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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 potential along the world famous East African Rift valley that transects the country from north to south. Exploration reveals that geothermal potential exceeds 4,000 MWe and is capable of meeting all of Kenya's electricity needs over the next 20 years. Out of this potential, only 130 MW_e is currently generated at the Greater Olkaria geothermal field. The Kenya Electricity Generating Company (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 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 are 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, KenGen has embarked on an ambitious generation expansion plan to install additional 1,260 MW of electric power by 2018 from geothermal sources. The planned geothermal developments require over 300 production and 60 re-injection wells to be drilled in the next ten (10) years and about 10 large power stations of about 140 MW_e each to be built at a total cost of over US$ 5 billion inclusive of wells and steam gathering systems.

1. INTRODUCTION

Kenya Electricity Generating Company Limited (KenGen) is a public company under the Ministry of Energy of Kenya and is listed in the Nairobi Stock Exchange. The Government owns 70% of the Company while the public owns the remaining 30%. The Company currently has an installed electric plant capacity of 1005 MWe, which comprises a mix of hydro, geothermal, thermal, wind and gas turbines and diesel power generators. KenGen currently produces about 80% of the total interconnected power supply in Kenya.

Kenya has a demand growth of 8%. The growth is driven by, increased consumption from existing customers amounting to 5% and new customers that account for 3%. However, installed capacity 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 are, thus, recommended for additional expansion.

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 on average 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 Holocene. Most of the volcanic centres have had one or more explosive phases including caldera collapses. The centres 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.

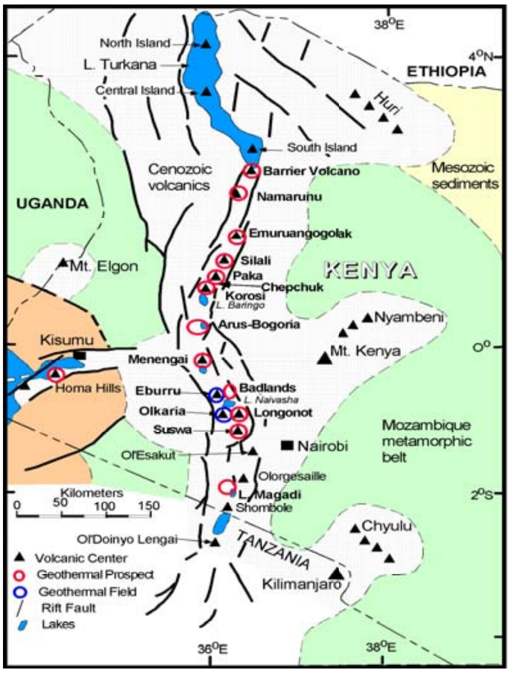

FIGURE 1: Simplified geological map of Kenya showing locations of the geothermal fields and prospects

1.2 Status and history of 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 at Olkaria 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 MWe generating unit was commissioned. The second 15 MWe unit was commissioned in November 1982 and the third unit in March 1985 which increased the total generation to 45 MWe. This was the first geothermal power station in Africa and is owned and operated by KenGen. In 2003, KenGen commissioned a 2 x 35 MWe Olkaria II power plant in the Northeast field. An IPP is generating 12 MWe from a pilot plant at Olkaria West (Olkaria III) and has plans to increase the capacity to 36 MWe by 2009. British Geological Survey, Geotermica Italiana Srl, KenGen and the Government of Kenya (MoE) have continued to carry out detailed studies for geothermal energy in the Kenya rift and the potential has been estimated at over 4,000 MWe.

2. COUNTRY UPDATE AND PIPELINE PROJECTS

2.1 Greater Olkaria geothermal field

Currently in Kenya, geothermal energy is only being utilised in the Greater Olkaria field. Three of the seven Olkaria sectors, namely Olkaria East field, Olkaria West field and Olkaria Northeast field (Figure 2) are generating a total of 130 MWe. The resource is being utilized mainly for electric power generation (130 MWe) but also for direct use (1.3 MWt). The proven geothermal resource at the Greater Olkaria geothermal field is more than 400 MWe and plans have been put in place to develop the resource faster.

2.1.1 Olkaria I power plant

The Olkaria I power plant (Figure 2) is owned by KenGen and 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 supplies steam to the Olkaria I power plant has thirty three (33) wells drilled. Thirty one (31) of them have been connected to the steam gathering system, and 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. Some of these are earmarked to serve as reinjection wells and/or for deepening.

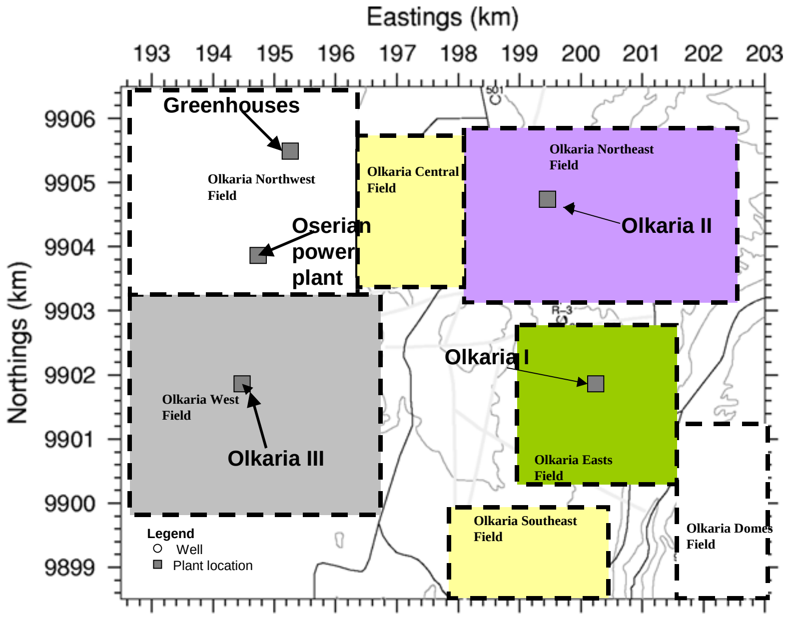

FIGURE 2: The Greater Olkaria geothermal fields and locations of the power plants and greenhouses

2.1.2 Olkaria II Power Plant

Construction of the 2 x 35 MWe Olkaria II geothermal power station started in September 2000, and it 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.

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, three (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, six appraisal wells have been drilled; 5 of which are directional and 1 vertical. The capacities of the wells range from 4-8 MWe. Production drilling of 15 wells has commenced using 2 hired rigs from GWDC. A 140 MWe power plant will be constructed in Olkaria Domes and is anticipated to be commissioned in the year 2012.

2.1.4 Olkaria III power plant

The 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). The first phase of the project included drilling of appraisal wells and construction of a 12 MWe pilot plant. The first 8 MWe were put in commercial operation in 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 in the range 1850-2750 m) and adequate steam was proved for a total development of 36 MWe over the PPA period of 20 years. The power plant is expected to be commissioned in 2008/9.

2.1.5 Oserian plant

Oserian Development Company Ltd (ODLC) constructed a 2.0 MWe binary plant and a smaller 1.4 MWe back pressure turbine in Olkaria Central to utilise fluids from wells OW-306 and OW-202, respectively, leased from KenGen. The plants provide electrical power for the farm's operations and were commissioned in 2004 and 2007, respectively. ODLC who grows cut flowers for export is also utilizing steam to heat fresh water through heat exchangers, to enrich CO_2 levels and to fumigate the soils utilizing H_2S. The heated fresh water is circulated through the greenhouses. The use of geothermal energy for heating the greenhouses has resulted in drastic reduction in operating costs.

2.2 Geothermal fields outside Olkaria

Geothermal resource inventory of fields to the south and north of Olkaria has been carried out, amongst all these prospects, Eburru is the only field where exploration wells have been drilled. The other fields are at various exploration stages ranging from reconnaissance studies to advanced surface exploration with wells sited. The fields' status and estimated potential are described below starting from Suswa in the south to the Barrier Volcano in 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.

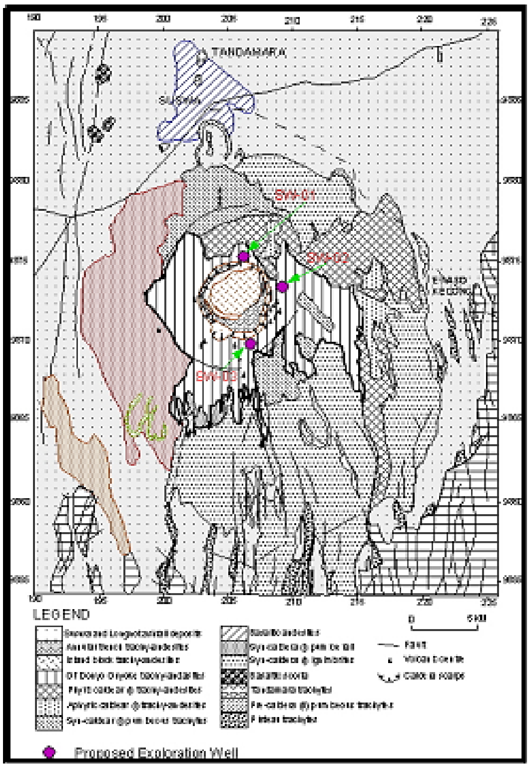

FIGURE 3: Simplified geological map of Suswa volcano (Omenda, 1997)

Results from detailed surface studies done by KenGen in 1993 and 1994 suggest reservoir temperatures of 220-300°C, which is comparable to that at Olkaria. High amount of CO_2 in the fumaroles sampled indicates high-fracture density. Low amount of H_2S in the sampled steam suggests influence of steam condensate and shallow ground water on the fumaroles. Relatively high pH of the condensate supports the mixing hypothesis (Muna, 1994). Seismic and gravity studies show that the heat source under the caldera is at 8-12 km deep. Resistivity at 1000 m a.s.l. indicates a low (15-20 ohm-m) anomaly under the island block which extends to the north out of the inner caldera. This resistivity value is high compared to Olkaria and even Longonot where values below 10-15 ohm-m were obtained.

Proximity of the resource to the rift flanks suggests good recharge but the lack of hot springs indicate a deep water table. Three exploration wells were sited within the anomalous region (KenGen, 1999). The power potential of the prospect is about 200-400 MWe (Omenda et al., 2000). Exploration wells are expected to be drilled from year 2009.

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).

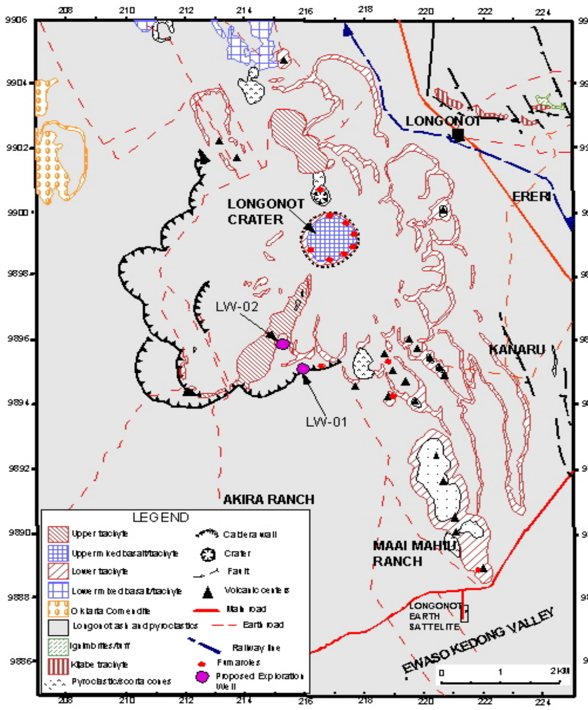

FIGURE 4: Geological map of Longonot volcano (Lagat, 1998)

Detailed surface exploration work in Longonot was carried out in 1998, with some follow-up MT studies in 2005. Magmatism directly associated with the development of the volcano started about 0.4 million years ago and involved eruption of trachytes and their pyroclastic equivalent. These activities were succeeded by a 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 caldera. 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 being expected, suggest 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 (Onacha, 1990) that culminated in the drilling of six exploration wells in Eburru between 1989 and 1991. The results from the exploration wells indicate that the field had experienced temperatures of over 300°C possibly due to a localized intrusive.

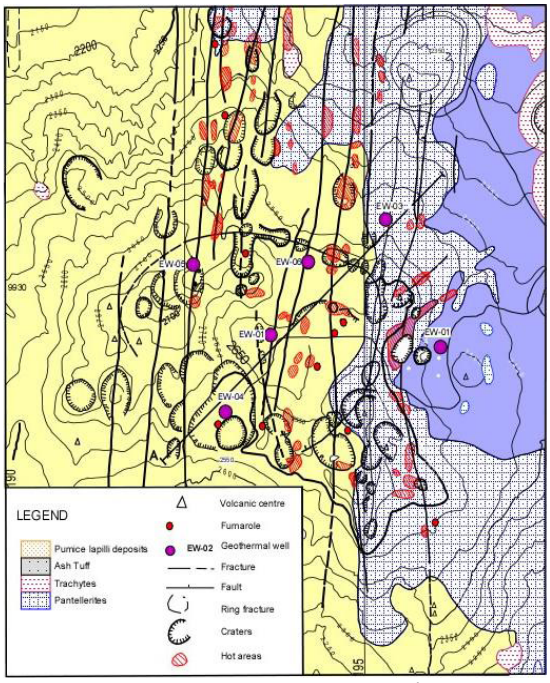

FIGURE 5: Geological map of Eburru geothermal field (Omenda and Karingithi, 1993)

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 (956-1976 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 more than 50 MWe (Wameyo, 2006; Mburu, 2006; Omenda et al., 2000) and conceptualized as in Figure 5. The area has a fairly well established infrastructure and for this reason a 2.5 MWe binary pilot plant is planned and construction will start in 2009.

2.2.4 Menengai

Menengai is a major Quaternary caldera volcano located within the axis of the central segment and is one of the high-potential prospects in the Kenya Rift. Detailed surface exploration was carried out in 2004. 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. MT resistivity distribution at 2000 m b.s.l. shows a conductive body of less than 5 ohm-m centred in the western caldera floor and a smaller anomaly at the centre of the caldera (Figure 6). Fumaroles are scarce in the prospect with the few strong ones occurring within the caldera floor. Fumarole steam has low contents of CO_2, H_2S, H_2, CH_4, and N_2. Gas geothermometry based on

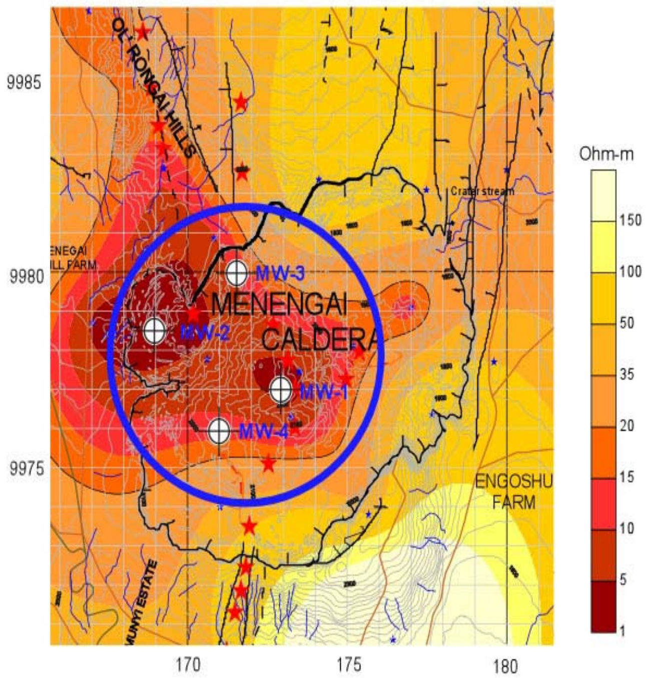

FIGURE 6: MT resistivity at 2 km m b.s.l., the anomalous area and proposed well sites

H_2S and CO_2 indicates that the reservoir temperatures are greater than 250ºC (Mungania, et al., 2004, Ofwona, 2004a). The mapped potential area in Menengai is about 48 km^2 translating to over >720 MWe of electric power. KenGen plans to undertake drilling of three exploratory in the prospect from 2009.

2.2.5 Lake Baringo

Lake Baringo geothermal prospect is in the northern part of the Kenya 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 indicates occurrence of trachyte and trachy-phonolites, basalts and alluvial and fluvial deposits in the lower parts.

Resistivity at sea level indicates occurrence of fault controlled, discrete possible resource areas in the west of the Lake. Fluid geothermometry indicate reservoir temperature of over 200^{o}C 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, 2004b). 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 are 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.

2.2.6 Arus and Lake Bogoria

Arus and Lake Bogoria is an area with no observable central volcano. Geothermal manifestations are mainly hot springs, hot grounds, fumaroles and steam jets that occur along the shore of Lake Bogoria and at Arus. One of the hot springs is used for heating at a near by hotel. Preliminary results suggest that the heat source is associated with intrusives. 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 (Mwawongo, 2005). Figure 7 shows the spouting hot spring at the edge of Lake Bogoria. Geothermometry estimates reservoir temperatures of about 248ºC (Karingithi, 2005). These are ideal for direct uses and binary cycle electricity generation technologies.

FIGURE 7: Hot spring at the western edge of Lake Bogoria

2.2.7 Korosi-Chepchuk

Exploration in Korosi-Chepchuk prospect was carried out in 2006. The geology of Korosi is dominated by intermediate lavas, mainly trachytes and trachy-andesite (Figure 8), 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. Most of the fumaroles are situated along the Nakaporon fault and the summit of Korosi. Temperatures range from 80 to 96°C. Activities at Chepchuk consist of hot altered grounds and fumaroles and have temperatures of up to 96°C. The manifestations mainly lie along the main fault trends with higher concentrations occurring along fault intersections.

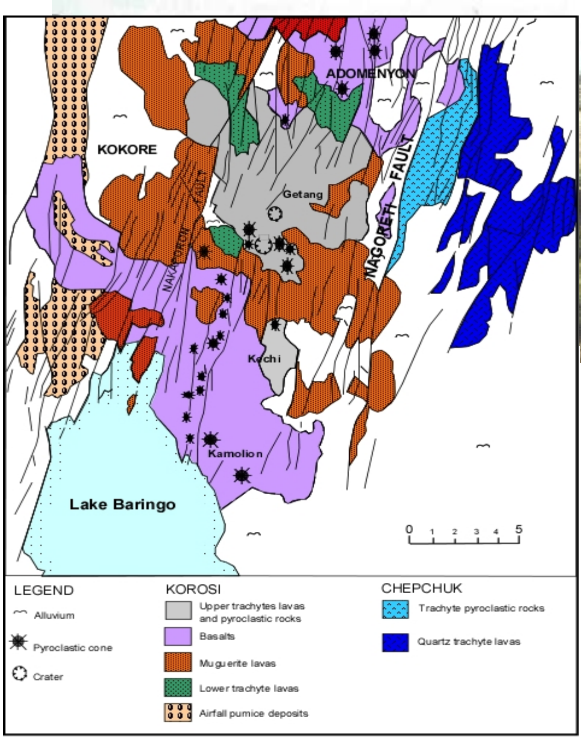

FIGURE 8: Geological map of Korosi-Chepchuk geothermal prospect area

Results from the studies indicate existence of a geothermal resource in this prospect possibly underneath Korosi volcano with reservoir temperatures in excess of 300°C as deduced from gas geothermometry. The estimated potential of the prospect is over 200 MWe.

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 (Figure 9). Occurrence of a geothermal system at Paka is manifested by the widespread fumarolic activity, hot grounds, sulphur deposits and hydrothermally altered rocks.

FIGURE 9: Aerial view of the trachytic pumicous cones on the upper northeastern flanks of Paka

Results from these surveys indicate that there exists a geothermal system at Paka prospect driven by a heat source at depth and centred below the summit crater and extending to the east. A 4 km wide graben structure running north-northeast 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. Estimated potential of the prospect is greater 200 MWe.

2.2.9 Silali

Silali is the largest caldera volcano on the axis of the northern Kenya Rift. Geothermometry temperatures from the reconnaissance survey carried out by Dunkley et al. (1992), indicate subsurface

FIGURE 10: Kapedo hot springs discharging 1000 l/s of hot water at 55°C

temperatures between 238 and 325ºC. The Kapedo hot springs at the base of the western slopes of the volcano discharge hot water at 45-55°C (Figure 10) with a combined estimated flow rate of about 1,000 l/s, which translates to 100 MWt. Detailed geoscientific studies will be carried out in 2009-2010. The estimated potential of the prospect is more than 800 MWe.

2.2.9 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. CURRENT AND FUTURE DEVELOPMENT PLANS

The initial design of Olkaria I power plant and steam field had proposed a life of 25 years. Units I, II and II have been in operation for 27, 25 and 23 years respectively and therefore Units I and II have exhausted their initial design life while Unit III still has 2 years to go. Currently, the steam available from this field is more than what is required to generate 45 MWe and plans are underway to refurbish Olkaria I by retiring the old Olkaria I power plant and replacing it with a 70 MWe new Olkaria I power plant. The power plant will be commissioned in year 2014. Olkaria I utilizes 9.2 t/hr of steam per MWe as opposed to the 7.2 t/hr of steam per MWe for Olkaria II. Since the two turbines installed at Olkaria II plant are more efficient, there is excess steam at Olkaria NE 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 will be commissioned in 2010. In Olkaria west, the construction of a 36 MWe Olkaria III power plant by Orpower 4 has commenced. The plant is to be commissioned in 2009/2010.

Drilling of 6 appraisal wells in Olkaria Domes has been completed and drilling of 15 production wells has commenced using two hired rigs from GWDC. The tender documents for the construction of the steam gathering system and the power plants is being prepared and will be floated later next year alongside the new Olkaria I power plant. A 140 MWe plant (two 70 MWe) will be constructed in Olkaria Domes and is to be commissioned in the year 2012. In Eburru, the tender for the construction of a 2.5 MWe binary pilot plant was floated and is currently being analysed. Construction of the power plant will commence later in the year and the station is to be commissioned in the year 2010.

In an effort to transform itself from a good to a great company (G2G), KenGen has embarked on an ambitious generation expansion plan to install additional 1,260 MW of electric power by 2018 from geothermal sources. In order to accelerate geothermal development, KenGen intends to acquire 4 new rigs, 2 to be delivered in July 2009 and the other 2 to be delivered in December 2009. All the 4 rigs will be dedicated to drilling in the Menengai geothermal prospect where the potential has been estimated at over 720 MWe. The contract to drill shallow groundwater boreholes to be used during drilling of the geothermal wells has been awarded and the contractor will commence the work soon. Drilling of exploration wells will commence in September 2009 then followed by appraisal and production wells. Menengai I power plant of 140 MWe is expected to be commissioned in March 2013, followed by Menengai II power plant of 140 MWe in September 2014, Menengai III power plant of 140 MWe in December 2015, Menengai IV power plant of 140 MWe in April 2016 and Menengai V power plant of 140 MWe in May 2017.

The development of the Menengai prospect will be closely followed by the Longonot prospect where the capacity has been estimated at 700 MWe. Drilling in Longonot will commence in December 2014, utilizing 6 rigs at the same time. Two power plants of 140 MWe each (Longonot I and II) shall be commissioned in March 2018 and March 2019, respectively. The development of Suswa caldera volcano will depend on the commitment of an IPP which has been given the license to develop the prospect. If KenGen will become the developer, then drilling of geothermal wells in Suswa shall commence in December 2016, and as in Longonot utilizing 6 rigs at the same time. Two power plants of 140 MWe each (Suswa I and Suswa II) shall be commissioned in December 2019 and December 2020, respectively. The prospects to the north of Menengai will either be developed by private investors or as joint ventures and might come on-line sooner or later than those outlined by the above development programme.

These scheduled ambitious geothermal developments require over 300 production wells and 60 re-injection wells to be drilled in the next ten (10) years, and about 10 large power stations of about 140 MWe each to be built at a total cost of over US$ 5 billion, including wells and steam gathering systems.

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