LECTURE 4

KENYA'S GEOTHERMAL PROSPECTS OUTSIDE OLKARIA: STATUS OF EXPLORATION AND DEVELOPMENT

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ABSTRACT

Implementation of the geothermal resource assessment program (GRA) has resulted in exploration studies being done in five other prospects in the Kenyan rift between 2004 and 2005. The same studies in all the geothermal prospects north of Lake Baringo will be complete by 2010. So far Menengai is ranked first followed by Longonot and Suswa. For prospects with no central volcano, L Baringo is ranked last after L Bogoria and Arus. Over 6,838 MWt is lost naturally from the already explored geothermal prospects in the rift. Areas of heat leakages in the rift are controlled by NW-SE trending faults. At Olkaria, over 84,800 GWH have been generated from geothermal resulting to a saving of over 4,900 million US$ in foreign exchange.

1. INTRODUCTION

Kenya is located in the eastern part of Africa with 14 geothermal prospects identified in the Kenya rift starting from Barrier in the north to L Magadi in the south with an estimated potential of over 2000 MWe (Omenda et al., 2000). Studies done in the rift in mid 1960 identified Olkaria as the most economical prospect to develop (KPC, 1994). Exploration and field development was then done leading to the establishment of sectors which form the Great Olkaria Geothermal area (GOGA) currently with an installed capacity of 130 MWe. Over 84,800 GWH have been generated from geothermal resulting to a saving of over 4,900 million US$ in fossil fuel cost.

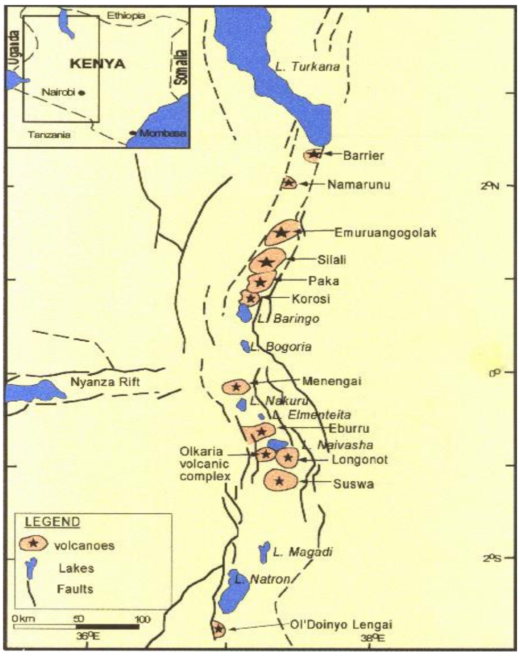

FIGURE 1: Geothermal fields in the Kenyan Rift

Performance of Olkaria power plants indicate that geothermal power is cheap and feasible and for this reason the Government of Kenya (GOK) through KenGen implemented a geothermal resource assessment program (GRA) aimed at systematically exploring all the geothermal prospects outside Olkaria with the aim of ranking them for further development.

So far surface studies have been conducted at Eburru, Suswa, Longonot, Menengai, Lake Baringo, Arus and Lake Bogoria prospects with exploration drilling only done at Eburru. This paper presents the current status of exploration and development of other geothermal prospects outside Olkaria.

2. EBURRU

Eburru volcanic complex is located to the north of Olkaria. Structures in the prospect mainly have a N-S trend (Figure 2). Hot grounds and fumaroles in the area produce steam at 95°C. (JICA, 1980). Exploration drilling of 6 deep wells was done between 1989 and 1991 by Kenya Power Company for the GOK. Hydrothermal minerals assemblages suggest that the area had experienced temperatures of over 300°C possibly due to localized intrusives.

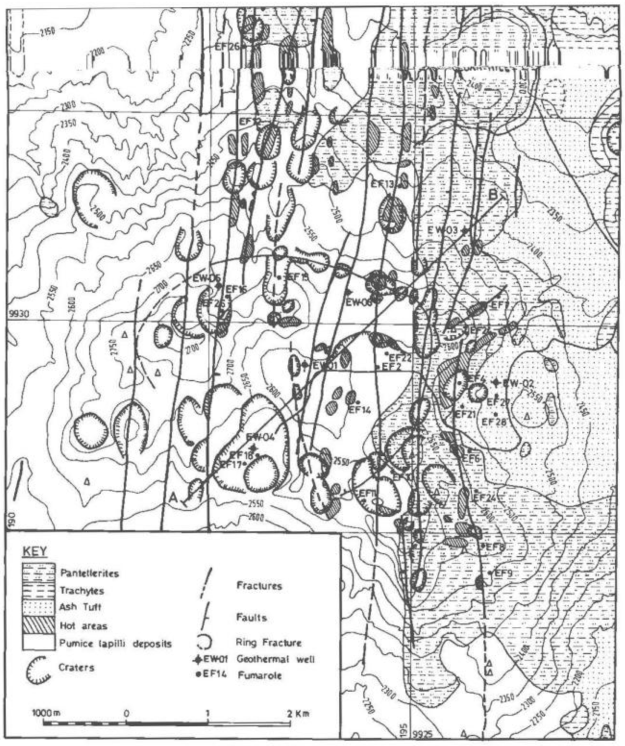

Figure 2: Geological map of Eburru (Omenda and Karingithi, 1993

The lithology indicates that rhyolite is the most abundant together with basalts and trachytes. Resistivity indicates that the field is delineated by the 30 ohm-m anomaly with an outflow towards the NE towards Badlands volcanic field (Figure 3). The Badlands volcanic field was investigated together with Eburru and expansive low resistivity anomaly was detected. However, drilling has not been done to confirm its potential.

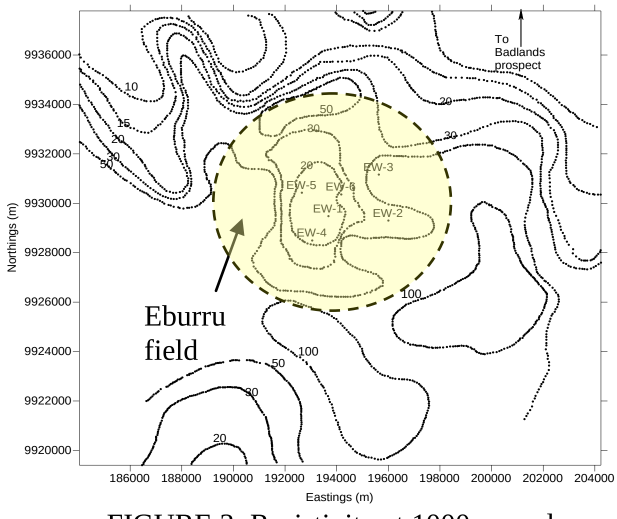

FIGURE 3: Resistivity at 1000 m a.s.l. in Eburru (Onacha, 1991)

Discharge fluid chemistry from the wells (EW-1) indicates that the reservoir is non-boiling with very saline brine and a high amount of non condensable gases (NCG), however scaling problem is not anticipated due to the low calcium and magnesium in the brine. Despite the almost similar geology, the chloride level of EW-I (956 to 1976 ppm) is higher than that of Olkaria. As compared to Olkaria, the reservoir permeability is moderate (KPC, 1990).

The maximum 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 is about 20 MWe (Omenda et al., 2000). The area has a fairly well established infrastructure and for this reason a 2.5 MWe binary plant for early generation will be commissioned in 2007. Additional studies will also be done to refine the field model prior to commissioning of the plant.

3. MENENGAI

Menengai is a large caldera volcano on the floor of rift valley. Pervious studies of the volcano indicated probable occurrence of a high temperature geothermal resource (Omenda et al., 2000). The youngest eruptive activity is about 1400 BP. Surface manifestations are mainly steaming grounds at a temperature of 88°C. The Government of Kenya and KenGen carried out surface studies between January and May 2004 in an area of about 900 km^2 (Mungania et al., 2004). Integrated results of geological, geophysical, geochemical and heat loss surveys indicate existence of a hot, ductile and dense body under the caldera. It is modeled that the hot magmatic body resulted in the development of a geothermal system with an up-flow under the caldera and an outflow to the north (Figure 4).

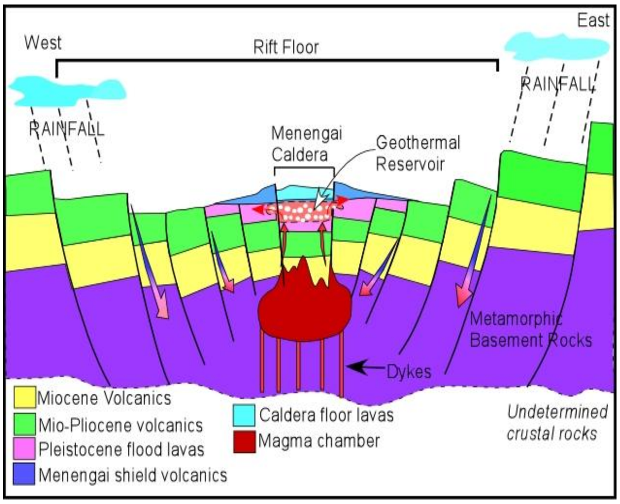

FIGURE 4: Conceptual model of Menengai

Gravity suggests that the dense body is 3.5 to 4 km deep (Omenda et al., 2000). Good permeability in the subsurface is shown by the shallow low resistivity of <15 ohm m at 1000 ma.s.l. Seismic studies indicate clusters of shallow micro-earthquakes under the caldera and from experience at Olkaria this is related to a high temperature geothermal field associated with shallow magma bodies (Simiyu and Keller, 1997). 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). Heat loss results from this prospect together with those obtained in others are plotted on Figure 5.

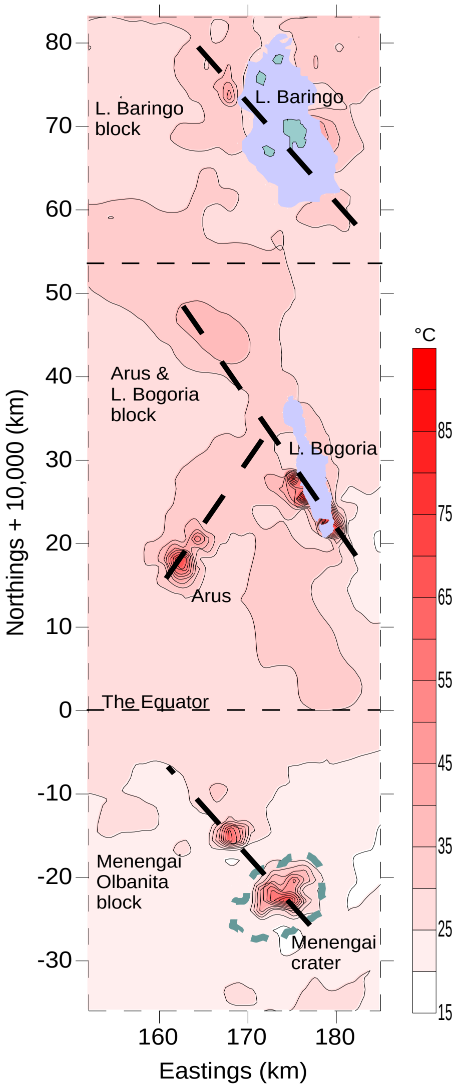

FIGURE 5: Ground temperatures at 1 m depth from Menengai to L. Baringo

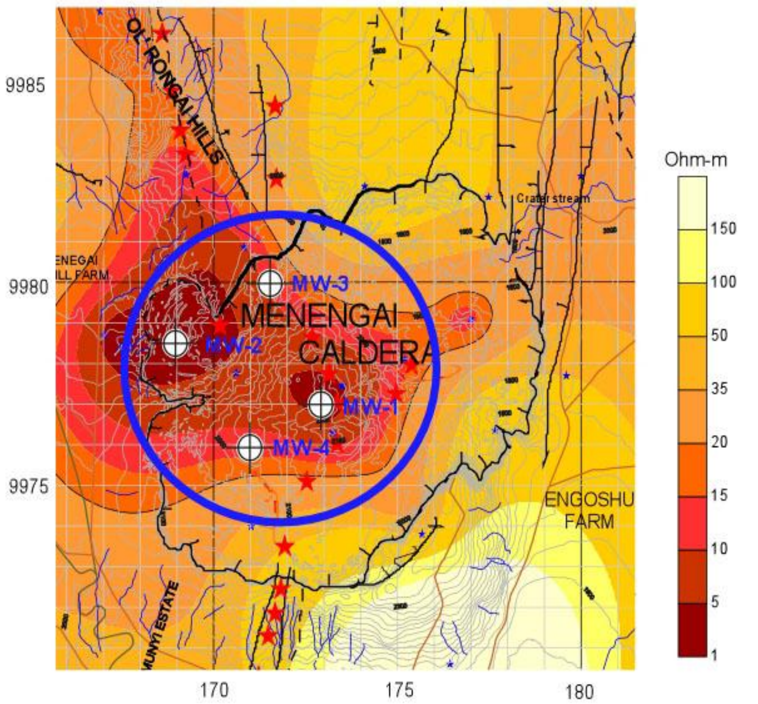

FIGURE 6: MT resistivity at 2000 m b.s.l. and proposed well site locations

The mapped potential area is about 40 Km^2 translating to over 700 MWe of electric power (Figure 6). 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 favor 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. The reservoir rocks are expected to be trachytes 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. From geothermometric estimates, the reservoir is expected to be at more than 300^{o}C.

4. LONGONOT

Longonot geothermal prospect occurs within the Longonot volcanic complex which is dominated by a central volcano with a summit crater of about 35 km^2 and a large outer caldera (Figure 7). Geothermal surface manifestations are mainly fumaroles. KenGen carried out surface studies at Longonot in 1998 and the results suggest that Longonot has a centralized magma chamber beneath the summit crater. Resistivity data shows a low anomaly that covers about 70 km^2 (Figure 8). The Geochemical analysis projected reservoir temperatures in excess of 300^{o}C. CO_2 and Radon counts at Longonot and Olkaria are similar. 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 at 6 km deep (KenGen, 1999). Three exploration wells have been sited and will be drilled soon. Estimated power potential is over 200 MWe (BCSE, 2003, Omenda et al., 2000).

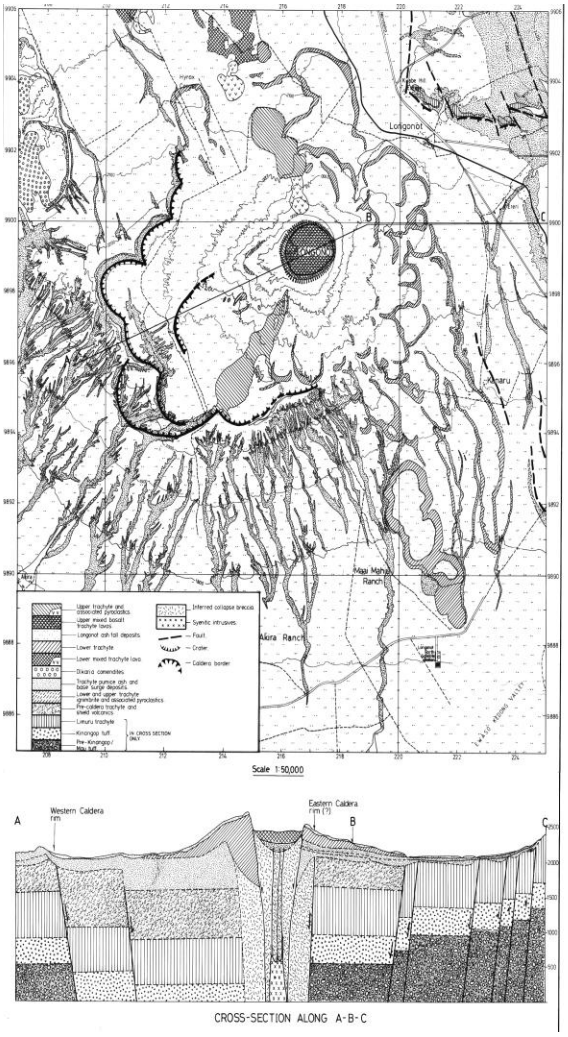

FIGURE 7: Geology of Longonot prospect (Lagat, 1998)

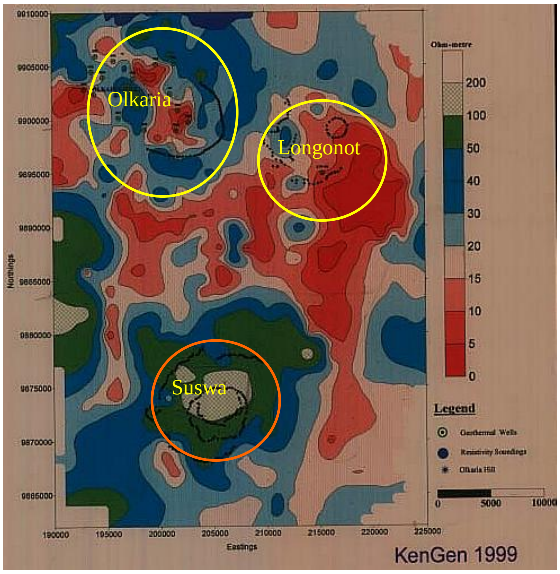

FIGURE 8: Resistivity map of Olkaria, Longonot and Suswa (KenGen, 1999)

5. 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 9). 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 93°C.

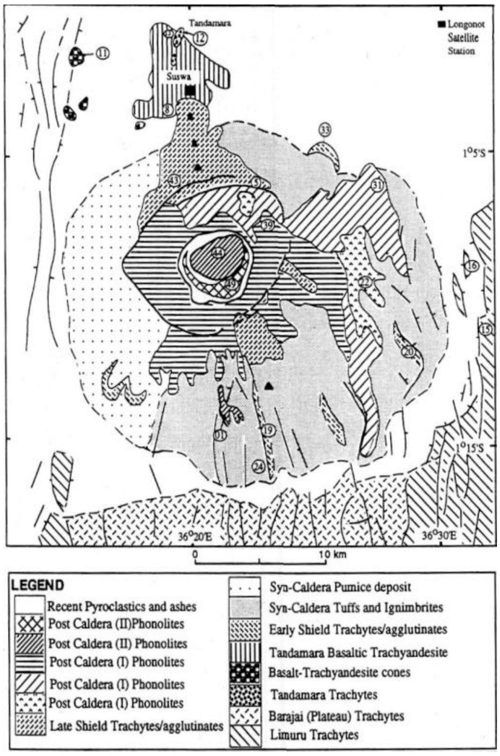

FIGURE 9: Suswa caldera (Omenda, 1997)

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 ma.s.l indicates a low (15-20 ohm m) anomaly under the island block and extends to the north out of the inner caldera. Another low was obtained to the NW of the inner caldera close to the wall of the outer caldera (Figure 8). This resistivity value is high compared to Olkaria and even Longonot where values of less than 10-15 ohm-m were obtained. This could possibly be due to low bulk permeability and low level of alteration. Lack of low resistivity at shallower depths suggests that the reservoir is deep. This suggests that the resource area at economical depth could be small.

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 about 100 MWe (Omenda et al., 2000).

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 to the east and west while basalts occur to the north and alluvial deposits to the south (Figure 10). 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. However geology of this prospect is expected to compare well with that of Lake Bogoria and so are the two reservoirs (see Section 9).

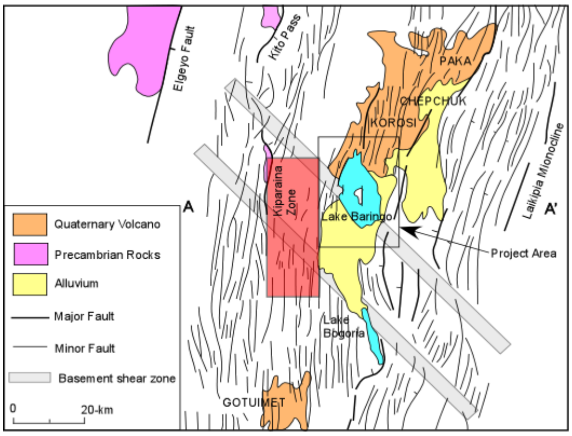

FIGURE 10: Geology of L. Baringo and L. Bogoria prospects (Mungania et al., 2005)

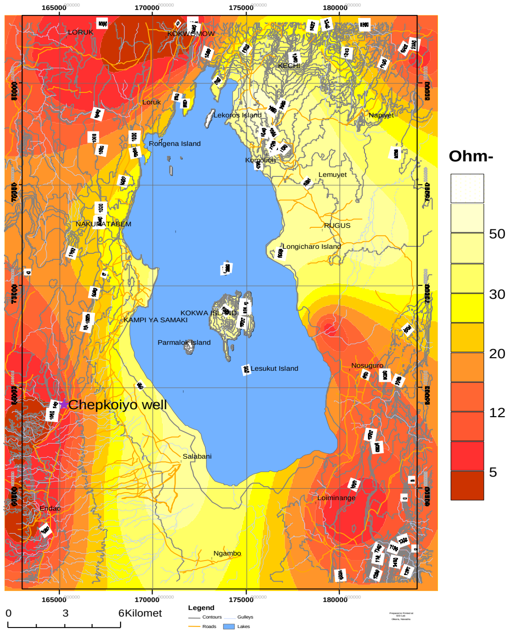

FIGURE 11: Resistivity at sea level at L. Baringo prospect

Resistivity at sea level indicates occurrences of fault controlled, discrete possible resource areas in the west of the Lake (Figure 11). Fluid geothermometry indicate reservoir temperature of over 200°C 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). Results of this survey are plotted in Figure 5. The prospect is not associated with a centralized volcano and the heat sources are probably deep dyke swarms along the faults. Drilling deep slim holes that can be geologically logged and be used to determine temperature gradients and reservoir permeability has been recommended for the prospect.

7. ARUS AND LAKE BOGORIA

Arus and Lake Bogoria is an area of volcanic rocks 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 near by hotel. Surface studies are still ongoing. Preliminary results suggest that the heat source could be due to intrusives. Geothermometry indicates moderate reservoir temperature (Karingithi, 2005). Heat loss survey indicates that L Bogoria area loses about 1199 MWt while Arus loses 467 MWt (Figure 5). Heat loss at Arus is mainly conductive with negligible convective component. Convective heat loss at L Bogoria is about 437 MWt (Mwawongo, 2000). From geological observations, reservoir characteristics of this prospect are expected to compare well with those at L Baringo (Figure 9).

8. OTHER GEOTHERMAL FIELDS

The prospects that occur to the north of Lake Baringo include Korosi, Chepchuk, Paka, Silali, Emuruagogolak, Namarunu, and Barrier volcanoes. Plans are underway to undertake surface studies at Korosi and Chepchuk from 2005 to 2006. The other prospects in the north will systematically be studied under the ongoing GRA exercise. It is believed that the caldera volcanoes in the north host large geothermal systems as manifested by the Kapedo hotsprings at Silali volcano that discharge fluid at 1,000 litres/sec at 55°C. Other prospects include Lake Magadi and Badlands.

9. DISCUSSION

Results from surface studies conducted under the GRA program are summarised in Table 1. Eburru prospect was included in the analysis for comparison purposes but not for ranking since the field has been proven by deep drilling. From geology central volcanoes are associated with Menengai, Longonot and Suswa. Trachytes as the expected reservoir rocks dominate the same prospects but Suswa has phonolites that were from recent volcanism. This may seal older faults making Suswa have low permeability compared to Menengai and Longonot. As for the age of volcanism, all the volcanoes have comparable ages of last activity. Higher reservoir temperatures are associated with young age.

From surface manifestations, areas covered by Suswa and Longonot are the same while smaller area covers manifestations at Menengai. This may suggests that resources at Longonot and Suswa are bigger than that at Menengai or alternatively the resource at Menengai is better capped.

The low resistivity anomaly at Suswa still has higher resistivity values (15-20 ohm-m) as compared to Longont and Menengai (10-15 ohm-m). This suggests a better resource in the later two. Gravity indicates a deeper heat source at Suswa followed by Longonot and the shallowest being at Menengai. Also shallow low resistivty at Menengai suggest shallow permeability as compared to Suswa and Longonot.

Geothermometry suggest low reservoir temperatures at Menengai compared to both Suswa and Longonot but lack of hot springs in the prospect make these results unreliable. Silica (quartz) geothermometer related to hot springs is more reliable than gas geothermometer. For this reason, the reservoir temperatures computed need to be treated with caution. Only deep drilling can give a good reservoir picture in these prospects.

Heat sources at Arus, L. Bogoria and L. Baringo prospects are associated with dyke swarms and not centralized volcanoes. Dykes are related to low temperature systems while centralized volcanoes most often results in high temperature reservoirs. This makes the prospects be ranked low as compared to the ones discussed above. When compared, L Baringo appears a smaller resource than both Arus and L Bogoria. From the active manifestations at L Bogoria, the same appears better than Arus. However, geology of the prospects suggests similar reservoir characteristics in terms of reservoir rocks and permeability.

Heat loss survey has not been conducted in all the studied prospects except at Menengai, Arus, L Bogoria and L Baringo (Ofwona, 2004a, Ofwona, 2004b, Mwawongo, 2005). It's important to note the limitations of this method in that high heat loss may not necessarily mean a big resource. Big reservoirs may have low heat loss due to sound surface cover like Olkaria with 400 MWt yet it is a proven big resource (Mahon, 1989).

The already explored prospects dissipate over 6,338 MWt naturally to the atmosphere. With the other prospects north of L Baringo yet to be explored, this figure is bound to rise. This is further evidence that power potential in the Kenyan rift is high. The high convective heat loss at Menengai suggests that the prospect is well recharged. High heat loss at L Bogoria suggests a larger resource compared to L Baringo.

Although Menengai is estimated to have a huge potential the mapped hot area is still smaller than that at Olkaria of over 80 km^2. However, the area may be extended when exploration drilling and subsequent development of the area starts. The Agro based industries close to Menengai can utilize geothermal heat for their processes. Space heating of greenhouses in the surrounding farmlands can also be enhanced. This will greatly increase direct utilizations of geothermal heat in Kenya which is currently low.

TABLE 1: Summarized results

RANK	Name of prospect	Geological setting	Age of last volcanism	Nature of geothermal activity	Area of activity (km2)	Max. measure surface T (°C)	Geothermometry (°C)		Geophysical indications	Heat source
							Range	Ave.		
3	Suswa	Central volcano with two calderas and N-S trending fissure zone. Volcano active between 400ka – Recent and dominated by phonolite. Dike swarms thus permeability compromised. Rocks are dominantly trachytes and phonolites	0.24 Ma-400 yr BP (est)	Fumaroles, steaming and altered grounds. Deposits of sulphur occur within the annular trench. Altered lithics (T>250°C) common.	3	93	230-310	265	High gravity in the south of caldera which is also the most seismically active. 15-20 ohm-m anomaly, strong magnetic anomaly, shallow attenuating bodies.	Large magma chamber at shallow depth (8-12 km) immediately below Caldera II.
1	Menengai	Central caldera volcano. The volcanic activity has been active since 0.2 Ma to present. The volcano is built dominantly of trachyte lavas.	1.4 ka 0.7-0.3 Ma	Medium strength fumaroles, steaming, and altered grounds. Scarce manifestations within Menengai caldera. Boreholes in the immediate neighbourhood discharge steam and warm water.	<2	90 67	170-220 170-220	200 200	Resistivity lows occur within the caldera floor with bias to the NE. High, shallow seismicity under the caldera. High gravity anomaly occurs superimposed on a regional low associated with the caldera.	The main heat source is associated with a magma chamber at 6km under the caldera as shown by seismics, MT and gravity.
4	L. Bogoria and Arus	No clear magmatic and volcanic association noted. However, the Plio-Pleistocene lavas that cover the area are extensively faulted.	<1.6 Ma	Hot springs, geysers, and steam jets common and occur along fault zones. The springs discharge at low temperatures. CO_2 gas emissions common. Hot water boreholes.	2	98	120	120	High gravity and positive magnetic anomaly. Intense, deep (>15km) seismicity on the east along Marmanet fault. Low resistivity occurs to the east of Lake Bogoria	No magmatic body anticipated. Heat probably associated with dike swarms.
NR	Eburru	The volcanic massif is built dominantly of trachytes, rhyolites and their pyroclastic equivalent. The eastern volcano which is more promising has a pseudo craters defining a small caldera structure.	28 ka	Fumaroles, steaming and altered grounds occur along crater walls and N-S faults. The hydrothermal zones in Eburru contain alteration minerals such as kaolinite, smectite, native sulphur, and sinter.	>3	93	285	285 (Actu.)	Low resistivity anomaly (15ohm-m) enclosed by the ring of craters define the resource. High gravity body under the volcano.	Centralized solidified dense body under the massif. No molten body expected at shallow depth.
2	Longonot	Quaternary caldera volcano with summit crater. Latest lava flow was inside the crater and along NW-SE volcano tectonic line. The rock types are mainly trachytes and mixed basalt-trachyte lavas.	0.4 Ma -400 BP	Fumeroles, hot grounds, altered grounds along walls of the crater.	2	93	300	300	Low resistivity anomaly (10 ohm-m) on the southern slopes of the summit volcano and extending southwards along NW-SE fault line.	Centralized magmatic body under the summit volcano at 6km depth.
5	Lake Baringo	No clear magmatic and volcanic association noted. However, the Plio-Pleistocene lavas that cover the area are extensively faulted.	<1.6 Ma	Weak fumaroles, altered ground, hotsprings and sulphur deposits. Hot water boreholes.	<1	98	280	280	N-S fault controlled low resistivity anomaly on the west side of the lake.	No magmatic body anticipated. Heat probably associated with dike swarms.

It is important to note that exploration drilling is currently lagging far behind surface investigations due to high cost of drilling as opposed to surface work. Proper ranking of these prospects and energy utilization strategy is only possible after exploration drilling. Therefore, lack of drilling is also discouraging development of geothermal resources in Kenya as well as speeding up diversification of utilization of geothermal energy.

Kenya has saved over 4.900 million US$ in fuel cost at GOGA through geothermal power generation hence proposed early generation at Eburru should be encouraged even in other prospects to start early revenue generation that could enhance studies and development of other resources. This practice will also greatly reduce the cost of well head maintenance in fields already with exploration wells.

Even after the recent studies done under GRA, Eburru development should proceed as planed due to the already existing drilled wells and infrastructure. As for exploration drilling, so far Menengai appears most promising as compared to Longonot and Suswa. Longonot appears better than Suswa.

10. CONCLUSIONS

Geothermal development in Kenya has been slow. With implementation of the ongoing GRA, surface studies of all the prospects in the rift north of Olkaria will be complete by 2010. Exploration drilling at Menengai should be of high priority. Longonot and Suswa reservoir characteristics may be similar to that at Olkaria while that at Arus, L Bogoria and L Baringo may be the same but different from Olkaria. Deep NW-SE crustal faults control occurrence of heat sources in the rift while thinning of the earths crust has resulted in high temperature gradients north of Menengai Kenya will save a lot in foreign exchange through development of its geothermal resources.

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