of over US$16 billion inclusive of wells and steam gathering system.

1. INTRODUCTION

Kenya has a demand growth of 8%. The growth is driven by increased consumption from existing customers of 5% and new customers account for the 3%. However, installed capacity of 1005 MWe has not increased to match the demand growth thus emergency power has been procured to satisfy peak demand. The Least Cost Power Development Plan (2008-2028) prepared by the Government of Kenya indicates that geothermal plants have the lowest unit cost and therefore suitable for base load and thus, recommended for additional expansion. The existing Olkaria Power plants have operated as base load power with an availability factor of more than 95% and therefore saved the country on imported fuel cost and power outages during un-favourable weather conditions. This success is a testimony of the viability of the geothermal energy in Kenya.

In recognition of the importance and reliability of geothermal power and the energy requirements to meet the vision 2030 objectives, the government has embarked on an ambitious generation expansion plan to increase the installed capacity through enhanced geothermal development. Geothermal power can contribute at least 1,500 MWe by 2020 and 4,000 MWe by 2030. Development of 4,000 MWe of geothermal steam equivalent over the 20 year period requires drilling about 1,000 deep wells, using 10 rigs at a total cost of about US$ 5 Billion. 30 Power stations (about 140 MW each) would be required at a total cost of about US$ 8 Billion; steam gathering systems at about US$ 1 Billion; and power transmission lines at about US$ 2 Billion. It is clear that such a massive (US$ 16 Billion) capital intensive undertaking can only be realized through a joint effort by both the public and private sectors.

1.1 Regional Geologic Tectonic Setting

The Kenya rift valley (Figure 1) is part of the African rift system that runs from Afar triple junction in the north to Beira, Mozambique in the south. It forms a classic graben averaging 40-80 km wide. Geologically, the rift is an intra-continental divergence zone where rift tectonism accompanied by intense volcanism, has taken place from late Tertiary to Recent. Most of the volcanic centers had one or more explosive phase including caldera collapse. The centers are dotted with hydrothermal activity and are envisaged to host extensive geothermal systems. The prospects from south to north are Lake Magadi, Suswa, Longonot, Olkaria, Eburru, Badlands, Menengai, Arus Bogoria, Lake Baringo, Korosi, Paka, Silali, Emuruangogolak, Namarunu and Barrier.

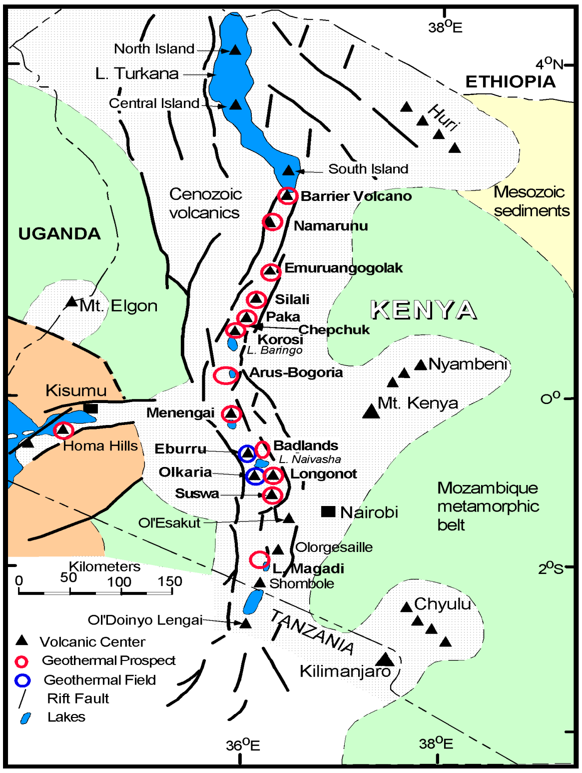

Figure 1: Simplified geological map of Kenya showing locations of the geothermal fields and prospects.

1.2 History of Development and the Potential

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 at Olkaria commenced and was funded by UNDP. The Government through the Ministry of Energy, GDC, KenGen and other partners has undertaken detailed surface studies of some of the most promising geothermal prospects in the country. The areas that have been studied in detail include Suswa, Longonot, Olkaria, Eburru, Menengai, Arus-Bogoria, Lake Baringo, Korosi and Paka. Other areas with not very detailed studies include Lake Magadi, Badlands, Silali, Emuruangogolak, Namarunu and Barrier geothermal prospects. Evaluation of these data sets suggest that over 7,000 MWe can be generated from the high temperature resource areas in Kenya. The Ministry of Energy is keen in continued exploration and drilling of the high potential areas.

2. COUNTRY UPDATE AND PIPELINE PROJECTS

2.1 Greater Olkaria Geothermal field

Currently, in Kenya, geothermal energy is being utilised in Olkaria field only. Three of the seven Olkaria sectors namely Olkaria East field, Olkaria West field and Olkaria Northeast field (Figure 2) are generating a total of 167 MWe. The resource is being utilized mainly for electric power generation (167 MWe) and direct uses (18 MWt). The proven geothermal resource at the greater Olkaria geothermal field is more than 450 MWe and accelerated development if envisaged in the near future.

2.1.1 Olkaria I Power Plant

The Olkaria I power plant is located in the Olkaria East field (Figure 2) is owned by Kenya Electricity Generating Company Ltd (KenGen) has three turbo generating units each generating 15 MWe. The three units were commissioned in 1981, 1983 and 1985 respectively. The plant has therefore been in operation for the last twenty seven (27) years. Olkaria East field, which supply steam to Olkaria I power plant has thirty three (33) wells drilled. Thirty one (31) of them were connected to the steam gathering system 9 of them drilled as makeup wells. Currently, twenty six (26) of them are in production while the rest have become non-commercial producers due to decline in output over time and some of these are earmarked to serve as reinjection and or for deepening. Currently, the steam available from this field is more than what is required to generate 45 MWe and studies are underway to determine the viability of increasing generation by adding a 70 MWe Unit IV.

2.1.2 Olkaria II Power Plant

Olkaria II is located in Olkaria northeast (Figure 2) and the construction of 2 x 35 MWe Olkaria II geothermal power station started in September 2000 was completed November 2003. The plant is more efficient than the Olkaria I with a specific steam consumption of about 7.2 t/hr per MWe as opposed to the 9.2 t/hr for the Olkaria I plant. As a result of the efficiency of the machines there is excess steam available in this field. Consequently, KenGen decided to make use of the existing excess steam to add a 35 MWe, Olkaria II 3rd unit. The construction of Olkaria II 3rd unit is underway and is expected to be commissioned in 2010.

2.1.3 Olkaria IV (Olkaria Domes)

Surface exploration was carried out in 1993-1994 and a working model for drilling exploration wells was conceptualized. In 1998-1999, 3 exploration wells were drilled and all encountered a geothermal system. In June 2007, drilling of appraisal wells commenced using a hired rig from Great Wall Drilling Company Ltd (GWDC) of China. Currently appraisal 6 wells have been drilled 5 of which are directional and 1 is vertical. The capacities of the wells range from 4-13MWe.

Production drilling is currently underway utilizing 2-3 hired rigs from GWDC and a total of 15 production wells will be drilled. Tender documents for the construction of the steam gathering system and the power plant are being prepared and will be floated later next year. Two 70 MWe power plants totaling 140 MWe will be constructed in Olkaria Domes and is anticipated to be commissioned in the year 2012 and 2013 respectively.

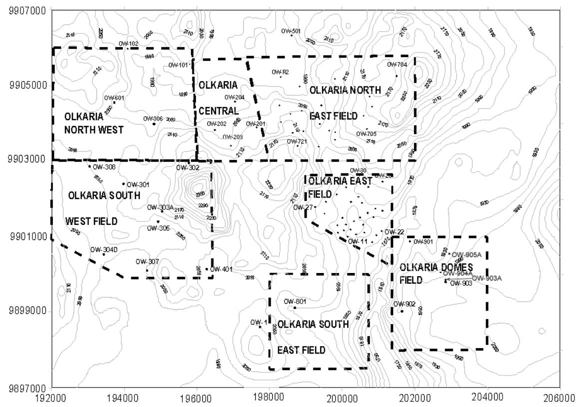

Figure 2: Map of the Greater Olkaria geothermal area showing the locations of the fields.

2.1.4 Olkaria III Power Plant

Olkaria III project is the first private geothermal power plant in Kenya. A 20-year Power Purchase Agreement (PPA) was awarded to Orpower 4 Inc. by Kenya Power and Lighting Company (KPLC) under a World Bank supervised international tender for the field development of up to 100 MWe. The first phase of the project included drilling of appraisal wells and construction of a 12 MWe pilot plant. The first 8 MWe was put on commercial operation on September 2000 and the other 4 MWe in December 2000. The appraisal and production drilling commenced in February 2000 and was completed by March 2003, after drilling a total of 9 wells (depth ranging between 1850-2750 m) and adequate steam was proved for total development of 48 MWe over the PPA period of 20 years. The 48 MWe power plant was commissioned in the year 2008.

2.1.5 Oserian Plant

Oserian Development Company Ltd (ODLC) constructed a 2.0 MWe binary plant Ormat OEC in Olkaria Central to utilise fluid from a well (OW-306) leased from KenGen. The plant, which is supposed to provide electrical power for the farm's operations, was commissioned in July, 2004.

ODLC who grow cut flower for export is also utilizing steam from a 1.28 MWe well to heat fresh water through heat exchangers, enrich CO_2 levels and to fumigate the soils. The heated fresh water is then circulated through greenhouses. The advantage of using geothermal energy for heating is that it results in drastic reduction in operating costs.

2.2 Geothermal Field Outside Olkaria

Geothermal resource potential of fields to the south and north of Olkaria has been studied and Eburru is the only field amongst these that has had exploration wells drilled. The other fields are at various exploration stages ranging from reconnaissance studies to advanced surface exploration with wells sited. The field's status and estimated potential are described below starting from Suswa to the south to Barrier Volcano to the north of the Kenya rift.

2.2.1 Suswa

Suswa is a Quaternary caldera volcano in the southern part of the Kenya rift. The prospect has a central volcano with an outer and inner caldera (Figure 3). The inner caldera has a resurgent block with a trench around it. The diameter of the outer caldera is 10 km while that of the inner is 4 km. Volcanism at Suswa started about late Pleistocene and the earliest products overlie the faulted Plateau Trachyte of late Pleistocene epoch. The Plateau Trachyte Formation comprises of flood trachytes that erupted on the developing graben. The age of the recent volcanism is <1000 years and this resulted in the formation of the annular trench and the Island block while the oldest forming the outer caldera is 400±10 ka (Omenda et al, 2000). Surface manifestations occur around the margins of the outer and inner caldera, on the Island block and in the trench surrounding it. These include fumaroles, steam jets, steaming and hot grounds and solfatara with temperatures of over 93ºC.

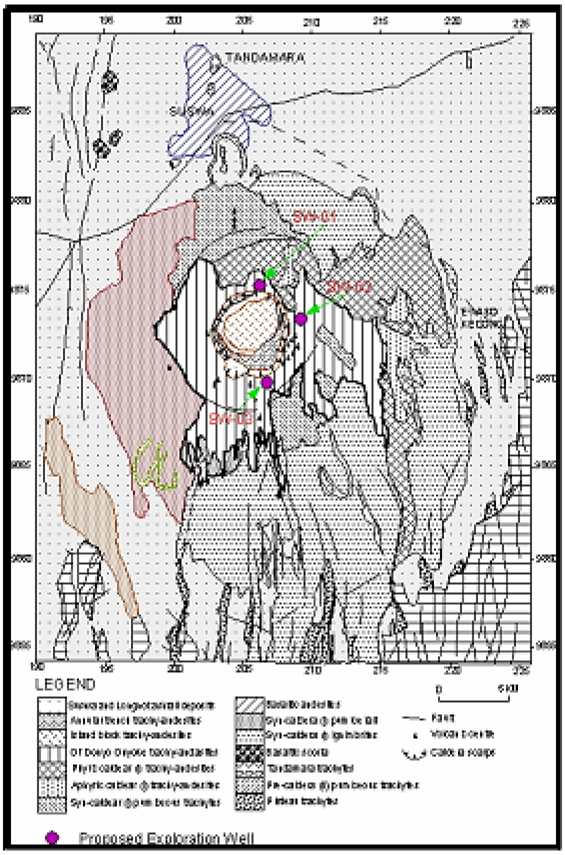

Figure 3: Simplified Geological map of Suswa volcano (Omenda, P. A, 1992)

Results from detailed surface studies done by KenGen in 1993 and 1994 suggest reservoir temperatures of 220°C to 300°C, which is comparable to that at Olkaria. High amount of $C0_2$ in the fumaroles sampled indicated high fracture density. Low amount of H_2S in the sampled steam suggests influence of steam condensate or shallow ground water on the fumaroles. Relatively high pH of the condensate supports this mixing hypothesis (Muna, 1994). Seismic and gravity studies show that the heat source under the caldera is at 8 to 12 km deep with a NE-SW bias. Resistivity at 1000 m.a.s.l indicates a low (15-20 ohm m) anomaly under the island block and extends to the north out of the inner caldera.

Proximity of the resource to the rift flanks suggests good recharge but the lack of hot springs indicate a deep water table. It is postulated that dikes may be abundant in the prospects and hence act as hydrological barriers and may compromise reservoir permeability. Three exploration wells were sited within the anomalous region (KenGen, 1999). The power potential of the prospect is over 600 MWe (Omenda et al., 2000).

2.2.2 Longonot

Longonot geothermal prospect occurs within the Longonot volcanic complex, which is a Quaternary caldera volcano in the southern sector of the Kenya rift. The volcano is dominated by a central volcano with a summit crater and a large outer caldera (Figure 4). Detailed surface exploration work in Longonot was carried out in 1998, with some follow-up MT studies in 2005.

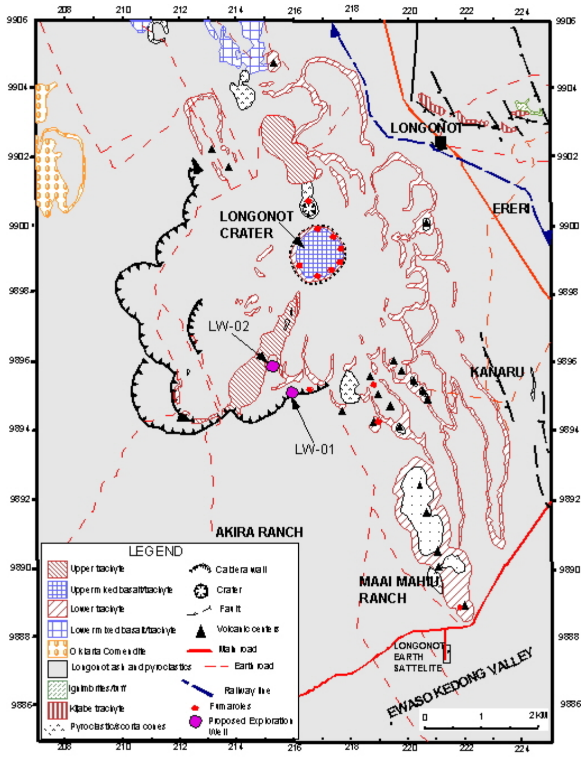

Figure 4: Geological map of Longonot volcano (Lagat, J. K., 1998)

Magmatism directly associated with the development of the volcano started about 0.4 ma BP and involved eruption of trachytes and their pyroclastic equivalent. These activities were succeeded by caldera collapse and resurgence within the caldera floor, which resulted to the present day high rising volcano with a crater at the top. The latest trachytic lava flow has been dated about 200 years BP. Surface studies indicate that Longonot volcano has a centralized magma chamber beneath the summit crater. The geothermal reservoir from the low resistivity anomaly occurs in the southern part of the crater. The geothermal reservoir is most likely hosted within the faulted Plio-Pleistocene plateau trachytes, which is common within the floor of the southern Kenya rift valley. The recharge of the system is controlled largely by the rift master faults on the eastern scarp and to a lesser extent by the flow along the rift axis. The Geochemical analysis projected reservoir temperatures in excess of 300°C. CO_2 and Radon counts at Longonot and Olkaria are similar and these together with similar reservoir rocks expected, suggests that the reservoir characteristics of the two could be comparable. The heat source is expected to be about 6 km deep (KenGen, 1998). Three exploration wells have been sited and will be drilled in the year 2009. Estimated power potential is over 700 MWe (BCSE, 2003, Omenda et al, 2000).

2.2.3 Eburru

Eburru volcanic complex (Figure 5) 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 is able to support up to >60 MWe. The results from the exploration wells indicate that the field had experienced temperatures of over 300°C possibly due to localized intrusive.

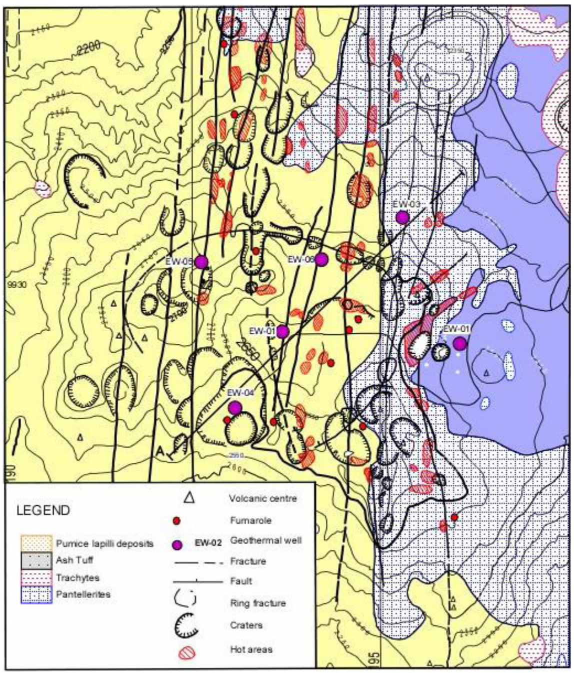

Figure 5: Geological map of Eburru Geothermal Field (Omenda et al, 1993).

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 3. The area has a fairly well established infrastructure and for this reason a 2.5 MWe binary pilot plant is planned for commissioning in 2010.

2.2.4 Menengai

Menengai volcano caldera is one of the high potential prospects in Kenya. It is Located in Nakuru and therefore is close to high power transmission lines and is situated close to a populated town. Detailed surface exploration was carried out in 2004.

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

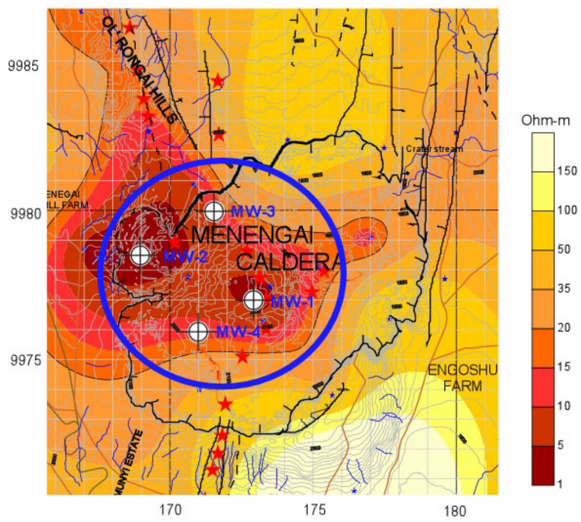

Figure 6: MT Resistivity at 2000 mbsl and proposed well site locations.

MT resistivity distribution at 2000 mbsl shows a conductive body of less than 5 ohm-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 7-8 km 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 modeling also shows the presence of dense bodies at about 4 km depth under the caldera floor.

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_2, H_2S, H_2, CH_4, and N_2). Gas geothermometry based on H_2S and CO_2 indicates that the reservoir temperatures are greater than 250ºC. The mapped potential area in Menengai is about 48 Km^2 translating to over >750 MWe of electric power when conversion rate of 15 MWe per square kilometre is used (Figure 6). KenGen/GDC plans to undertake drilling of three exploratory in the prospect in 2009-2010. Appraisal and production wells and construction of 140 MWe power plants (Menengai I, II and III) will be commissioned in the year 2012, 2013 and 2014 respectively.

2.2.5 Arus and Lake Bogoria

Arus and Lake Bogoria is an area with no observable central volcano. Geothermal manifestations mainly hot springs, geysers, hot grounds, fumaroles and steam jets occur along the shore of Lake Bogoria and at Arus. One of the hot springs is used for heating at a nearby hotel. Surface studies are still ongoing. Preliminary results suggest that the heat source is associated with intrusives. Heat loss survey indicates that Lake Bogoria area loses about 1199 MWt while Arus loses 467 MWt. Convective heat loss at Lake Bogoria is about 437 MWt (Mwawongo, 2000). Detailed geoscientific surveys were conducted in 2005 and results from the analyses of data acquired from the field indicate existence of low to intermediate temperature fracture controlled geothermal systems in the prospect area. Figure 7 shows the sprouting hot spring at the edge of Lake Bogoria. Geothermometry estimate reservoir temperature of <248ºC (Karingithi, 2005) and are ideal for direct uses in swimming, bathing, balneology, agriculture, residential and industrial sectors and binary cycle electricity generation technologies. Power potential in both Arus and Bogoria is estimated at 400 MWe.

Figure 7: Hot spring at the western edge of Lake Bogoria.

2.2.6 Lake Baringo

Lake Baringo geothermal prospect is in the northern part of the Kenyan rift. Surface manifestations include fumaroles, hot springs, thermally altered hot grounds and anomalous ground water boreholes. The Kenya Government and KenGen carried out surface studies in 2004 (Mungania et al, 2005). The geology indicate occurrence of trachyte and trachy-phonolites, basalts and alluvial and fluvial deposits on the lower parts. Lack of a centralized volcano or a caldera in this prospect suggests that its reservoir characteristics may be different from that of the prospects mentioned above.

Resistivity at sea level (Figure 8) indicates occurrences of fault controlled, discrete possible resource areas in the west of the Lake. Fluid geothermometry indicate reservoir temperature of over 200ºC near the Chepkoiyo well, west of Lake Baringo. Heat flow surveys indicate that the prospect loses about 1049 MWt to the atmosphere with 941 MWt being the conductive component (Ofwona, 2004). The prospect is not associated with a centralized volcano and the heat sources are probably deep dyke swarms along the faults. The estimated reservoir temperatures of low to intermediate are ideal for direct uses and binary cycle electricity generation technologies. Drilling deep slim holes that can be geologically logged and be used to determine temperature gradients and reservoir permeability have been recommended for the prospect. Estimated power potential in the prospect is over 200 MWe.

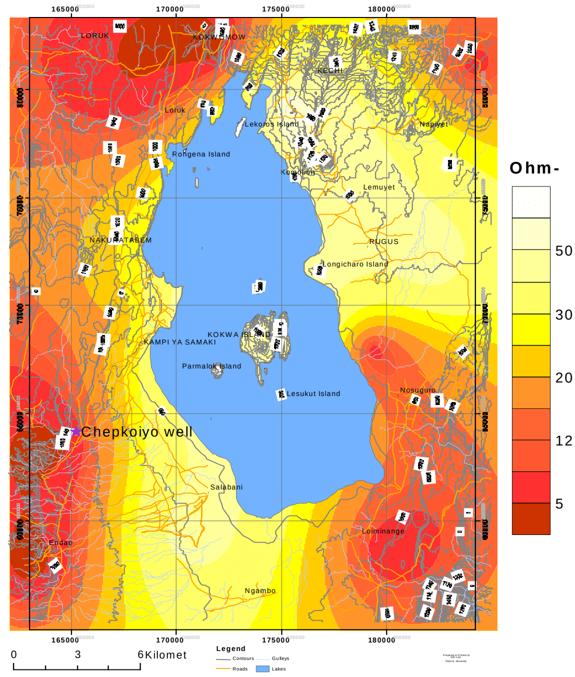

Figure 8: Resistivity at sea level at Lake Baringo prospect.

2.2.7 Korosi-Chepchuk

Exploration in Korosi-Chepchuk prospect was carried out in 2006. The geology of Korosi is mainly dominated by the intermediate lavas mainly trachytes and trachy-andesite (Figure 9), which cover the central and eastern sectors of the prospect area and basalts dominating the south, north and western sectors. The southwestern plain is, however, dominated by fluvial and alluvial deposits whereas the air-fall pumice deposits dominate the western plains.

Chepchuk volcanic complex consists of a sequence of flows of trachyte with inter-layering of basaltic lavas of various ages and pyroclastics. Surface geothermal manifestations in Korosi occur in form of hot grounds, steaming grounds and fumaroles. Hydrothermal alteration is associated with these areas. Most of the fumaroles are situated along the Nakaporon fault and temperatures range from 80-96^{o}C. The summit of Korosi has a number of scattered areas of geothermal activity, which are mainly associated with the NNE trending faults. These fumaroles and hot grounds recorded temperature range of 40-96^{o}C. Activities at Chepchuk consist of hot altered grounds and fumaroles and have temperatures of up to 96^{o}C. The manifestations mainly lie along the main fault trends with higher concentrations occurring along fault intersections. Silica sinters occur within the prospect indicating that the system associated with Chepchuk is long lived. The occurrences of silica sinters further indicates that there were hot springs in the area, which have since ceased flowing probably due to changes in the hydrological regime.

Results from the studies indicate existence of a geothermal resource in this prospect area possibly underneath both Korosi volcano with reservoir temperatures in excess of 300°C as deduced from gas geothermometry. Exploration studies indicate that the power potential for the prospect is over 450 MWe.

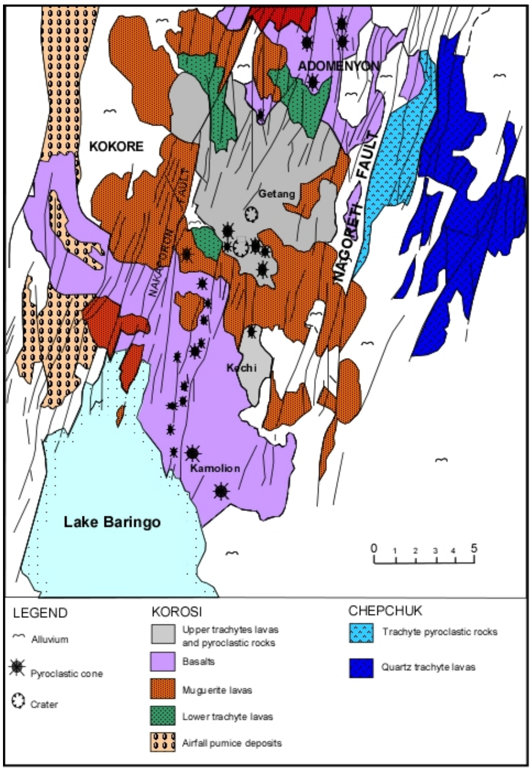

Figure 9: Geological map of Korosi-Chepchuk geothermal prospect area.

2.2.8 Paka

Detailed surface investigations to determine the geothermal potential of Paka was carried out in 2006-2007. Paka volcano is one of the localities in the Kenya Rift endowed with geothermal resource potential. Occurrence of a geothermal system at Paka is manifested by the widespread fumarolic activity, hot grounds and hydro thermally altered rocks. The Paka prospect is located atop a very young volcano that is marked by recent (~10 Ka) eruptions.

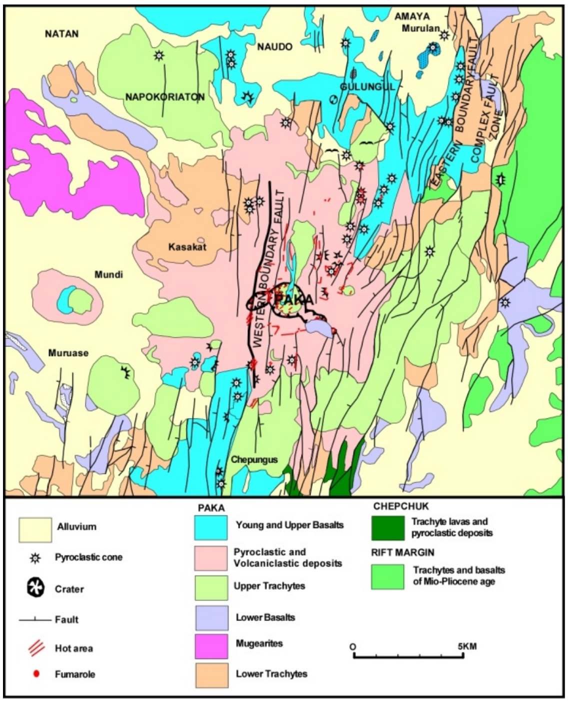

Figure 10: Geological and structural map of Paka volcano.

Paka volcano is made predominantly of trachytic volcanism with minor basaltic lavas erupted within the caldera and in the flanks along the NNE-SSW trending fissures. The magma chamber in Paka is still active as indicated by the eruptions of the young basalt lavas within the caldera and along fissures to the north of the volcano. Occurrences of a shallow magmatic body are evidenced by presence of abundant syenitic nodules within the pyroclastic deposits that were erupted during the formation of the caldera at Paka. The main heat source for the geothermal system at Paka is possibly a trachyte or trachyte-basaltic body underlying the volcano. This body has had re-injection from time to time of basaltic of material from depth.

Presence of well-crystallized sulphur deposits at fumaroles found at the Eastern crater indicates that the faults are deep seated and are source magmatic derivative. Ground water flow in the North Rift area around Paka is a combination of the lateral flows from the rift margin and the northerly axial flow along the inner trough of the rift floor. The recharge is laterally from the Escarpment to the east and range to the west and axially from Lake Baringo as indicted by the general northern groundwater flow along the rift floor.

Results from these surveys indicate that there exists a geothermal system at Paka prospect driven by a heat source at depth and centered below the summit crater extending to the east. A 4 km wide graben structure running NNE across the volcano massif acts as the main structure controlling the reservoir permeability at the subsurface. Reservoir temperatures of between 180-300°C have been estimated based upon chemical geothermometry. Deep exploratory wells to confirm the geothermal reservoir have been sited. Estimated potential of the prospect is >500 MWe.

Figure 11: Kapedo hot springs discharging 1000 l/s of hot water at 55°C.

2.2.9 Silali

Silali is the largest caldera volcano in the axis of the northern Kenya Rift and is ranked highly among the prospects to be developed. This is because from the available regional reconnaissance survey data available, the volcano is very promising. The young activity associated with the volcano indicates that the magmatic body under the volcano could still be hot and able to sustain a geothermal system. Geothermometry temperatures indicate subsurface temperatures between 238-325ºC. The Kapedo hot springs base of the western slopes of the volcano discharge at hot water at 45-55°C (Figure 11) with a combined estimated flow rate of about 1,000 l/s, which translates to 100 MWt. The shield building episode was dominated was dominated by eruptions of trachytes and relatively minor tuffs hawaiite, and trachy-andesite. Minor faulting, quiescence and further eruption of pyroclastics and fissure basalts followed. The caldera collapse was formed by magma withdrawal accompanied by dike injection at depth. Trachytes, basalts and minor pyroclastics express the post caldera events. The latest activity is basaltic was erupted about 200-300 years BP. The hydrogeological flow is a combination of northerly axial flow along the rift and lateral flow from the eastern and western rift flanks. Detailed geoscientific studies will be carried out in 2009-2010, and exploration drilling is to be carried out in 2010-2011. The estimated potential of the prospect is >800 MWe.

2.2.10 Emuruangogolak, Namarunu, Barrier, Lake Magadi, Akira and Elmenteita

Reconnaissance studies have been carried out in Emuruangogolak, Namarunu, Barrier, Lake Magadi, Akira and Elmenteita and geothermometry temperatures in the prospects indicate promising temperatures of over 200°C. Further detailed surface studies are required to determine the potential of these prospects.

3. CONCLUSIONS

- The estimated power potential of the Kenya rift from recent studies has been put at over 7000 MWe and is capable of meeting all the country's power needs in the next 20 years.
- The Government through GDC has embarked on an ambitious generation expansion plan to install additional 1500 MW and 4000 MWe of electric power by the year 2020 and 2030 respectively.
- Direct use application is being encouraged to make use of the low enthalpy fluids in swimming, bathing, balneology, agriculture and in residential and industrial sectors.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (Wind and cogenaration)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2009	167	1430	497	3412	749	3543	0	0	36.0	247	1449	8632
Under construction in December 2009	228		531		83	523	0	0	340		1182	
Funds committed, but not yet under construction in December 2009	140		600		60		0	0	0		800	
Total projected use by 2015	813		1628		952		0	0	496		3888.6	

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2009

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash   B = Binary (Rankine Cycle)
2F = Double Flash   H = Hybrid (explain)
3F = Triple Flash   O = Other (please specify)
D = Dry Steam

3) Data for 2009 if available, otherwise for 2008. Please specify which.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1]	Type of Unit[2]	Total Installed Capacity MWe	Annual Energy Produced 2009[3] GWh/yr	Total under Constr. or Planned MWe
Olkaria	Olkaria I	1981, 198[illegible]	3		1F	45		140
	Olkaria II	2003	2		1F	70		35
	Olkaria III	2000, 200[illegible]	2		B	48		50
	Oserian	2004, 200[illegible]	2		B	4		0
	Olkaria IV				1F			140
Eburru	Eburru Pilot				B			2.5
Total						167		367.5

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2009 (other than heat pumps)

[1] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

[2] Enthalpy information is given only if there is steam or two-phase flow

[3] Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[4] Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

[5] Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (^{o}C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Olkaria	G	13					16			
TOTAL		13					16			

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2009

[1)] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)]

[2)] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 1
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3)] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW =
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1)] (MWt)	Annual Energy Use[2)] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3)]
Individual Space Heating[4)]			
District Heating [4)]			
Air Conditioning (Cooling)			
Greenhouse Heating	16	126.624	4.015247
Fish Farming			
Animal Farming			
Agricultural Drying[5)]			
Industrial Process Heat[6)]			
Snow Melting			
Bathing and Swimming[7)]			
Other Uses (specify)			
Subtotal	16	126.624	4.015247
Geothermal Heat Pumps			
TOTAL	16	126.624	4.015247

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2005 TO DECEMBER 31, 2009 (excluding heat pump wells)

Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperatu	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploratior	(all)					
Production	>150^{o}C	21	_	_		63
	150-100^o C					
	<100^o C					
Injection	(all)					
Total		21	_	_		63

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Progra
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	2	37		0		9
2006	2	37		0		9
2007	2	40		0		9
2008	2	57		5		12
2009	2	67		5		12
Total	10	238		10		51

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	8.8	5	0	13.8	0	100
2000-2004	0.125	20	8	194	13	87
2005-2009	0.5	130	5	210	50	50