Situation Analysis Study on Geothermal Development in Africa

(Annex)

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JAPAN INTERNATIONAL COOPERATION AGENCY

WEST JAPAN ENGINEERING CONSULTANTS, INC.
Situation Analysis Study on Geothermal Development in Africa

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<th>Field Name</th>
<th>Olkaria</th>
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<tbody>
<tr>
<td>Country</td>
<td>Kenya</td>
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</table>

**Present Status**
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 are generating a total of 167 MWe. The resource is being utilised mainly for electric power generation (167 MWe) and direct uses (16 MWe). The proven geothermal resource at the greater Olkaria geothermal field is more than 450 MWe and accelerated development if envisaged in the near future.

**Accessibility/Plant operation**
The Olkaria I power plant is located in the Olkaria East field and has three turbo generating units each generating 15 MWe. The three units were commissioned in 1981, 1983 and 1985 respectively. Olkaria II is located in Olkaria northeast and the construction of 2 x 35 MWe Olkaria II geothermal power station started in September 2000 and was completed November 2003. The construction of Olkaria III unit is expected to be commissioned in 2010. Olkaria II project is the first private geothermal power plant in Kenya. A 20-year Power Purchase Agreement (PPA) was awarded to Orpower 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 1998 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 2006. In addition, Oserian Development Company Ltd (ODLC) constructed a 2.0 MWe binary plant Ormat OEC in Olkaria Central to utilise fluid fort

**Resource characteristics**

<table>
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<tr>
<th>Geology</th>
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<tbody>
<tr>
<td>Olkaria is characterized by numerous Quaternary volcanic centers, including a ring of volcanic domes on the east and south sides of the field area, which may represent a caldera boundary. The surface geology is dominated by rhythmic lavas and pyroclastic rocks. Beneath this is a series of basaltic, trachytic and pyroclastic units above the Proterozoic basement rock, which is composed of gneiss, schists and other metamorphic rocks belonging to the Mozambiquan group.</td>
</tr>
</tbody>
</table>

**Volcanic activity (heat source)**
The temperature distributions at 0m asl suggest the likely location of heat sources (upflow of deep hot fluids) for the GOGA. Also it suggests the permeability structure and the possible lateral connections. Although it is difficult to define the position of heat sources, at least two deep upflow zones can be identified in the eastern side of the Old Butul fault, one located in the NEPF and other comprising the EPF and the Domes. The analysis of the fluid geochemistry also suggests these two upflow zones. In addition, another upflow zone is identified for the WPF. The reliability of these assumptions will be discussed upon numerical simulation studies. Upflow zones are usually modeled as constant pressure and temperature boundaries or as mass and energy sources (or conductive heat sources). The former type is defined using constant pressure and temperature boundary sticks at the bottom most layer of the numerical model while the position and strength of the latter type of heat sources is defined by trial and error during the calibration process of the numerical model.

**Geological Structure**
Volcanic units are cut by numerous faults, some of which can be mapped on the evidence of aligned features such as hot ground, extrusion centers and craters. Notable among these are the Old Butul and the Olkaria Faults. While the dominant fault direction is N-S, parallel to the rift trend, other faults have been inferred that trend NNW (such as the Gorge Farm Fault and the Suswa Lineament).

**Geochemistry**
Fumaroles are widespread over the greater field area, often associated with structures (faults or fractures and volcanic centers) visible at the surface, and represent discharge from the shallow two-phase part(s) of the system(s). The Domes area lacks fumarolic activity, probably due to a thick pile of impermeable pyroclastic rocks which acts as a seal. Fumarolic chemistry across the field could be taken to indicate that a hot water reservoir underlies the whole geothermal field, and that there were no clear indication of significant later movement of boiled hot water. Muna (1993) concluded from soil gas (radon) and fumarole surveys that there may be a distinct upflow in the area between the Olol Butot lava flow (to the north), the Ol Njorowa Gorge (to the east) and the Olol Butot Fault (to the west), and the southmost edge of the ring structure to the south. In addition, the data presented do support this suspicion, but no deep drilling has been done in this area, named the South Olkaria Upflow Zone, which lies SSW of the EPF.

**Work done so far**
The data obtained from a selection of reports by KenGen and others include 119 water analyses and 61 gas analyses, many of which are presented by these reports as “averaged” or “best” data from selected wells which represent conditions prior to or early during field production. These selected data have been used as the basis for establishing and representing an overview of initial reservoir conditions in the five major production and exploration areas: Olkaria East (EPF or Olkaria I), Olkaria Northeast (NEPF or Olkaria II), Olkaria Central (OC), Olkaria West (WP or Olkaria III) and Olkaria Domes (OD). In contrast, the larger part of the dataset has been used for more detailed well-by-well comparisons.

**Geophysics**
- Bouguer gravity data (882 stations).
- Aeromagnetic survey (75,495 stations).
- Power spectra data of a Magnetotelluric (MT) survey (80 stations).

Data in and around the Olkaria geothermal field and surroundings.
- Bouguer gravity data (882 stations).
- Aeromagnetic survey (75,495 stations).
- Power spectra data of a Magnetotelluric (MT) survey (80 stations).
- Data of all covering the Olkaria geothermal field and surroundings.

Further details and references can be found in the original document.
Gravity

A NW-SE trending positive anomaly is recognized. This anomaly was interpreted as occurring in a demagnetized zone corresponding to the main heat source with a temperature above the Curie point at a depth of around 6km. Another positive anomaly trending NE-SW can also be seen as a reflection of Olkaria fault zone. This minor anomaly was interpreted as representing rocks demagnetized due to alteration by chemical and thermal processes at reservoir depth. In addition, a steep gradient zone of the relative east production field. This tendency seems to indicate rapid changes in the magnetic properties of the subsurface rock, so the tendency is possibly indicative of a fault structure trending in a NNW-SSE direction.

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Gravity lineaments reflect fault structures, so these gravity lineaments detected in the filtered Bouguer anomaly maps possibly reflect fault-like structures in the Olkaria geothermal field. Moreover, the low Bouguer anomaly zone roughly distributed in the Olkaria fault zone is p

TEM

A remarkably low resistivity zone of less than 10ohm-m is widely distributed in the northern, central and southeastern portions of the Olkaria geothermal field. And the low anomaly zone has a very clear tendency to extend in a NNW-SSE direction. The widely distributed low resistivity zone detected in the resistivity maps at 1600m msl and 1400m msl probably reflects the areas where conductive clay products such as smectite and zeolite are abundant. The low resistivity zone seems to be separated into two low anomalies. One low anomaly seems to be centered in the Olkaria northeast field and another low anomaly seems to be centered in the east production field. The fact may suggest that there are two separate up-flow zones in the Olkaria northeast field and the east production field. On the other hand, a relatively high resistivity zone of greater than 20ohm-m is widely distributed in the northeastern and eastern portions of the field. In between the low-resistivity zone and the relatively high resistivity zone, a steep gradient of resistivity values trending roughly NNW-SSE is recognized. In addition, a relatively high resistivity zone located in and around Olkaria Peak could be due to a low degree of hydration. The orientation of the low anomaly is similar to that of the low resistivity anomaly at shallow depths recognized in the resistivity maps obtained from MT surveys.

Well Drilling

To date, more than 100 wells have been drilled in the Olkaria area. KenGen already has the abundant data of downhole pressure and temperature profiles of 82 wells with the flow test records of 55 wells, the production history of 47 wells, and the injection history of 8 wells.

Temperature Survey

The temperature distributions indicate that the whole GOGA can be considered divided into two main sectors, the western (WPF) and eastern sides (NEPF, EPF, and the Domes). The separation is a low temperature region approximately coinciding with the Olol Butot fault. The general trend of the temperature contours of the eastern side seem to stretch in NNW-SE direction, which coincides with the direction of the inferred main geophysical. Thus, the eastern side should be considered basically as one geothermal system with the N-S structure separating the western and eastern sides a hydraulic boundary. The low temperature is in between two N-S trending structures, F2 and Old Butut. The low temperature area detected from elevations of 1000m msl (and higher) at the northeastern portion of the NEPF could be reflecting influx of cooled water from the northeast.

Pressure distributions show that the northern pressures are higher than those of southern pressures, which suggests that the natural trend of fluid flow is from north to south.

Conceptual Model

There are two major geothermal systems separated by a N-S structure corresponding to faults F1, F2 and Old Butut. The eastern side is comprised by the NEPF, EPF and the Olkaria Domes and the western side comprises the WPF, the Olkaria northwest and southwest. These systems seem to be heated by remaining magmatic intrusions beneath the GOGA. The eastern side may be primarily fed by meteoric water from the northeast which is heated by conductive heat changing its chemical characteristics to neutral chloride type by interacting with deep rocks. The western side might be receiving its primary deep recharge from meteoric water directly from the sea. Geothermal surface manifestations such as fumaroles and hot springs are found along the border of the N-S hydrothermal barrier zone between F1 fault and Old Butut fault and to the south of the GOGA. The temperature decreases toward this area, which is considered the main discharge zone.

Well testing

Since results of spinner test are not available, a qualitative analysis was done on the shape of the temperature profiles of the several wells. Almost all wells showed a shallow feed zone and a deep feed zone.

Conceptual Model

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Present Status of Development

Currently, in Kenya, geothermal energy is being utilized in Olkaria field only. Three of the seven Olkaria sectors namely Olkaria East field, Olkaria West field and Olkaria Northeast fields generate a total of 107 MW. The proven geothermal resources at the greater Olkaria geothermal field is more than 450 MW and accelerated development if envisaged in the near future.

Geothermal Environment - Natural Resources

The Olkaria area is characterized by the presence of a number of geothermal manifestations, including hot springs, fumaroles, and geysers. These geothermal resources are hosted in a series of fractured porphyry dikes and stocks that intrude the Plateau Trachyte formation. The geothermal fluids are thought to be primarily fed by meteoric water that infiltrates from the escarpment into the Plateau Trachyte formation and becomes heated by conductive heat. The chemical characteristics of the geothermal fluids are neutral chloride types, with temperatures ranging from 200°C to 300°C.

Scope for Power Development

KenGen is currently undertaking production drilling in Olkaria I for a planned 140 MWe plant by 2012. The proven geothermal resources at the greater Olkaria geothermal field is more than 450 MW and accelerated development if envisaged in the near future.

Geothermal Development Schedule

KenGen is currently undertaking production drilling in Olkaria I for a planned 140 MWe plant by 2012. The proven geothermal resources at the greater Olkaria geothermal field is more than 450 MW and accelerated development if envisaged in the near future.
**Field Name**: Eburru  
**Country**: Kenya  
**Province/Location**: Eburru volcano is located about 50 km north of Olkaria geothermal field. Lake Elementaita is located about 20 km north of Eburru.

**Accessibility/Infrastructure**: The Eburru area has a fairly well established infrastructure and for this reason a 2.5 MWe binary pilot plant is planned for commissioning in 2010.

<table>
<thead>
<tr>
<th>Resource Characteristics</th>
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<td><strong>Geology</strong></td>
<td>The Eburru volcanic complex is situated within the East Africa Rift Valley. It is part of a volcanic belt of peralkaline rocks trending in the NS that extends far to the south close to the Suswa volcanic complex. The Eburru volcanic complex extends towards the EW to the Mau escarpment and it comprises two major volcanic centers with an elevation of more than 2,600 masl. The western volcanic center is older and is overlain by younger pyroclastics from the eastern volcanic centre. The top of the eastern volcanic center has numerous volcanic craters of various volcanic episodes. Some of these craters describe a ring structure, which is interpreted as a caldera. Others coincide with the NS trending faults. Eburru is characterized by highly evolved trachytic and rhyolitic lava compositions. These differ in detail from those of adjacent Longonot and Olkaria volcanic complexes.</td>
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**Volcanic activity (heat source)**: Eburru volcano is elongated perpendicular to the Gregory Rift NW of Lake Naivasha. The 2856-m-high, E-W-trending main edifice is eroded, but young partly vegetated rhyolitic domes occur on the east flank and are probably of Holocene age (Thompson and Dodson, 1963). Pleistocene phonotitic and trachytic lava flows are overlain by rhyolitic obsidian lava flows forming much of the northern and NE slopes of the main massif. A prominent late-Pleistocene rhyolitic lava flow from a SE-flank vent extends almost to Lake Naivasha. Extensive fumarolic activity occurs at cinder cones and craters constructed along dominantly N-S-trending faults cutting the massif.

**Geological Structure**: In Eburru area, two major fault systems can be identified, i.e., the old Rift system trending in the NNW-SSE and the NS younger Rift floor faults. The NNW-SSE faults form the main rift valley escarpments. The Rift floor faults have a smaller throw and form a shallow graben structure running in the N-S and which passes through the eastern volcanic center. These faults are numerous and in some cases occur at intervals of a few meters.

**(Past Geological Studies included)**: Thomson and Dodson (1963) carried out the first systematic work in Eburru in 1963 while they were describing the geology of the Naivasha area. They pointed out the age differences between the rift faults and the rift floor faults. Later on, in 1972 the UNDP executed a work that covered only the Eburru area with emphasis on geothermal activity. In 1983, JICA carried out a comprehensive study of geothermal activity and proposed the position of the heat source and defined the outflow area. KenGen carried out detailed surface studies between 1987-1990 that culminated in the drilling of six exploration wells in Eburru between 1989 and 1991.

**Geochimistry**: 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-1 (956 to 1,976ppm) 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 (Awona, 1998).

**Work done so far**: In 1986, the Eburru geothermal field was classified as the next geothermal energy exploration target, then the Kenya Power Company (KPC) scientists carried out intense geological, geophysical and geochimical surveys. The results indicated that an area around the main crater area was the best target for exploratory drilling in the whole prospect. A soil and fumarolic survey was carried out in 1990 and in 1991 this was complemented with an additional downhole chemistry of the last five wells drilled.

**Geophysics**: Exploration drilling started in Eburru in 1988 and by 1990 four deep wells had been completed. The information recovered from this drilling together with some additional geophysical measurements were used to assess the resource potential and to identify further sites for exploration drilling. Two additional wells have been drilled and completed successfully; however, the temperature recovery information reveals that only one of the drilled wells was prone to produce fluids.
Gravity
The Eburru area has a complex gravity structure. The results show a N-S axial high along a graben caused by
dense intrusives along N-S fault zones and at major structural intersections within the area. Low frequency
filtering delineates a major NE-SW negative anomaly modelled as a basin structure, at whose intersection with the
N-S graben occurs the Eburru caldera. Within it, one well has been drilled with a 2.5 MW e production capacity.
High frequency anomalies are related to vertical intrusives at shallow depths, occurring at fault junctions. Analysis
of these anomalies has led to a proper definition of a NW-SE structural and resistivity discontinuity, dividing the
study area into two regions. This has also led to the confinement of the Eburru caldera boundaries. Fluid feed for
the geothermal system is along vertical conduits and the heat coming from narrow intrusive bodies at fault
junctures. Several intrusions exist at the intersections of the NW-SE structure and the N-S fault zone west of the Eburru
volcano. (From Simiyu 1990)

Resistivity
The interpretation of Schlumberger data from Eburru identified two anomalous areas of low resistivity (<10 ohm-m)
at 1,000masl. The first anomaly is in the Eburru crater area. The low resistivity seems to define an area of
interpolated reservoir temperature of 200°C. The low resistivity above 1,800masl is caused by hydrothermal
alteration of pyroclastics by acidic steam condensates and lateral outflows mainly to the northwest, northeast and
south along fault lines. The low resistivity area has sharp boundaries. Outside this area the resistivity is higher
(>30 ohm-m) due to low permeability and temperature which has been confirmed by exploration wells. The
second anomaly is found in the Badlands in association with a gravity high and a magnetic low. The two areas are
separated by high resistivity and an E-W structural discontinuity. MT surveys done in 2006 revealed that the Eburru area is able to support up to ~60 MW e. The results from the exploration wells indicate that the field had experienced temperatures of over 300°C possibly due to localized
intrusive.

Well Drilling
6 deep wells:
Three wells, EW-01, EW-04, and EW-06 discharge geothermal fluid. Only EW-01 produced steam.
Exploration drilling started in Eburru in 1988 and by 1990 four deep wells had were completed. Two additional
wells have been drilled and completed successfully, however, the temperature recovery information reveals that
only one of the drilled wells was prone to produce fluids.

Temperature Survey
The maximum temperatures of EW-01 to EW-06 indicated 244, 131, 161, 185, 158 and 218 °C respectively.

Well Testing
Discharge tests showed that at 6.0 bars the well produces 825 metric tons per hour of steam with enthalpy of 1150 kJ/kg
equivalent to 2.3 MW e. The well produced fluids at 265 °C and at a thermodynamic state close to saturated
conditions. Drawn down tests indicated relatively low transmissivity of 0.35 x 10^-8 m²/s if major production
comes from well bottom. Shut in tests indicated much higher transmissivity (5.2 x 10^-8 m²/s) but is most likely
exaggerated if by the internal flow which starts immediately after shut in, masking true temperature recovery as
well. Maximum temperature is 276 °C at 1550-2100 m, but temperatures are near-boiling between 1000-1200 m.

Conceptual Model
The Eburru caldera is covered by pyroclastics (low density) of a thickness less than 500m and intruded by narrow
volcanic bodies which may be related to a heat source. There exists a NW-SE buried graben structure that
divides the Eburru massif from the Badlands area. On the contrary, there occurs a major low frequency NE-SW
structure which may be related to the rift structure with the Eburru caldera occurring at its intersection with the N-S
graben structure. Several intrusions exist at the intersections of the NW-SE structure and the N-S fault zone west
of the Eburru volcano.

Present Status of Development
- Explored between 1988-1991
- 6 exploration wells were drilled
- Estimated resource: 200 MW e (20-25 MW e in Eburru areas),
- 2.5 Mwe binary pilot plant to be installed in 2010 by KenGen

Natural/Social Environmental Condition
Power Sector Situation
Power Output Potential
Resource Potential
- Eburru-Badlands: 200MW (estimated), Reconnaissance and detailed surface exploration planned for 2011.
Restricted by National Park
Restricted by Power Demand
None
Rank of Development Priority
Feasibility Study
Potential (Expected) Developer
GDC, KenGen, Private
Proposed Geothermal Development Plan
Outline for Power Development
Possible or Recommended Multi-purpose Geothermal Heat Use
- Supply of fresh water
Scope for Power development
CO2 emission Reduction (1000 tonnes/year)
Proposed Geothermal Development Schedule
Annex-1-2  The Evaluation Sheet of the Eburruto (Kenya) Geothermal Field (2)

(location map of geothermal area in Kenya)
Suswa is the southern-most caldera in the Kenyan Rift Valley. It contains a 12 x 8 km caldera with the rim at an altitude of 1890 m. Suswa is the closest active volcano to Nairobi, the capital of Kenya (50 km).

Accessibility
Suswa lies south of Longonot volcano and about 50 km WNW of the capital city of Nairobi.

Resource characteristics
Geology
Suswa Geothermal Prospect is associated with a central volcano with an outer and inner caldera. The inner caldera has a resurgent block in the middle, which has created a circular trench around the block. The outer caldera has a diameter of about 10 km and the inner caldera has a diameter of approximately 4 km. The mountain has a maximum height of 2356m above sea level with the caldera floor elevation of about 1900m. Geothermal surface manifestations occurring around the outer and inner caldera where near North South structures intersect the calderas, including the trough surrounding the island block make the volcano an attractive prospect for geothermal energy investigations.

Volcanic activity (heat source)
Suswa is the southernmost Quaternary volcanoes in the central Kenya rift. Earlier investigations indicated that the latest magmatic activity in Suswa is estimated to have occurred about 200 years ago within the annular trench in the caldera (Turfanson, 1987a; Turfanson, 1987b; KPC, 1992). The phonolitic nature of the lava implies medium level magma chamber, which could provide a heat source for a geothermal system. NE-SW gravity high sitting directly on Suswa caldera suggesting a massive dense body, most likely to be a shallow magma chamber at depth of 8 km in to NE and 4 km below Oldoinyo Nyukie. This also coincides with a reverse (positive) magnetic anomaly. This could be the heat source.

Geological Structure
All the lava flood formations are heavily faulted trending N-S and NNW-SSE. There are accurate fault systems to the SE and SW which may be acting as up-flows from the reservoirs.

(Past Geological Studies included)
KenGen carried out detailed scientific studies that included geology, geochemistry and geophysics (MT/TEM, Schlumberger, and micro-seismic).

Geochemistry
The presence of a degassing magmatic body is also indicated the presence of solfatara within the annular trench (Omenda, 1993). Low pH of fumarole condensate also suggests close proximity to magma bodies or upflow of a geothermal system (Halldor, 1987; Geotermica Italiana, 1987).

Work done so far
Geochemical studies were carried out on the fumaroles, and the waters from surface water points such as springs and rivers. These included major element chemical analyses on liquid phase samples; gas analyses on samples from fumaroles, isotopic determinations on all fluid sources in the area and soil survey have been done.

Geophysics
Interpretation of DC Schlumberger soundings was conducted by Geotermica Italiana in 1987. Subsequent analysis were added by KenGen geophysicists through MT/TEM and micro-seismic survey.

Gravity
A major NE-SW gravity high sitting directly on the Suswa Caldera with amplitude 250 g.u. and half wavelength of about 12.5 km in the caldera area. The anomaly appears to broaden and extend further south beyond the present area of investigation. The anomaly amplitude within the caldera is more pronounced to the south-west with its peak occurring slightly south of the Oldoinyo Nyukie peak then decreases gently further south. Some smaller anomalies superimposed on the gravity high in the region of the Suswa caldera which could be related to shallow structural variations and geology within and around the caldera. Generally low gravity values towards the west and east.
Interpretation of DC Schlumberger soundings by Geotermica Italiana in 1987 identified 3 anomalous regions of low to intermediate resistivity. The first region was found on the western half of the outer caldera extending to the south and southwest. The second region was found on the eastern slopes of the mountain with a N-S linear trend. The third region was found to NW corner of the prospect area. The boundaries of these anomalies were not defined but appeared to cover large areas.

The geothermal system developed prior to caldera collapse as hydrothermally altered lithics occur within the syn-caldera sequences. The geothermal system must have attained temperatures of more than 250°C as seen from the presence of hydrothermal epidote within the lithics. Gas geothermometry indicate that gases sampled in the prospect originated from sources having temperatures of more than 200°C. The size of the high potential area is not well-defined but is probably within the caldera floor and to the south. Resistivity data indicated that the top of the geothermal reservoir in the caldera is deeper than 1000 m. The prospect has a good recharge from both the west and east rift escarpments. Water table is probably lower than 300 m below the floor of the valley in the vicinity of Suswa or greater than 600 m below the caldera floor. Recharge could be mainly from western and eastern escarpments and hydraulic gradient from the north.

The existing investigations have inferred the presence of a geothermal resource in the Suswa prospect. However before exploratory drilling can commence there is need to carry out more detailed work (mainly involving MT resistivity and TEM) in western, southern and north-western parts of the caldera and if possible a few stations on the Central Island, areas that look promising from the analysis.

600MW (estimated): Detailed surface exploration has been done. Exploration drilling to commence 2011.
Longonot Volcano Caldera is located east of Olkaria geothermal field on the floor of the rift valley. It consists of a variety of structures on the western and the southern parts which mark remnants of a caldera boundaries. The area is a porphyring of fumaroles, hydrothermal springs and other manifestations that occur in the form of hot springs, altered grounds, fumaroles deposition and Cssuric deposition.

Resource Characteristics

Geology

It is a geothermal field that has been characterized by active manifestations that occur in the form of hot springs, altered grounds, fumaroles deposition and a variety of volcanic activities. The area is marked by active manifestations that occur in the form of fumaroles, hydrothermal springs and other manifestations that occur in the form of hot springs, altered grounds, fumaroles deposition and a variety of volcanic activities.

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Two shallow low (<10 ohm-m) resistivity anomalies were mapped. Interpretation of the data suggests a deep low resistivity anomaly exists in the area. The tilt anomaly lies to the south and southwest of the Longonot summit but within the caldera and covers about 15 km². It is shallower to the south of Longonot but deepens to the north. The anisotropy of the study area shows high (>20 ohm-m) resistivity. The low resistivity anomaly is attributed to lower subsurface temperatures, higher degree of hydrothermal alteration and higher permeability. The areas of higher subsurface resistivity are attributed to lower temperatures, lower degree of hydrothermal alteration and a deeper heat source. The heat source is postulated to be shallower to the south of the crater and deeper to the north as shown by RT interpretation.

Geophysical data has also mapped two resistivity areas that are coincident with regional NE and NW trending faults that cut across the rift floor through the geothermal prospect. Their interpretation is that these faults control fluid flow.

**Conceptual Model**

The prospect area is faulted through the faults are completely covered by the Quaternary lavas and pyroclastics from Longonot and adjacent volcanic centres. The area is most likely roofed by the Frank lavas from the western part of the rift floor. The deep temperature anisotropy of the study area is southwards and therefore the temperature from the south to the north is quite possible. The study area shows high (>20 ohm-m) resistivity. The low resistivity anomaly is attributed to lower subsurface temperatures, higher degree of hydrothermal alteration and higher permeability. The areas of higher subsurface resistivity are attributed to lower temperatures, lower degree of hydrothermal alteration and a deeper heat source. The heat source is postulated to be shallower to the south of the crater and deeper to the north as shown by RT interpretation.

**Resource Potential**

**Power Output Potential**

750MW (estimated). Detailed surface exploration have been done. Exploration drilling to commence mid-2010.

**Restrictions**

- Restricted by National Park
- Restricted by Power Demand

**Outline for Power Development**

Possible or Recommended Multi-purpose Geothermal Heat Use

**CO2 emission Reduction ('000 tonne/year)**

**Geothermal fluid flow model of Longonot field**

**Geothermal fluid flow model of Longonot field**

**Geothermal fluid flow model of Longonot field**
Annex-1-5  The Evaluation Sheet of the Menengai (Kenya) Geothermal Field (1)

**Field Name**: Menengai

**Province/Location**: The Menengai Caldera geothermal prospect is located to the E of the Rift Valley Province E of the Uluguru and Elgon mountains.

**Location**: The Menengai Caldera geothermal prospect is located in the Rift Valley Province E of the Uluguru and Elgon mountains.

**Resource Characteristics**

**Geology**: Menengai geothermal prospect is located within an area characterized by a complex tectonic activity associated with the rift triple junction. This is a zone at which the failed rift arm of the Nyanza rift joins the main Kenya rift. The Kenya rift is characterized by extensional tectonics where the E-W tensional forces resulted in block faulting, which include tilted blocks as evident in both the floor and scarps of the rift. Narrow scarps that show tilt effects of movements and have been eroded resulting in gentle scarps characterize the western margin. The eastern margin shows deep grabens and faulted inliers of steep scarps implying recent active movements. This is further confirmed by the presence of a detachment fault (bound by tectonic faults) that runs for hundreds of kilometers. The rift trough is partly tectonic normal faults that clearly represent controlled extensional tectonics under the rift floor. Two rift floor and scarps faults (TVAs) that are important in controlling the geothermal system in study area include the Molo and the Solai TVA.

**Volcanic activity (field source)**: The surface in proximity to volcanoes shows mafic pyroclastics emplaced from centres associated with Menengai volcanoes. Young lavas and cinder cones on the rift and the plateau show that this part of the rift is still in an active phase. The rift floor is characterized by scattered shallow fumaroles and widespread hot springs. The Mlili kiosk depression indicates a vast magmatic body underlying the volcano. The fractured structure (rift and post-caldera) which is evident in the rift zone, suggest that the magma body could still be active.

**Geological Structure**: The location of Menengai prospect on the rift floor where the hydrogeological regime comprises of recharge from the higher rift scarps and the intense rift floor thermal anomalies resulting from extensional tectonics of continental rifting, provide for a good structural setup that allows water from the rift scarps to penetrate deep into the crust. The water then flows into the rift floor through the hot magnetic materials that are found in the rift floor and the normal faults provide conduits for the hot fluids to percolate from depth into possible geothermal reservoirs at shallower depths. The regional block TVA may be such an important conduit of deep fluids than an important geothermal controlling feature in the area.

**Field geological Studies (radiated)**: Inventory of hydrothermal features, geological mapping and Petrographic studies.

**Geochemistry**: The geochemical survey in Menengai prospect conducted involved fumarole sampling and soil gas survey with emphasis on carbon dioxide (CO2) and radon (Rn-222) radioactivity in the soil air. The soil gas survey was conducted along traverse lines running E-W and were 1500 m apart while the sample points were taken at 500 m in areas with visible surface geothermal manifestations and wider apart in areas no manifestations.

**Geophysics**: Gravity and seismology data from studies of the Menengai area identified bodies postulated as magma chambers that could constitute the heat sources directly beneath the caldera (Geochemistry, 1997). On the basis of these previous surface exploration activities at Menengai geothermal prospect, three sites were proposed for exploration wells.

**Risk area so far**: The general geothermal water wells are located on the caldera and near the fumarole fields and rivers. These included major element chemical analyses on liquid phase samples; gas analyses on samples from fumaroles, isotopic determinations on all fluid sources in the area and soil survey have been done.

**Geological map of Menengai field and around**

**Location map of Menengai Field**

**Map of Menengai Field**

**LEGEND**

- Rift floor fault
- Fault inferred
- Rift floor block
- Major (rift scarp)
- Fumarole
- Hot spring
- Fumarolic issue
- Rift floor
- Road
- Railway line
- Lake, Pond
A high temperature geothermal system exists under Menengai caldera within the prospect. It is postulated that the geothermal reservoir is at temperatures of more than 250°C as inferred from gas geothermometry. It is envisaged that the reservoir is hosted within fractured trachytes and associated pyroclastics of the Menengai shield formation and flood trachytes of the Kenya rift floor. The intense fracturing of the formations is likely to have created high permeability within the reservoir. However, it is expected that some regions could have effects of sealing by pipe fractures. It is modelled that the reservoir primarily exists within but with extensions to the west and north of the caldera.

The main upflow of the geothermal fluids is postulated to be around the centre of the caldera and extending mainly west and northwest of the caldera. Resistivity data indicates the eastern half of the caldera to have relatively less potential as evidenced by higher values. The top of the reservoir is to be expected to be between 500-1,000 m depth and outflows at shallow levels to the east, west and north. However, it is not clear yet whether some of the outflows are connected with deeper reservoirs.

**Present Status of Development**

Drilling of exploratory wells represents the final phase of any geothermal exploration programme and is the only means of confirming the characteristics and potential of a geothermal reservoir. Based on results of the present study, it is concluded that Menengai has a high potential that warrants further exploration by drilling deep geothermal exploration wells. Based on results of the present study, it is concluded that Menengai has a high potential that warrants further exploration by drilling deep geothermal exploration wells. But before commencement of exploratory drilling, a full EIA study for the prospect area should be carried out. Further, the northern extent of the resource along the Molo and Solai TVA’s requires further investigation as preliminary studies indicate possible existence of geothermal systems. The surface studies should also be extended northwards to include Arus-Lake Bogoria area.

**Natural/Social Environmental Condition**

**Electric Sector Situation**

**Power Output Potential**

Resource Potential 1200MW (estimated); Detailed surface exploration done; Exploration drilling to commence mid-2010.

**Restrictions by National Park**

None

**Rank of Development Priority**

A

**Potential (Expected) Developer**

GDC (state-owned company)

**Proposed Geothermal Development Plan**

Outline for Power Development

The 840MWe power generation in Menengai prospect will be conducted in 6 phases (140MWe x 6 phases). The demand of electricity in Kenya is large, so a large scale power plant development as far as resource available is recommendable.

Possible or Recommended Multi-purpose Geothermal Heat Use

Lake

Caldera wall

Prospect area

**Proposed Geothermal Development Schedule**

**Location Map**

**Other Figures**

Geological structure of Kenya rift floor between Lake Naivasha and Lake Baringo

Fluid flow structure of Menengai field

MT resistivity map (altitude=2,000m) and planned well site of Menengai field
Field Name: Arus Bogoria

Country: Kenya
Province/Location: Arus and Lake Bogoria prospects is located within the Kenya Rift valley immediately south of Lake Baringo prospect and north of Menengai prospect. It is included mostly in the Baringo and Nakuru Districts and also extends parts of Nandi District and the area is bounded by longitudes 35°50’ and 36°10’ E and latitudes 0°00’ (Equator) 0°30’ N and is approximately 2000 km².

Accessibility/Communication: The prospect area is well served by a network of both all-weather and murram tracks and therefore is fairly accessible. Nakuru-Kabarnet tarmac road run across the prospect area near the western boundary from north to south. Theseasonal flood makes navigation difficult in the rainy season when the roads are turned into muddy tracks. These roads are usually free of obstacles except for occasional narrow bridges and washed-out sections.

Resource Characteristics:

Geology: The upper Plio-Pleistocene volcanism of the rift floor in the area between Arus and Lake Bogoria is characterized by large volumes of evolved lavas that consist mainly of peralkaline trachyte, trachyphonolite, and phonolite. Small outcrops of basaltic lavas occur in isolated areas within the prospect. The northern sector is, however, dominated by fluvial and alluvial deposits.

Volcanic activity (heat source): Major faults extended along the western side forming half graben bounded by monoclinic flexure on eastern side and development of major basaltic-trachytic shield volcanoes occurring. Major faults developed as the eastern block went into half graben changing into full graben accompanied by basaltic-volcanic eruptions. The formation of the graben structure started about 1 million years ago and was followed by fossil eruptions. The end of the rift is seen today as a 300 km long fault zone by about 1 million years ago. During the last 2 million years, active volcanoes became more intense while the area of the Cape town shield has subsided. The rift has been a very active zone for the past two to three million years.

Structure: The main structural features in the Arus and Lake Bogoria areas include; the eastern rift flank, the rift proper, NW, NNE, and N-S trending faults and fractures and the Marigat and Loboi lineaments. The most prominent of the NW trending faults zone display an en echelon displacement to the west.

Geochemistry: From the study done in the middle 2000's, geochemical exploration provides a greater understanding of the location, nature and origin of the thermal waters in a geothermal system. In addition, an insight into the recharge mechanism of these areas is obtained. These areas were employed during exploration of Arus-Bogoriawere, Magneto telluric (MT), Transient Electromagnetic (TEM) and Gravity.

Work done so far: Geochemical investigations of this area were carried out by Geotermica Italiana Srl, (1987) and Ministry of Energy (MOE) in 1985-1986 under the auspices of the United Nations Department for Technical Development (DTCD). The work by Omenda et al. (2001) focused on the western fault zone supplied water from the Arus-Bogoria geothermal system at Arus and Lake Bogoria prospects. Further surface exploration work has been carried out in the mid of 2000's by KenGen on behalf of the Ministry.

Annex-1-6: The Evaluation Sheet of the Arus Bogoria (Kenya) Geothermal Field (1)

Conceptualized Model of the Lake Bogoria Geothermal Prospect

Geologic Map of the Arus-Bogoria Geothermal Prospect

Location of MT soundings and interpreted profiles across the Arus-Bogoria region
The gravity measurements were carried out using Lacoste and Romberg gravimeter model G-767. One hundred twenty data points were collected in the Arus and Lake Bogoria prospects. These were merged with data collected by Resistivity techniques over a frequency range. The lower frequency penetrates deeper than higher frequencies. MT sounding is measured over a frequency range. The lower frequency penetrates deeper than higher frequencies. MT techniques acquire data in frequencies ranging from about 400 Hz to 0.0000129 Hz (a period of about 21.5 h), and are suitable for deeper investigations. Processing, analysis and interpretation of the MT data was carried out using the computer software WinGLink and the results presented by resistivity iso-maps at various elevations and cross-sections.

Present Status of Development

According to the recommendation of the Exploration study report prepared by KenGen in 2006, 6 exploration wells (>2,000 m) were selected to drill in the Arus-Lake Bogoria prospect to confirm and characterize the geothermal systems. The Structural controls of the hydrogeology and hydrothermal activity in the Arus and Lake Bogoria geothermal prospects

Map of the drainage system in the Arus and Lake Bogoria geothermal prospects

Map of the Kenya Rift showing the locations of major central volcanoes and the Arus and Lake Bogoria geothermal prospects

The Structural controls of the hydrogeology and hydrothermal activity in the Arus and Lake Bogoria prospect
The area referred to as "Lake Baringo Geothermal Prospect" is located within the eastern floor of the Kenya Rift valley. It is bound by latitudes 0°30'N and 0°45'N and longitudes 35°59'E and 36°10'E. Lake Baringo is a 40 km2 body of water, now about 80 meters deep, divided into two basins by a 3 km wide strip of land known as the "Loruk Ridge". The northern basin is shallower than the southern basin, which has a maximum depth of 80 meters.

Geology

Hydrothermal activity in the Lake Baringo prospect is manifested by extensive occurrence of fumaroles, hot springs, altered grounds and thermally anomalous groundwater boreholes. One of these boreholes, the Chepkoiyo borehole, which was drilled in April 2004, self discharged water at 98°C (local boiling point). The chemistry of the borehole water is typical of geothermal waters. The borehole also encountered thin, fractured, and altered sediments.

Geological Structure

The structural pattern of the Lake Baringo area is complex due to interaction between the old and young fault systems in the area. The dominant structure in the prospect is the young N to NNE trending fault pattern that forms a dense fault swarm restricted to the rift axis. Within the prospect, the faults dip west and east for those to the east and west of Lake Baringo, respectively. The main faults in the prospect have dips of up to 100°.

Geophysics

A geophysical survey comprising of gravity, ground magnetics, MT and TEM methods was carried out between May and June, 2004 in order to investigate the thickness of the sedimentary basins and the anticipated geothermal sources. The survey covered an area of 250 x 250 km².

Bouguer Anomaly Distribution in the Lake Baringo Geothermal Prospect

Shallow boreholes locations in the Lake Baringo Geothermal Prospect

Figure 2.2 Structural map of the area around Lake Baringo Geothermal Prospect: Major (Precambrian?) lineaments (Shear zones)
Conceptual Model

Geoscientific data indicate existence of a geothermal resource in Lake Baringo prospect, which is characterized by intermediate to high temperatures.

Present Status of Development

The results of the existing investigations clearly show that a geothermal system exists in the Lake Baringo prospect. The system's heat sources comprise of dyke swarms and small shallow magma bodies at faults that have intruded an already thinned crust. Subsurface permeability/reservoir host rocks are due to intensive fracturing due to shallow fluidization and intense faulting, which resulted in the movement of the lithosphere to its current location. The systems are therefore restricted mainly to fault zones and are discrete.

The following further work are necessary:

1. The northern extent of the resource requires further investigation as preliminary studies indicate possible outflow of Korosi. The surface studies should also be extended northwards to include Korosi and Chepchuk prospects.
2. Additional MT and TEM soundings would be necessary to increase density of sounding locations and thus improve the geothermal models. The area south of the OL-Kokwa Island needs further investigation to confirm, or otherwise, the existence of a geothermal resource.
3. Seismic studies on focal mechanisms and swarm activity location determinations are needed to be done. It is possible that the shallow seismic is due to fluid migration from deep geothermal zones.
4. Down-hole temperature and pressure profiles of boreholes, which are accessible, needs to be carried out.
5. A full Environmental Impact Assessment study for the prospect area should be carried out before commencement of any activity.

Simplified Geothermal Model of Lake Baringo Geothermal Prospect

Resource Potential


Power Sector Situation

Small-unit generation of electricity, through medium-low temperature geothermal waters (90-160°C), is particularly of interest due to the demand for cheap energy source is high and ever increasing.

Proposed Location for Exploratory Wells (BW-1 and BW-2) in the Lake Baringo Geothermal Prospect

Table 1: Chemical composition of water samples from Baringo boreholes

<table>
<thead>
<tr>
<th>borehole</th>
<th>Na (mM)</th>
<th>K (mM)</th>
<th>Mg (mM)</th>
<th>Ca (mM)</th>
<th>HCO₃⁻ (mM)</th>
<th>CO₂ (mM)</th>
<th>Cl⁻ (mM)</th>
<th>SO₄²⁻ (mM)</th>
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<tr>
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<td>526.3</td>
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<td>16.5</td>
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Legend

- Preparied & Printed at: GIS-Lab
- Contours
- Roads
- Lakes
- Gulleys
- Preparied & Printed at: GIS-Lab

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Proposed Location for Exploratory Wells (BW-1 and BW-2) in the Lake Baringo Geothermal Prospect
Annex 1-8  The Evaluation Sheet of the Lake Korosi (Kenya) Geothermal Field (1)

Field Name  Korosi
Country  Kenya Province/Location  Korosi - Chepchuk area is located in Baringo district of the Kenyan Rift Valley and is neighboring Lake Baringo to the south and Paka volcano to the north at approximately 00° 45'N, 36°05' E. The volcano occupies an area of about 5.6 km² and rises to about 500 m above the surrounding floor of the inner trough of the rift valley, reaching a maximum height of 1446 masl on the summit cone of Kotang in the northeast.

Accessibility  An all weather Marigat-Loruk road provides access to the area. The road branches at Loruk with one branch continuing eastwards passing the eastern side of Korosi, Chepchuk and Paka through Tangulbei and Churo before joining the ... branch. A rough track extending in an E-W direction between Nyipkat and Tangulbei provides access to the northern flanks of both Korosi and Chepchuk volcanoes.

The area is served by a network a fixed line telephone communication at most shopping centres within the area. Satellite phones can be accessed everywhere within the prospect area.

Resource Characteristics

Geology  The geology of Korosi is mainly dominated by the intermediate lavas (trachytes and trachy-andesite), 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. Upon which lesser amounts of basalt, mugearite and pyroclastic deposits have erupted.

The main faulting and basaltic activity was followed by the eruption of Upper Trachyte lavas, domes and pumice scoria cones, which are aligned along the NNW-trending faults. The majority of the lavas were erupted from the northern part of the area with noticeable climbing of the lava flow down the flanks of the volcanoes. The eruption of the lavas was controlled by faults and adjacent structural weaknesses. The airfall pyroclastic deposits dominate the western plains.

Structural development of the Korosi segment of the rift occurred between 5.3-1.6±0.01 Ma with the landscape as it is today having been formed during the latest 100,000 yrs BP. The structural setup of the area is defined by dominant NNE- to NE-trending structural elements. The occurrence of cinder cones and other volcanic centres are controlled by the major N and NNE trending faults.

Geochemistry  Fumarole steam chemistry indicate reservoir temperatures in the range of 200- 280 °C for both Chepchuk and Korosi prospects calculated using gas based geothermometers (TH2S). The fumaroles with the highest calculated geothermometry temperatures are found around Chepchuk (209 – 282 °C) and around Korosi (244 – 259 °C).

Work done so far  Fumarole steam discharges, borehole waters and carbon dioxide in soil gas were sampled and analysed. The results have been used to estimate reservoir temperatures based on geothermal history. Further exploration study, (2005-2006).

Location

Bouguer Anomaly Distribution in the Korosi-Chepchuk area. The triangular symbols indicate the locations of the geology stations.
Geophysics Gravity and Ground Magnetic surveys, Transient-ElectroMagnetic (TEM) measurements, Magnetotelluric (MT) measurements and Micro Seismic data collection were carried out in KenGen surface exploration study (2005-2006). A total of 100 TEM soundings, 36 MT soundings, 280 Gravity stations and 280 Ground Magnetic stations were covered. Results of these investigations have been used to infer the depth and extend of the possible heat source and geothermal reservoir and to site the exploration wells.

Gravity/Magnetics Aeromagnetic data exist over much of the Kenya rift valley. The data was collected by CCG for the National Oil Corporation of Kenya (NOCK, 1987). These data were examined along with gravity anomalies and a qualitative interpretation carried out over the Korosi-Chepchuk prospect. Magnetic anomalies were here not different from those over these coinciding with volcanic centres at Korosi, Olkaria, Chyulu and Meru. These anomalies are interpreted as being caused by changes in the susceptibilities of rocks due to magnetization by heating above the Curie point. It is observed that, both from gravity and magnetic data that an anomalous area exists in the central part trending in a NW direction, coinciding with the volcanic centres of Korosi, Chepchuk and Paka. The gravity and magnetic signatures suggest shallow magnetic intrusions.

These could be providing the heat source to possible geothermal reservoirs. The data shows that there could be a large resource in the western and north western parts of the prospect.

Resistivity (MT/TEM) From the resistivity results from TEM and MT suggest that the Korosi-Chepchuk prospect appears to host three large geothermal systems occupying the immediate NW of Lake Baringo (near Loruk centre), NW of Korosi massive and NE of Chepchuk. The resistivity cross-sections show low resistivity anomalies at depth that could be related to heat sources.

A high temperature geothermal resource do exist in the Korosi and therefore deep wells (~2000 m), should be drilled in the central northern portion of Korosi volcanic massif is proposed as the target area.

The reservoir rocks in the prospect are hypothesized to be either Loyamarok Trachy-phonolite or Baringo Trachyte together with associated volcanic rocks.

Natural/Social Environmental Condition

Restrict ted by National Park

L: Mt. Kenya region

Power Output Potential

Proposed Geothermal Development Plan

MT location

Baringo filtered gravity map of the northern part of the Kenya rift. (March, 2004)
Field Name Paka
Country Kenya
Province/Location Paka is situated approximately 25 km north of Lake Baringo at 00°25'N and 36°12'E, it is one of the promising prospects in the North Rift. The area covered by this survey extended about 400 km² around the volcano massif.

Accessibility/Communication
Paka Volcano lies in the inner trough of the Kenya Rift. The volcano massif extends over an area of about 280 km² and rises between 600-700 m above the rift floor. The central volcano (Paka) rising to a height of 1697 m asl, which is filled with young basaltic flows.

Several cross-cutting faults were observed in the WNW-ESE orientation (plate 1). The volcano is cut on its central and northern flanks by a series of fault and fractures. The main faults enclose the geothermal system at Paka, forming a low-angle fault zone extending in the main WNW direction.

Resource Sub-domain
Geology
Paka Volcano lies in the inner trough of the Kenya Rift. The volcano massif extends over an area of about 280 km² and rises between 600-700 m above the rift floor. The central volcano (Paka) rising to a height of 1697 m asl, which is filled with young basaltic flows.

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The central volcano (Paka) rising to a height of 1697 m asl, which is filled with young basaltic flows. The area covered by this survey extended about 400 km² around the volcano massif.

Geological Structure
The main structural features in the northern sector of the Kenya Rift where the prospect is located include; the eastern rift flank, the rift proper, the caldera, NW, NNE and N-S trending faults and fractures. The structure of Paka is dominated by a broad zone of normal faulting 7.5 km wide, bounded by the eastern and the western fault boundaries respectively. This zone shows a right stepping en echelon pattern, which extends southwards to Chepchesong and northwards to the northern face of Baringo. The general direction of the faults is N-S, but to the north of the summit, it shows arcuation into a NE-SW trend.

Past Geological Studies
Detailed surface investigations in Paka were carried out between September 2006 and April 2007 period by a team of KenGen Scientists and Engineers. Detailed geological and hydro-geological surveys were carried out to determine the volcanostructure of the Paka and surrounding.

Geochemistry
In some of these areas maximum temperatures exceeded the boiling point with the maximum temperature recorded being slightly over 97°C. Occurrences of sulphur were observed in the fumaroles in the Eastern crater and in an indication that these faults are deep seated, and stopping directly from the magma.

Several cross-cutting faults were observed in the WNW-ESE orientation and in the southern sector of the volcano. The faults are characterized by different types of fractures, some of which are well-developed and others are limited to small fractures. The main faults enclose the geothermal system at Paka, forming a low-angle fault zone extending in the main WNW direction.

Work done so far
Sampling of water, boreholes, fumaroles and steamy grounds was carried out to monitor the possible physical qualities of possible geothermal reservoir at the subsurface.
Geophysical methods including MT, TEM and gravity methods were employed to determine the subsurface structures that may control and contribute to existence of geothermal system. Gravity

A very conductive body directly below the Paka massif at depth of about 3km, which is a zone that has been intruded by magmatic material, could be one of the main heat sources for the geothermal activity in the prospect. This zone is relatively low resistivity showing extensive low resistivity altered formation covering all valleys and lower slopes of the Paka massif. Thus major leakage from the geothermal system occurs only on the volcano cone.

Well Drilling

The Paka geothermal prospect has very few boreholes drilled in the area. The boreholes were sampled simultaneously with volcanic fumaroles.

Temperature Survey

An attempt was made to apply various geothermometry functions to the thermal waters that were sampled in the geothermal prospect. The borehole geothermometry temperatures for the borehole waters yield very high temperatures. These range from 182 to 351°C for the borehole water in Orus to those at Nginyang.

Well Testing

None.

Conceptual Model

A geothermal system at Paka driven by a heat source at depth and entered below the summit crater and extending to the east. A 4km wide graben structure running NNE across the volcano massif being a main structural control on the geothermal system extend eastwards. The high geothermal anomalies may be related to the graben-like structure.

Well Drilling

Deep exploratory drilling in the volcanic edifice of Paka to confirm the geothermal reservoir and enable direct measurements into the subsurface, and determination of petro-physical state of the reservoir.

Natural/socio-environmental consideration

A base-line inventory was undertaken to create an inventory of the present status and predict any possible environmental impact that development/utilization of the geothermal resource in the area might have. Paka volcano is the center of one of the local communities who are mainly living on livestock and the environment cannot support other form of farming. Development of the geothermal resource at Paka would have a very positive socio-economic impact to the population of this area.

Power Sector Situation

Power Output Potential


Rank of Development Priority

A geothermal system at Paka driven by a heat source at depth and entered below the summit crater and extending to the east. A 4km wide graben structure running NNE across the volcano massif being a main structural control on the geothermal system extend eastwards. The high geothermal anomalies may be related to the graben-like structure.

Potential for multi-purpose geothermal heat use

Table 4.3: Aqueous geothermometry temperatures from Paka geothermal prospect.

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Figure 5.1 Temperature distribution at Paka (one metre depth).

Figure 7.2 Conceptual model of the geothermal system at Paka.
Field Name: Silali
Country: Kenya
Province/Location: Silali Volcano is located in the northern Kenyan rift valley, 1°10’N, 36°12’E.

Accessibility: Since the area is not motorable, the planned survey will be carried out using a helicopter so as to access the caldera floor and other difficult areas. Already helicopter services have been procured.

Resource Characteristics

Geology: Silali is the largest Quaternary caldera volcano in the northern Gregory Rift and is composed predominantly of peralkaline trachytic lavas and pyroclastic deposits, and mildly alkaline to transitional basalts. It contains a spectacular 8 x 5 km diameter summit caldera which formed 63,000 years ago. The steep caldera walls are up to 300 m high. The summit of Silali volcano rises 800 m above the surrounding terrain. The floor of the surrounding plain slopes northward from an altitude of 800 m to 600 m towards Emsuaguopiak. The surface features in Silali are manifested to the western slopes of the volcano in form of hot springs at Kapedo while the eastern part is characterized by numerous fumaroles and widespread hot and altered grounds with surface temperatures ranging from 65-90°C. The series of springs (Kapedo) to the western side discharge at temperatures of 45-55°C with a combined estimated flow-rate of about 1,000 l/s.

Volcanic activity (heat source): Detailed mapping combined with radiometric 40Ar/39Ar age determinations is used to constrain the evolutionary development of Silali. Activity commenced at c. 400–220 ka with the construction of a low relief lava shield whose summit area was subsequently modified by alternating periods of faulting, subsidence and inflating associated with two major periods of explosive activity. This activity ceased around 123–131 ka and was probably the result of fracturing and decompression of a high level magma chamber by regional extension and the injection of basaltic styles below the volcano. Later eruptions (c. 120 ka) along the western flanks migrated eastward with time and overlapped in the eruption of viscous trachyte lavas from a circumferential fissure zone. The emplacement of a basalt style lava swarm to shallow crustal levels beneath Silali resulted in the formation a broad volcanic rift zone within which large volumes of fluid basalt was erupted to mantle the flanks of the volcano. This activity mainly pre-dated, but probably also overlapped with, incremental subsidence and asymmetric downsagging of the summit area and the previous geothermal activity is present in the caldera and upper eastern flanks. Some eruptions may have occurred a few hundred years ago.

Geological Structure/Geographical Features: Early eruptions of Silali volcano formed a 500 m high lava shield. Construction of the shield was followed by eruption of Kapelo tuffs from pyroclastic cones on the western flanks. Eruption of Kapelo tuffs was followed by major eruption of summit trachytes which cover most of the western slopes. Lava was erupted from a lava tube rather than from a cone. Eruption of Kapedo basalt from fissures covered all of the western slopes. This stage was followed by development of three cones at the base of the east facing summit scarp. Lava flows from the cones extended northwards. The final stages of Silali volcano evolution involved the emplacement of Black Hills mounds on the upper eastern flanks of the mountain. Geothermal activity is present in the caldera and upper eastern flanks. Some eruptions may have occurred a few hundred years ago.

Past Geological Studies included: The reconnaissance survey in Silali was carried out late in 2009 and the inception report which includes the work program and logistics was prepared.
**Geochemistry**
Silali has some of the largest hot springs within the Kenya rift, indicating high likelihood of existence of a geothermal system under the volcano. It is estimated that Kapedo, which is one of the hot springs, associated with Silali, discharges 1000 liters per second of water at 50 to 55°C. This translates into about 100 MW from this region alone. Fluid chemistry, however, indicates that the fluids are not directly from the up flow but have undergone interaction with shallow ground waters.

**Work done so far**
Detailed geoscientific studies will be carried out in 2009-2010.

**Geophysics**
Detailed geoscientific studies will be carried out in 2009-2010.

**Gravity/magnetic**
The presence of a positive magnetic anomaly that is consistent with the dimensions of the caldera is further proof of the presence of a hot body under the caldera. High 3He/4He suggests the proximity of the fumaroles in Silali to a shallow magmatic body. Seismic studies indicate high activity in the east and south east of the caldera floor, which could be related to a geothermal system.

**Resistivity**
Detailed geoscientific studies will be carried out in 2009-2010.

**Well testing**
Exploration drilling is planned to be carried out in 2010-2011.

**Temperature survey**

**Well testing**

**Conceptual Model**
The model for the system can be explained in terms of an up flow within the caldera with a resource area being probably more than 75 km². The fluid then outflow mainly to the west and north through formational contacts and faults and fractures discharging on the surface at Kapedo springs and other manifestations in the area. The resource in the prospect is estimated equal to more than 300 MW for 25 years.

**Present Status of Development**
The Geo-scientific work to be carried out in Silali prospect will involve broadly the following:
- Geological mapping of the rock formations, structural mapping, hydrogeological and volcanological studies of the area,
- Geophysical measurements that shall include resistivity (MT and TEM),
- Geochemical sampling for fumarole steam, water points and soil gas survey,
- Heat loss measurements,
- GIS data acquisition
- Environmental baseline data collection

**Natural/Social Environmental Condition**

**Power Sector Situation**

**Power Output Potential**

**Resource Potential**
800 MW (estimated): Reconnaissance has been completed. Detailed Surface exploration to commence mid-2010 and exploration drilling planned for 2011.

**Restricted by National Park**

**Restricted by Power Demand**

**Rank of Development Priority**
Situated highly among the prospects to be developed. From the result of the regional reconnaissance survey data available. The volcano is very promising.

**Potential (Expected) Developer**

**Proposed Geothermal Development Plan**

**Outline for Power Development**

**Possible or Recommended Multi-purpose Geothermal Heat Use**

**Scope for Power development**

**Proposal for Power Development Schedule**

Kapedo hot springs discharging 1,000 L/s of hot water at 55°C.
### Field Name
Emuruangogolak

### Country
Kenya

### Province/Location
Emuruangogolak volcano is located 100 km south of Lake Turkana, at the narrowest part of the Baringo-Suguta trough. The rift valley at this latitude is about 125 km, wide. The volcano covers an area of about 600 sq km and rises to over 700 m above the rift floor. It has maximum E-W and N-S dimensions of 20 and 32 km respectively.

### Resource Characteristics

#### Geology
The broad Emuruangogolak shield volcano is situated at a narrow constriction in the Gregory Rift and almost completely straddles it. A 5 x 3.5 km summit caldera formed about 38,000 years ago. Since then trachytic and basaltic lava flows were erupted on the northern and southern flanks and within the caldera. A NNE-SSW-trending chain of lake-filled basaltic maars extends along the floor of the rift from the lower flanks of the volcano. Young lava flows were also erupted from vents along rift valley faults. Well-preserved parasitic cones erupted along rift-parallel faults cutting the volcano abound; the latest eruption produced a trachytic lava flow dated from secular magnetic variation measurements at about the beginning of the 20th century. Fumarolic activity and hot steaming ground occurs along NNE-trending fissures within the caldera and along the lower NW flanks.

Volcanic activity (heat source)
Volcanic activity commenced about one million years ago. Hot ground and fumaroles are located along fissures within the caldera and lower NW flanks. Emuruangogolak has experienced two episodes of summit collapse which produced shallow nested calderas. Parasitic pyroclastic cones situated on the upper western flanks of Emuruangogolak and represent Pre-caldera I Pyroclastic Activity.

The dimensions of the first caldera measure 9 × 7.5 km, slightly elongated along a north-west/south-east orientation. The caldera I wall is preserved as a 5 km section running south from Enambaba cone. On the eastern side of the volcano, the caldera I fault is difficult to identify. To the north caldera I rim is buried beneath eruption products from Enambaba and Nakot.

The second caldera measures 3.5 × 4.5 km and like the first, is elongated along a north-west/south-east direction. The maximum height of the caldera II wall of 75 m occurs on the south side. Basalt lava was erupted from the summit area soon after the second caldera collapse.

The most recent lava flow on Emuruangogolak is a trachyte block lava, erupted from a small cone lyin

#### Geological Structure
(Past Geological Studies included)

#### Geochemistry
Geothermal manifestations, some of which are at boiling point, suggests the presence of a geothermal system which gas geothermometry indicates to be at temperatures of 200°C to 350°C. Abundance of fumaroles at higher temperatures on the eastern half of the caldera floor may imply a better geothermal system in that segment.

#### Work done so far

#### Geophysics
- Gravity
- Resistivity
- Well Drilling

- Temperature Survey
- Well testing

#### Conceptual Model
It is anticipated that the recharge of the geothermal system is good as shown by the occurrence of hot springs on the eastern flanks of the volcano. It can be modeled that the geothermal fluid up flows within the caldera floor and immediate environs and largely outflows to the north and west. The geothermal prospect is capable of supporting more than 200 MW for 25 years.

#### Present Status of Development

### Natural/Social Environmental Condition

### Power Sector Situation

### Power Output Potential

- Resource Potential


#### Rank of Development Priority

#### Potential (Expected) Developer

#### Proposed Geothermal Development Plan

Outline for Power Development

#### Possible or Recommended Multi-purpose Geothermal Heat Use

#### Scope for Power development

- CO2 emission Reduction (1000 tonne/year)
- Proposed Geothermal Development Schedule

### Location Map

### Other Figures
### Field Name
Namarunu

### Country
Kenya

### Province/Location
Namarunu is located south of the Barrier Volcano in northern Kenya. Hot springs are located at the volcano.

### Geology
The largely Pliocene Namarunu trachytic shield volcano is topped by parasitic cones and lava flows of upper Pleistocene and Holocene age. Voluminous basaltic effusive and explosive activity took place during the early Holocene on the lower northern, eastern, and southern flanks along the axis of the East African Rift, producing fissure-controlled subaerial basaltic scoria cones and lava flows, and partially or completely sublacustral tuff cones, tuff rings, and pillow lavas. Fluid olivine basalts were also erupted from a breached scoria cone forming the summit of Namarunu. The youngest eruptions postdated the drying out of Lake Sugata about 3000 years ago. Some could be as recent as the historical eruptions at The Barrier volcano to the north (Dunkley et al., 1993). Hot springs are located on some of the young volcanic cones on the rift valley floor and on the eastern side of the rift along the base of the Tirr Tirr Plateau.

### Geological Structure
(Past Geological Studies included)

### Geochemistry
Fumaroles at temperatures ranging from 30 to 100 °C occur at the foot of eastern and western fault scarps. Fluid geothermometry indicates a reservoir at temperatures of more than 200 °C. The hottest springs occur along the eastern fault. Hydrological flow patterns indicate that recharge for the Namarunu prospect is largely from the east and south. The hot springs on the west are probably directly associated with a geothermal system in the south and south-east of Namarunu volcanic area. The area is capable of generating more than 20 MW using binary technology.

### Work done so far
Geophysics
- Gravity
- Resistivity
- Well Drilling
  - Temperature Survey
  - Well testing
- Conceptual Model

### Present Status of Development

### Natural/Social Environmental Condition

### Power Sector Situation
Power Output Potential
- Resource Potential
- Restricted by National Park
- Restricted by Power Demand

400 MW (estimated): Reconnaissance and detailed exploration planned for 2011.

### Rank of Development Priority

### Potential (Expected) Developer

### Proposed Geothermal Development Plan

Outline for Power Development
- Possible or Recommended Multi-purpose Geothermal Heat Use

Scope for Power development
- CO2 emission Reduction ('000 tonne/year)

### Proposed Geothermal Development Schedule

### Location Map

### Other Figures
## Field Name
Barrier

## Country
North Rift

## Province/Location
The Barrier volcanic complex separates Lake Turkana from the broad Suguta Trough to the south, the site of a former lake.

## Location

## Resource Characteristics

### Geology
The volcano is comprised of four overlapping shield volcanoes, with the youngest, Kakorinya, located over the axis of the East African Rift. Kalolenyang volcano lies west of Kakorinya, and Likaiu West and Likaiu East volcano are located to the ENE. A 3.8-km-wide summit caldera was formed at Kakorinya volcano about 92,000 years ago. Youthful-looking trachytic and phonolitic lava domes and flows erupted within the caldera and along its ring fracture fill much of the caldera floor. Early Holocene fissure-related scoria cones and lava flows dot the volcano's southern and northern flanks. Solfataric fields are located within the caldera and on the western and southern flanks of the volcano. Historical eruptions from Teleki's and Andrew's cones on the northern and southern flanks, respectively, have produced basaltic explosive activity and lava flows during the 19th and 20th centuries.

### Volcanic activity (heat source)
The complex consists of three volcanoes of which Kakorinya is the most promising in terms of geothermal potential. Kakorinya is a silicic volcanic center whose caldera formation was accompanied by a collapse about 92,000 years ago, followed by resurgence activity about 58,000 years ago. A caldera association implies that the volcano developed shallow magma chamber whose heat could still drive a geothermal system. Recent basaltic activity at Teleki's volcano (100 years) is a strong indicator that new magma injections still occur, which could raise the local geothermal potential.

### Geological Structure
(Past Geological Studies included)

### Geochemistry
Developing a geothermal model for the prospect is complicated by lack of geophysical data and conflicting geochemical information. Low H2 and CH4 in the fumaroles and springs indicate an indirect path between the discharges and the heat source suggesting that the potential for the area is low. In contrast, high gas geothermometric temperatures (218 to 328 °C) suggest proximity to an up flow.

### Work done so far
- Geophysics
- Gravity
- Resistivity
- Well Drilling
- Temperature Survey
- Well testing
- Conceptual Model
It is likely that a high temperature geothermal system exists under the Kakorinya volcano. Sulphur deposits that are indicative of shallow, degassing magmas occur within the caldera, further indicating that a large heat source exists under the volcano. Preliminary indications are that the resource is capable of generating more than 100 MW.

## Present Status of Development

### Natural/Social Environmental Condition

### Power Sector Situation

### Power Output Potential
- Resource Potential
- Restricted by National Park
- Restricted by Power Demand

### Power Output Potential

### Rank of Development Priority

### Potential (Expected) Developer

### Proposed Geothermal Development Plan
- **Outline for Power Development**
- **Possible or Recommended Multi-purpose Geothermal Heat Use**
  - Scope for Power development
- **CO2 emission Reduction (1000 tonne/year)**
- **Proposed Geothermal Development Schedule**

### Location Map

### Other Figures

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# Annex-1-13  The Evaluation Sheet of the Barrier (Kenya) Geothermal Field