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COUNTRY UPDATE REPORT FOR KENYA 2016

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ABSTRACT

Geothermal resources in Kenya have been under development since 1950's and the current installed capacity stands at 676.8 MWe against total potential of about 10,000 MWe. All the high temperature prospects are located within the Kenya rift valley where they are closely associated with Quaternary volcanoes. Olkaria geothermal field is so far the largest producing site with current installed capacity of 674.4 MWe from five power plants and wellheads owned by Kenya Electricity Generating Company (KenGen) (533.5MWe), Oserian (4.3 MWe) and Orpower4 (139 MWe). 12 MWt is being utilized to heat greenhouses and fumigate soils at the Oserian flower farm and Olkaria geothermal spa. Power generation at the Eburru geothermal field stands at 2.4 MWe from a pilot plant. Development of geothermal resources in Kenya has been fast tracked with 335 MWe commissioned in 2014-2016 from conventional power plants and well head units. Production drilling at the Olkaria geothermal project for the additional 560 MWe power plants to be developed under PPP arrangement between KenGen and private sector is ongoing. The Geothermal Development Company (GDC) is currently undertaking production drilling at the Menengai geothermal field for 105 MWe power developments to be commissioned in 2018. Detailed exploration has been undertaken in Suswa, Longonot, Baringo, Korosi, Paka and Silali geothermal prospects and exploration drilling is expected to commence in year 2017 in Baringo – Silali geothermal area.

1. INTRODUCTION

Commercial energy in Kenya is dominated by petroleum and electricity while wood fuel provides energy needs for the traditional sector including rural communities and the urban poor. At the national level, wood fuel and other biomass account for about 68% of the total primary energy consumption, followed by petroleum at 22%, electricity at 9% (121 KWh per capita) while others including coal accounts for less than 1%. Solar energy is also extensively used for drying and, to some extent, for heating and lighting. Current installed electric capacity in Kenya is dominated by hydro sources which has installed capacity of 820 MWe while fossil fuel fired plants had 776 MW. Geothermal accounted for 672.5 MWe of installed interconnected while wind has capacity of 69.5 MW from wind (Table 1).

All the high temperature geothermal occurrences in Kenya are mainly associated with Quaternary volcanoes in the axis of the main rift valley (Mwangi, 2005; Omenda et al. 2000). The heat sources for most of the systems are due to shallow magma bodies under the volcanoes estimated. There are 14 large Quaternary volcanoes in Kenya and together with other prospective sites provides an estimate of possible generation of 10,000 MWe. The Government of Kenya has therefore set up an ambitious expansion plan that will provide additional generation of about 1,646 MWe from geothermal resources by 2018. Total generation from geothermal sources is planned to exceed 5,000 MWe by year 2030.

2. GEOLOGICAL BACKGROUND

The East African rift system is part of the Afro Arabian rift system that extends from the Red Sea to Mozambique in the south. As the rift extends from the Ethiopian segment southwards it bifurcates at about 5°N into the eastern and western branches. The two branches of the rift skirts around the

Tanzania craton and formed within the Late Proterozoic belts adjacent to the margins of the craton (Mosley, 1993; Smith and Mosley, 1993). The eastern branch that comprises the main Ethiopian rift and Kenya rifts is older and relatively more volcanically active than the western branch that comprises Albert–Tanganyika-Malawi rifts (Figure 1).

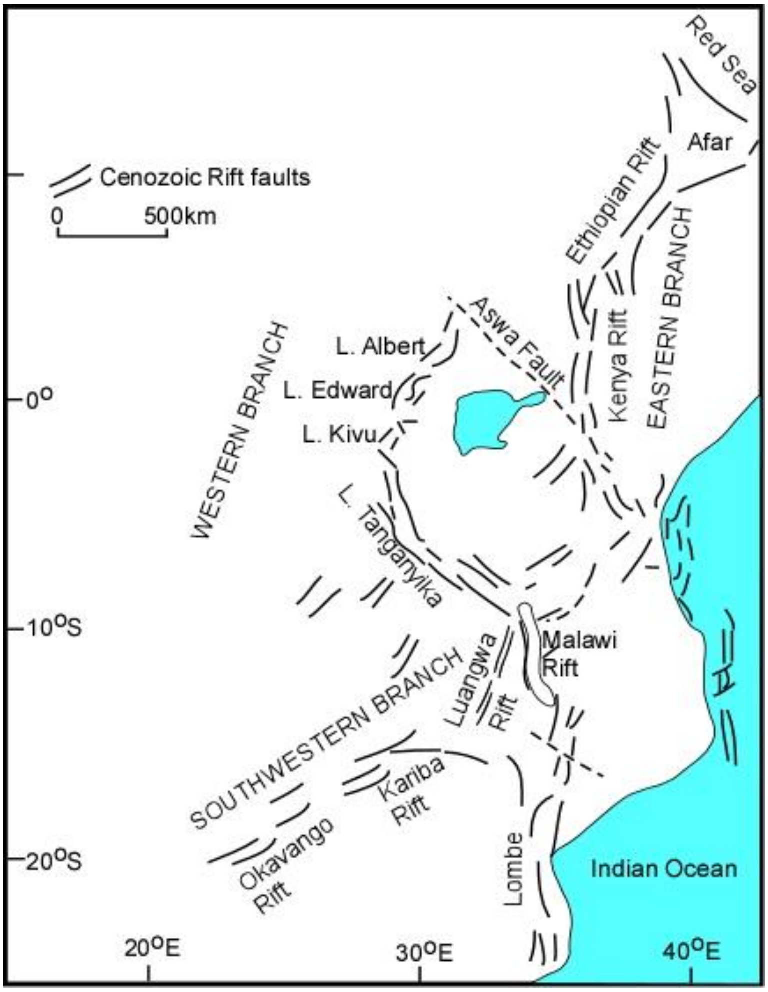

Figure 1: Structural map showing the East African Rift System

The development of the Kenya followed the standard model for active rift formation that involved lithospheric extension accompanied by upwelling of the underlying asthenosphere and collapse. Decompression of the asthenosphere resulted in large volumes of magma generation and development of volcanoes on the crest of uplift. Some of the volcanoes developed shallow magma chambers of intermediate to silicic composition which are the most important geothermal resources. Further brittle extension of the crust resulted in down-faulting and formation of the graben. In the case of the EARS, extensions is more active in the north being more than 3-4 cm/year in the Red Sea – Gulf of Aden, 2-3 mm/year in the Main Ethiopian Rift, and less than 2 mm/year in the Kenya Rift and southwards. In response to the increased extension in the EARS, the Moho is at between 0-5 km at Afar to 35 km along the axis of the rift in Kenya.

In the rift axis of the eastern branch occurs numerous central volcanoes of Quaternary age overlying products of Miocene and Pliocene volcanism. The shield volcanoes are built largely of intermediate lavas and the associated pyroclastics, thus indicating the presence of shallow hot bodies (magma chambers). In the Western Branch, there is paucity of volcanism along the entire length of the rift with the main volcanic areas being Virunga and Rungwe. The geothermal activity in the East African rift occurs in the form of hot springs, fumaroles, hot and altered grounds, and is closely associated with

Quaternary volcanoes in the axis of the rifts (Figure 2). The association is related to the shallow hot magma bodies under the massifs, which are the heat sources. In the Afar, Ethiopian and Kenya rifts where the crust has been thinned due to extension, high heat flux is contributed by shallow mantle. In the less magmatic western branch of the rift, heat sources are a combination of buried intrusions and high heat flux associated with relatively thinned crust.

The rifting activity in Kenya rift began about 30 million years ago with uplift in the Lake Turkana area and then migrated southward being more intense about 14 million years ago. Formation of the graben structure in Kenya 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 due to extension (Dunkley et al. 1993). 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.

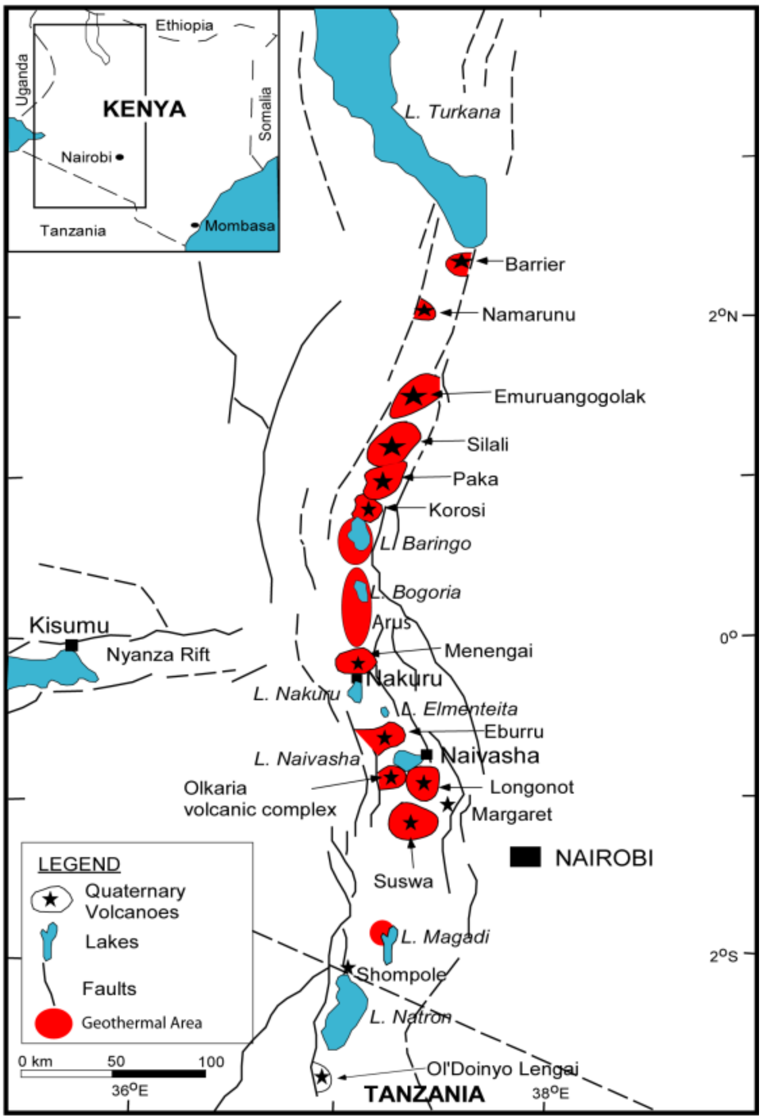

Figure 2: Simplified geological map of Kenya showing locations of the geothermal fields and prospects.

3. GEOTHERMAL RESOURCES IN KENYA

Exploration for geothermal energy in Kenya started in the 1950's with surface exploration that culminated in geothermal wells being drilled at Olkaria, Eburru and Menengai geothermal fields. The Greater Olkaria geothermal field has over 300 wells drilled producing 674.4 MWe while six wells have been drilled in Eburru and more than 30 wells at Menengai. Geothermal development is currently being fast-tracked in Kenya with drilling ongoing in Menengai Olkaria geothermal fields.

3.1 Olkaria Geothermal field

The Olkaria volcanic complex lies on the axis of the rift but with a bias towards the Mau escarpment. The rock outcrops is dominated by rhyolite flows and pyroclastics of which the youngest is the Ololbutot rhyolite obsidian flow that erupted at 180 ± 50 yr BP (Clarke et al., 1990). The landscape is also dotted with volcanic centres (Figure 1). Fault systems at Olkaria are dominantly in three directions: NW-SE, N-S and NE-SW (Figure 3). The latter two are younger and have affected even the Holocene flows while the NW trending faults are older and often associated with the rift graben formation. They are more common in the west where the field merges into the Pliocene Mau escarpment. In the sub surface, the volcanic complex has been divided into the east and west with the divide being the fault zone that runs through Olkaria Hill (Omenda, 1994, 1998). The lithology in the western sector is dominated by the Mau Tuffs but minor trachytes, rhyolite and basalt occur within the formation. The Greater Olkaria geothermal field has been divided into seven fields for ease of development and management, namely, East, West, North-West, North-East, Central, South-East, and Domes (Figure 4). The field has capacity to generate more than 1,500 MWe and direct utilization of hundreds of MW_t.

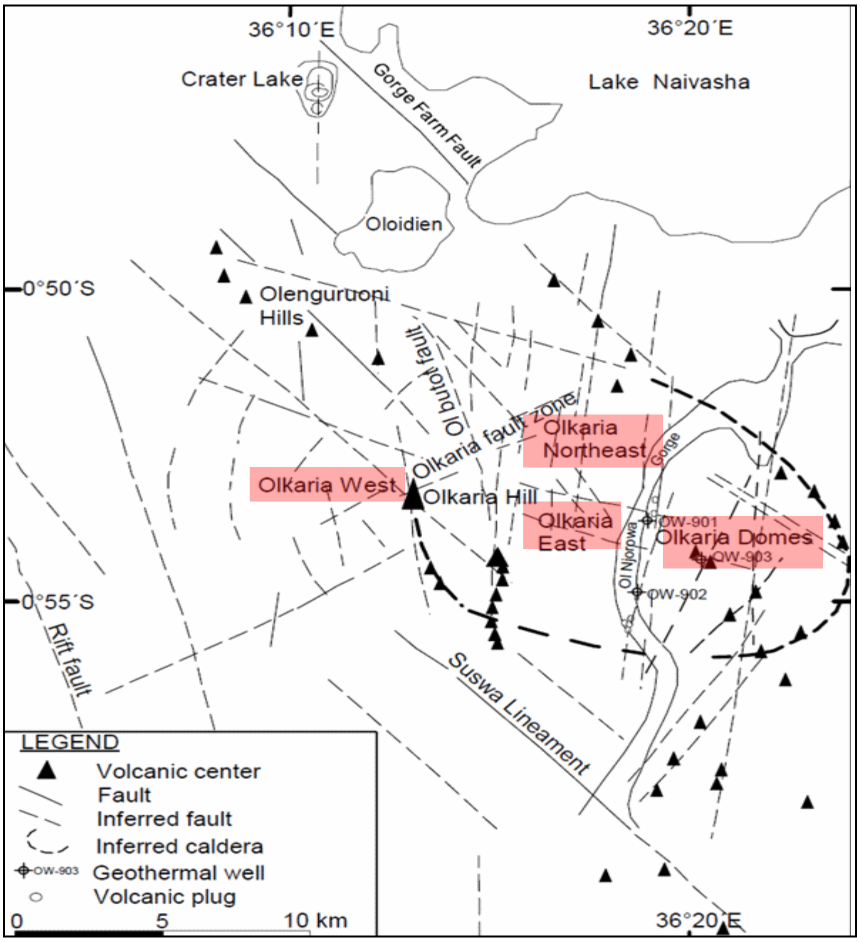

Figure 3. Structural map of Olkaria Geothermal field

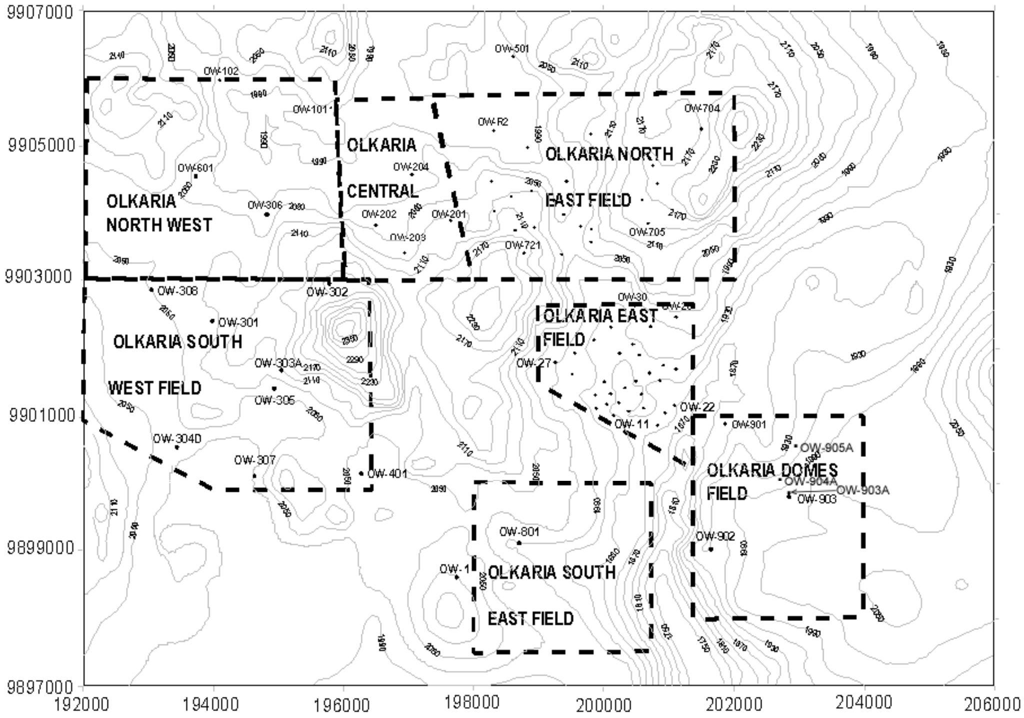

Figure 4: Map of the Greater Olkaria geothermal area showing the locations of the fields.

3.1.1 Olkaria I

The Olkaria I field is located in the eastern sector of Olkaria field (Figure 4). The field is the home to Olkaria I power plant owned by Kenya Electricity Generating Company Ltd (KenGen) has three turbo generators each generating 15 MWe. The three units were commissioned in 1981, 1983 and 1985, respectively. The field was been expanded in 2014 by 150 MWe in two units. In addition 38.3 MWe wellhead generators have been installed and commissioned. Increase of steam in the field was due to drilling of deeper directional wells of 3,000m than the earlier wells that were drilled to between 900 m and 2200 m. KenGen is currently considering to refurbish Olkaria 1 power plant to give it more operational life.

Plans are at an advanced stage to construct wellhead units with a total installed capacity of 85 MW within the Olkaria I Geothermal field.

3.1.2 Olkaria II field

Olkaria II is located in Olkaria north-east field (Figure 4). The 2 x 35 MWe Olkaria II power plant was commissioned in 2003 while the third 35MWe unit was commissioned in 2010. The current total installed capacity at Olkaria II is 105MWe. Production drilling is ongoing in the field with intention of increasing the capacity of the field by 140 MW.

3.1.2 Olkaria IV field

Also known as Olkaria Domes field, surface exploration was carried out in 1993 and three exploration wells drilled in 1999. Appraisal drilling was undertaken in 2006 and 2007 and paved way for production drilling that has continued to date. 2x75 MWe Olkaria IV power plant was completed and commissioned in December 2014. 42.8 MWe wellhead units have been installed in Olkaria IV field. The eastern sector of the field production drilling has been completed and will host 140 MWe for Olkaria V power plant.

3.1.3 Olkaria Central field

Olkaria Central field is located between Olkaria West and NE fields (Figure 4). All the wells drilled in the field have relatively lower outputs resulting from lower reservoir temperatures and lower permeability. Oserian Development Company (ODC) constructed two plants with installed capacity of 2.5 and 1.8 MWe plants of ORC and back pressure technologies, respectively. The plants are located in Olkaria Central field and use steam from wells OW-306 and OW-202 leased from KenGen. The plants which were commissioned in 2004 and 2006 provide electricity requirements for private use. ODC who grows cut flower for export also utilizes geothermal heat for greenhouse farming. The steam for direct use comes from well OW-101 which is a 1.28 MWe also leased from KenGen. Plate heat exchangers are used to heat fresh water which is then used to heat the greenhouses and sterilize soils. Separated CO_2 is used to enrich the levels in the green house. The use of geothermal heat has resulted in drastic reduction in operating costs in the flower farm.

3.1.4 Olkaria III field

Olkaria III field is located in the Olkaria west field (Figure 4). The field hosts the Olkaria III power plant is owned and operated by Orpower 4, a subsidiary of Ormat International. It was the first and so far the only operational private geothermal power plant in Kenya. The project was developed in phases that started with an 8 MWe plant that was commissioned in 2000. Since then the power plant has been expanded to the current installed capacity of 139 MWe, operating on Organic Rankine Cycle (ORC) binary plants turbines. Orpower4 is planning to further expand the field by 12MWe in 2017/2018.

3.2 Eburru Geothermal Field

Eburru geothermal field is located to the north of Olkaria at the foot of the Mau escarpment (Figure 5). Detailed surface studies were concluded in 1990 and culminated in the drilling of six exploration wells between 1989 and 1991 (Figure 8). One of the six exploration wells encountered high temperature geothermal system at $>250^{\circ}C$ (Omenda and Karingithi, 1993; Onacha, 1990). A 2.4 MWe condensing pilot plant was constructed and commissioned in 2012. MT/TEM surveys were done in 2006 and revealed that the Eburru field is capable of supporting up to 60 MWe within an area of 12 km^2.

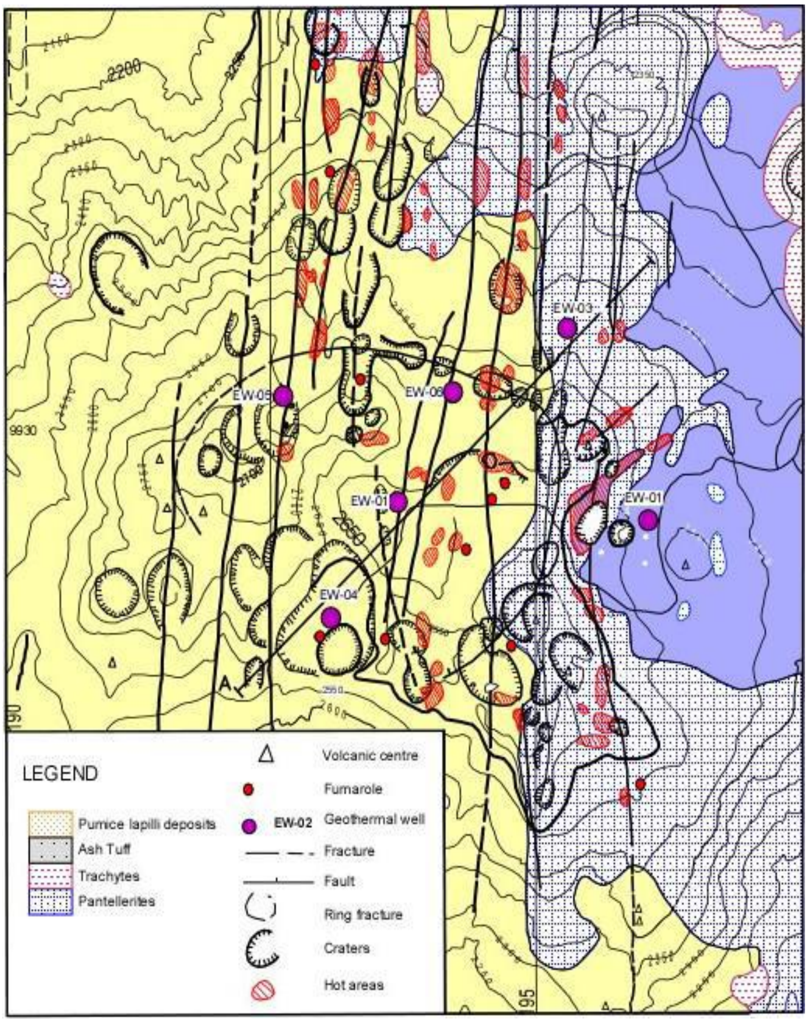

Figure 5: Map of Eburru geothermal field

3.3 Menengai geothermal field

Menengai is a Quaternary caldera volcano located within the axis of the central segment of the Kenya Rift. The volcano has been active since about 0.8 Ma to present. The volcano is built of Trachyte lavas and associated intermediate pyroclastics. Resurgent post caldera activity (<0.1 Ma) occurred on the caldera floor with eruption of thick piles of trachyte lavas from various centres. MT resistivity distribution at 2000 m b.s.l shows a conductive body of less than 5 ohm-m under the caldera floor with westward extension (Figure 6). Seismology indicates seismic wave attenuation at <6 km depth underneath Menengai caldera suggesting occurrence of shallow magma bodies which would be the heat sources for the geothermal system. Simiyu (2003) predicted that the Vp/Vs ratios of 1.6-1.7 at Menengai suggest/ occurrence of steam-dominated reservoir. Gas geothermometry based on H_2S and CO_2 indicates that the reservoir temperatures are greater than 250°C (Mungania et al., 2004).

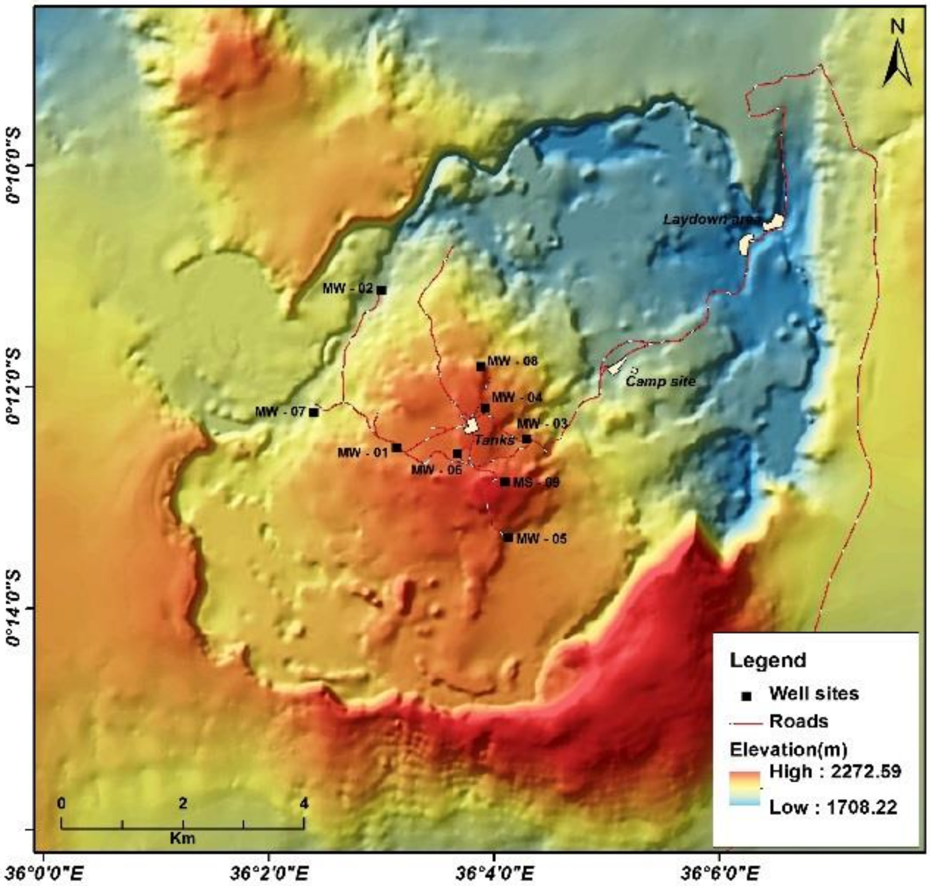

Figure 6: DEM image of Menengai geothermal field

Exploration drilling commenced in Menengai in 2011 and currently over 30 deep wells of depths varying from 2,100 m to 3,200 m have been drilled. Reservoir temperatures of up to 400°C at 2000 m have been encountered in several wells making it the hottest geothermal system in Kenya. Steam production from the wells varies from small to greater than 10 MWe. Currently over 100 MWe of steam equivalent is on the wellhead and full steam production for the planned 105 MWe power plants is expected before end of 2016. Three companies have been licensed for 20 years to operate 35 MWe modular plants each which are due to be commissioned in 2018.

3.4 Suswa

Suswa is the southernmost of a series of Quaternary caldera volcanoes in the Kenya rift. The volcano has two nested calderas: outer and inner with diameters of 10 and 4 km, respectively (Figure 7). Volcanism at Suswa started during late Pleistocene and continued to less than 1,000 years ago (Omenda, 1997). The volcanic products comprised trachytes, phonolites and their pyroclastic equivalents.

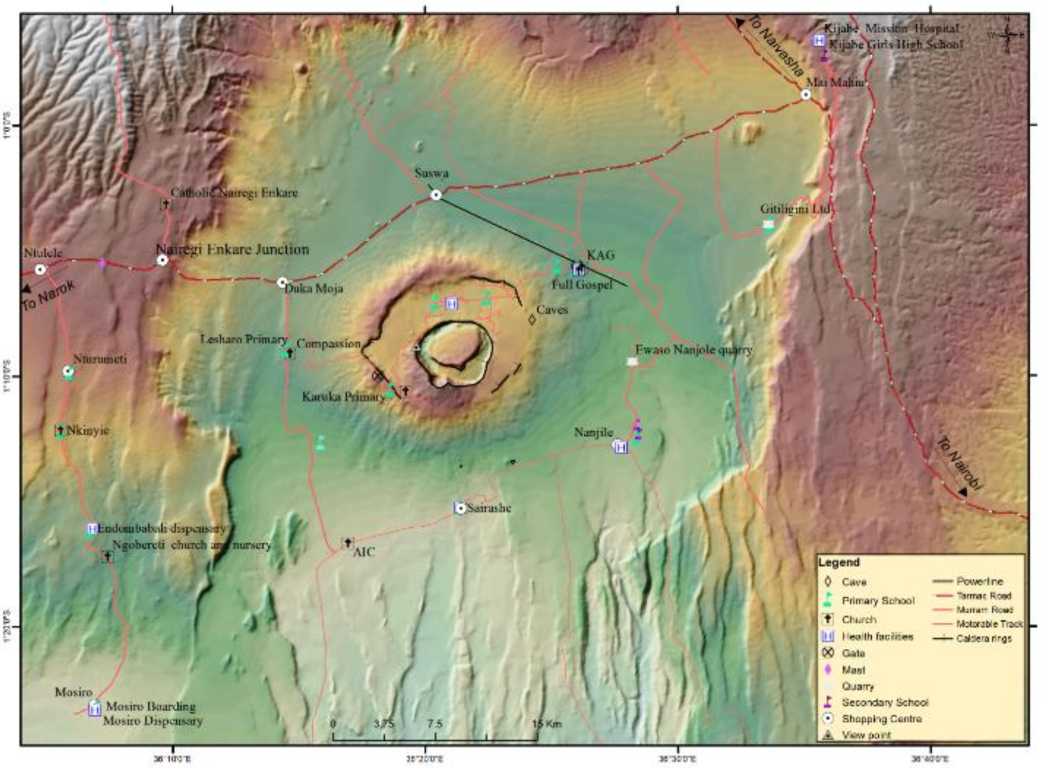

Figure 7: DEM image of Suswa geothermal prospect

Results from detailed surface studies suggest reservoir temperatures of >300°C based on gas geothermometry. Seismic and gravity studies show that the heat source under the caldera is at about 6 km depth. Resistivity (MT) indicates an anomaly centred below the inner caldera and extending to the northeast out of the inner caldera. Exploratory drilling is expected to commence in year 2017. The prospect is licensed to GDC and will be developed under PPP arrangement.

3.5 Longonot Prospect

Longonot is a large caldera volcano within the floor of the southern Kenya Rift adjacent to Olkaria Geothermal field (Figure 8). The volcano comprises of a large trachyte caldera of about 11 km 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. Geothermal surface manifestations are mainly fumaroles and hot grounds within the central crater. The geochemical survey revealed high radon and CO_2 gas discharges with gas geothermometry indicating geothermal reservoir temperatures of more than 300°C (KenGen, 1998).

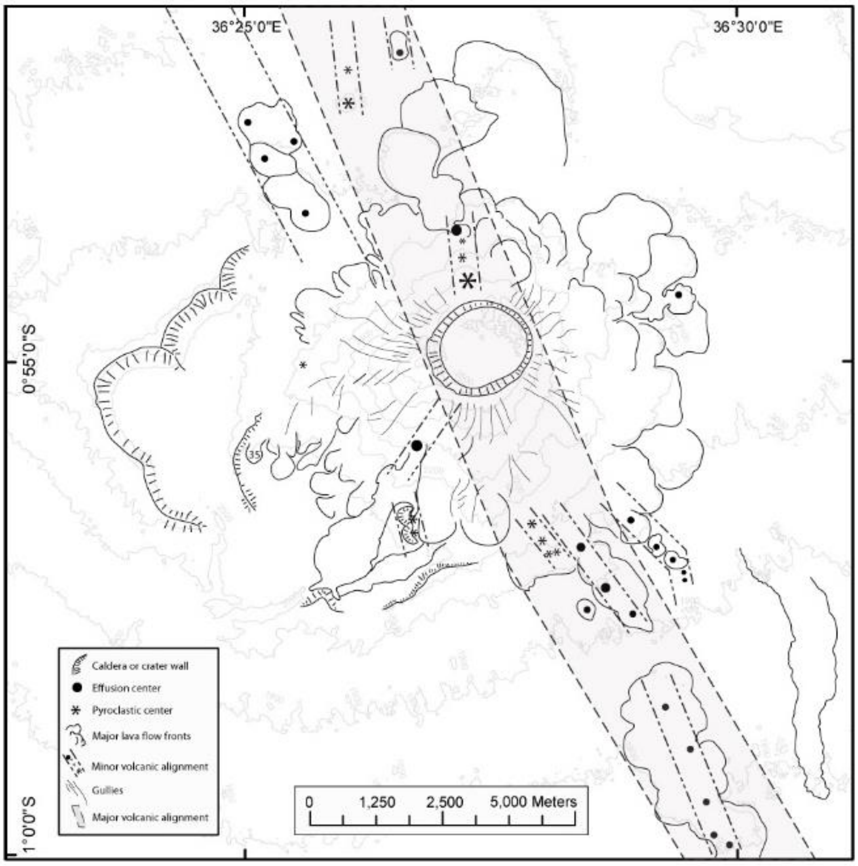

Figure 8: Structural map of Longonot Prospect

Combined MT, gravity and seismics indicate that the heat source is at 6 km deep with the shallowest portion directly under the central volcano (Alexander and Ussher, 2011). Geothermometry indicates that a high temperature geothermal system >250°C exists under the volcano. The prospect was leased to African Rift Geothermal Limited (AGIL) for 20 years. The company plans to commence exploratory drilling in 2017 which would lead to staged development of 70 MWe power plants with full commissioning in 2019.

3.6 Baringo prospect

Lake Baringo geothermal prospect is in the northern part of the Kenyan rift adjacent to Lake Baringo (Figure 2). 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. There are no Quaternary volcanoes within the prospects. Gas geothermometry indicates reservoir temperatures of 120-200°C in the western sector of the field. Resistivity suggests the occurrence of fault controlled, discrete reservoirs in areas to the west of the prospect. Since the prospect is not associated with a young centralized volcano, it is postulated that the heat source for the geothermal system is due to deep circulation along the fault planes (Mungania et al., 2004; Ofwona, 2004). GDC plans to drill at least two exploration wells in the prospect in 2017.

3.7 Korosi prospect

Korosi volcano is located in the northern part of Kenyan rift valley and neighbours Lake Baringo to the south and Paka volcano to the north (Figure 2). Detailed surface studies were undertaken between 2005 and 2012. The latest volcanic activity associated with Korosi volcano was of basaltic composition and occurred a few hundred years ago while the last trachytic volcanism occurred about

100ka. The MT resistivity surveys indicate an anomaly below the Korosi massif. Gas geothermometry indicates reservoir temperatures of more than 250°C. Exploration drilling in the prospect is planned to be undertaken by GDC in 2017.

3.8 Paka Prospect

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 2). Volcanic activity commenced about 390 ka and continued to 10 ka. 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. Surface geothermal activity is widely developed at Paka particularly within the summit craters and the northern flanks where fumaroles at >97°C are common. Gas geothermometry of fluids from Paka indicate the reservoir system to be at more than 250°C. MT resistivity at Paka prospect shows a conductor under the volcano. Seismic studies indicate shallow events directly under Paka suggesting that a hot body exists below about 5 km depth. GDC plans to undertake exploration drilling in the prospect in 2017.

3.9 Other Geothermal Prospects

The other potential geothermal prospects within the Kenya rift that have not been studied in great depth include Lake Magadi, Emuruangogolak, Namarunu and Barrier volcanic complex (Figure 2). Detailed studies of these prospects are planned by GDC for the period between 2014 and 2017. Other areas with geothermal potential include Lake Bogoria and Arus (Karingithi, 2005; Mwawongo, 2005)

4. DISCUSSION

Kenya is currently the epicenter of geothermal developments in Africa with current installed capacity of 676.8 MWe and a further ~12 MWt. Installed electric capacity has seen a growth of over 300% from 2010 when installed geothermal capacity was 167 MWe (Simiyu, 2010). Part of the new generation comes from wellhead power plants (83.5 MWe) which KenGen has constructed to utilize idle steam prior to construction of main plants. Plans are underway to increase the capacity to 1,646 MWe by 2017 and a total of 2,765 MWe by 2020. The increase will be achieved through the additional plants under construction at Olkaria and new plants at Menengai field and Silali prospect. Some of the new plants will be owned by private developers, e.g. 560 MWe at Olkaria through PPP arrangement. Other IPP plants will be by AGIL plant at Longonot; Akiira One plant at Olkaria; and 3 IPPS at Menengai. PPP projects are also planned for Silali and Suswa prospects.

Direct use of geothermal energy has not grown significantly since 2010 and greenhouse heating remains the leader with installed capacity of 10 MWt (Lagat, 2010). Pyrethrum drying still exists but amount of energy used is low. KenGen recently commissioned their equivalent of “the blue lagoon” at the Olkaria II plant where brine from production wells is channeled into the pool (Mangi, 2014). The energy used at the pool is still not well documented but is estimated to be about 5 MWt. Ground source pumps have not been installed in Kenya. The number of drilled wells in Kenya have increased steadily from the 1950’s and increased significantly during the last few years. The wells that were drilled for exploration, appraisal, production and injection vary in depth from 2,100 m to 3650 m focusing mainly on the high temperature systems. In Kenya, exploration and development has focused mainly on the high temperature systems as shown by the over 206 wells that have been drilled into the high temperatures resources. The wells that recorded lower temperatures were drilled as high temperature wells bur encountered low enthalpy.

5. CONCLUSIONS

It is clear that indirect utilization of geothermal energy in Kenya improved dramatically in the last few years and future outlook is even brighter with more projects lined up. It is also gratifying to note that the private sector will increasingly play a major role in both greenfield and brownfield developments as Kenya focuses on the 2,765 MWe generation by year 2020. Future developments will not only result in increased generation at Olkaria and Menengai fields but discovery and developments of new fields at Baringo-Silali and Suswa geothermal areas. Direct utilization increased marginally but growth is expected with both GDC and KenGen putting focus not only on electricity generation but also direct use.

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