# Situation Analysis Study
# on Geothermal Development
# in Africa

# (Annex)

October 2010

JAPAN INTERNATIONAL COOPERATION AGENCY

WEST JAPAN ENGINEERING CONSULTANTS, INC.


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# Situation Analysis Study on Geothermal Development in Africa
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Annex-1-1 The Evaluation Sheet of the Olkaria (Kenya) Geothermal Field (1)

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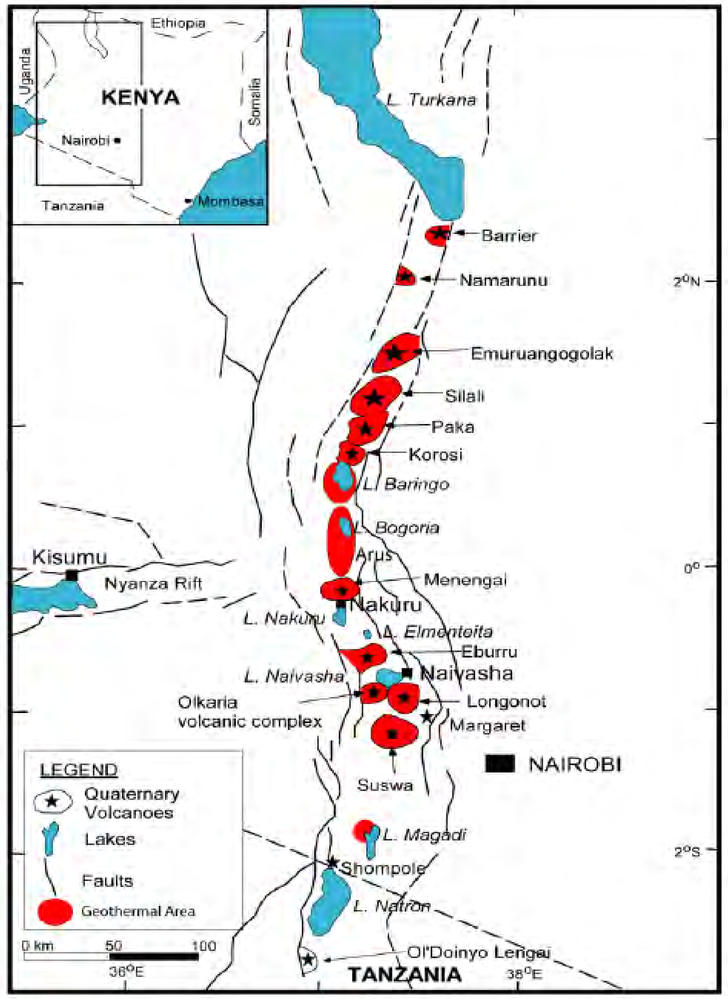
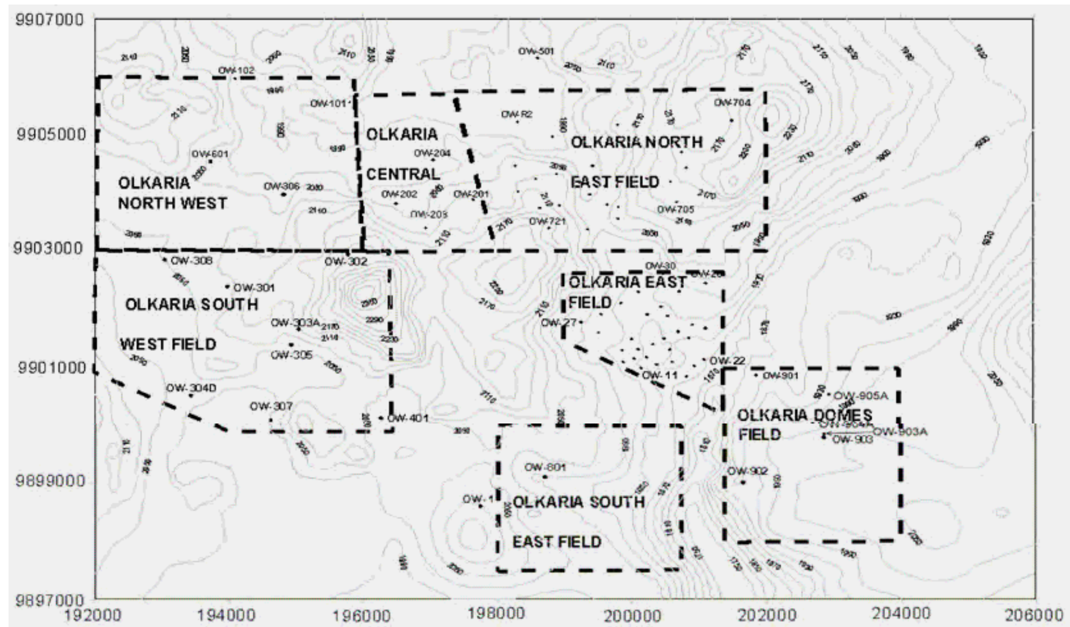
| Field Name | Olkaria |
| Country | Kenya |
| Present Status | Currently, in Kenya, geothermal energy is being utilised in Olkaria field only. Three of the seven Olkaria sectors, namely Olkaria East field, Olkaria West field and Olkaria Northeast field are generating a total of 167 MWe. The resource is being utilized mainly for electric power generation (167 MWe) and direct uses (18 MWt). The proven geothermal resource at the greater Olkaria geothermal field is more than 450 MWe and accelerated development if envisaged in the near future. |
| 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.<br>Olkaria II is located in Olkaria northeast and the construction of 2 x 35 MWe Olkaria II geothermal power station started in September 2000 was completed November 2003. The construction of Olkaria II 3rd unit is expected to be commissioned in 2010.<br>Olkaria III project is the first private geothermal power plant in Kenya. A 20-year Power Purchase Agreement (PPA) was awarded to Orpower 4 Inc. by Kenya Power and Lighting Company (KPLC) under a World Bank supervised international tender for the field development of up to 100 MWe. The first phase of the project included drilling of appraisal wells and construction of a 12 MWe pilot plant. The first 8 MWe was put on commercial operation on September 2000 and the other 4 MWe in December 2000. The appraisal and production drilling commenced in February 2000 and was completed by March 2003, after drilling a total of 9 wells (depth ranging between 1850-2750 m) and adequate steam was proved for total development of 48 MWe over the PPA period of 20 years. The 48 MWe power plant was ommissioned in the year 2008.<br>In addition, Oserian Development Company Ltd (ODLC) constructed a 2.0 MWe binary plant Ormat OEC in Olkaria Central to utilise fluid from |
| Resource Characteristics<br>Geology | 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 rhyolitic lavas and pyroclastic rocks. Beneath this is a series of basalts, trachytes and pyroclastic units above the Proterozoic basement rock, which is composed of gneiss, schists and other metamorphic rocks belonging to the Mozambiquian group |
| 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.<br>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 Olol Butot 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.<br>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 blocks 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 Structrure | 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 Olol Butot 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). |
| (Past Geological Studies included) | KenGen already carried out detailed scientific studies that included geology, geochemistry and .geophysics (MT/TEM, Schlumberger, and micro-seismic). |
| 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.<br>Fumarole chemistry across the field could be taken to indicate that a hot water reservoir underlies the whole geothermal field, and that there was no clear indication of significant later underground 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. It appears that 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 (WPF 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 | Data of All covering the Olkaria geothermal field and surroundings.<br>- Bouguer gravity data (882 stations),<br>- Aero-magnetic survey (75,495 stations),<br>- Resistivity data at different depths of DC surveys (369 stations), and<br>- Transient Electromagnetic (TEM) surveys (395 stations)<br>Data in and around the Olkaria domes field<br>- Power spectra data of a Magnetotelluric (MT) survey (80 stations) |



Location of Geothermal Fields in Kenya



Prospect of the Great Olkaria Geothermal Area

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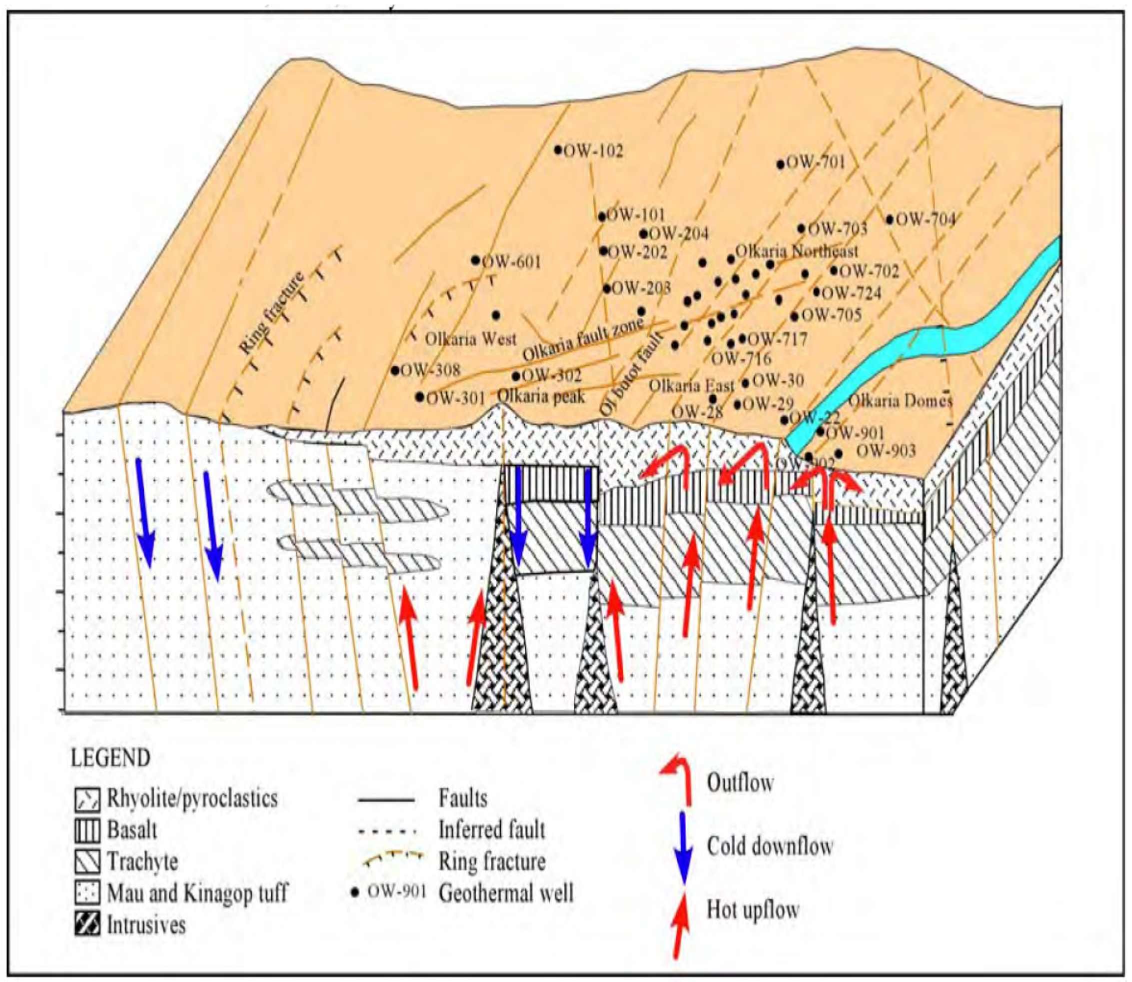
|---|---|
| Gravity | **Aero Magnetic:** a NW-SE trending positive anomaly is recognized. This anomaly was interpreted as occurring in a demagnetized zone corresponding to the main heat source with a temperature above the Curie point at a depth of around 6km. Another positive anomaly trending NE-SW can 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 intensity values trending roughly NNW-SSE can be seen extending from the eastern portion of the Olkaria northeast field to the east of the 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.<br>**Gravity**: 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 |
| Resistivity | **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 widely distributed 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. This fact may suggest that there are two separate up-flow zones in the Olkaria northeast field and the east production field.<br>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 hy<br>**MT**: The orientation of the low anomaly is similar to that of the low resistivity anomaly at shallow depths recognized in the resistivity maps obt |
| 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 (OWPF) 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 stretch in NW-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 Olol Butot. The low temperature area detected from elevations of 1000m msl (and higher) at the northeastern portion of the NEPF, could be reflecting inflow of cooled water from the northeast.<br>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. |
| 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 | There are two main geothermal systems separated by a N-S structure corresponding to faults F1, F2 and to Olol Butot. The eastern side is comprised by the NEPF, EPF and the Olkaria Domes and maybe the Olkaria Central too.<br>The western side comprises the WPF, the Olkaria northwest and southwest. These systems seem to be heated by remaining magmatic intrusions beneath the GOGA.<br>The eastern side may be primarily fed by meteoric deeply infiltrating from east escarpment of the rift valley into the Plateau Trachyte formation and migrating toward the west. This infiltrated meteoric water 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 deeply infiltrating from the west escarpments of the rift valley.<br>Geothermal surface manifestations such as fumaroles and hot springs are found along the border of the N-S hydrological barrier zone (between F1 fault and Olol Butot fault) and to the south of the GOGA. The temperature decreases toward this area, which is considered the main discharge zone. |
| Present Status of Development | 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 fieldare generating a total of 167 MWe. The resource is being utilized mainly for electric power generation (167 MWe) and direct uses (18 MWt).<br>The proven geothermal resource at the greater Olkaria geothermal field is more than 450 MWe and accelerated development if envisaged in the near future. |
| Natrural/Social Environmental Condition | Hell Gate National Park/Maasai Village |
| Power Sector Situation | Installation of Sub-station at Olkaria-II Plant |
| Power Output Potential | |
| Resource Potential | 1,000 MW (estimated): Olkaria I, II and III are already producing 209 MWe (by both Kengen and Or Power 4 Inc.). |
| Restrictted by National Park | Hell Gate National Park situated between Olkaria-I area and Olkaria-IV area |
| Restricted by Power Demand | None |
| Rank of Development Priority | OP: Operation stage |
| Potential (Expected) Developer | Operated by KenGen |
| Proposed Geothermal Development Plan | |
| Outline for Power Development | GDC is currently undertaking production drilling in Olkaria IV for a planned 140 MWe plant by 2012 |
| Possible or Recommended Multi-purpose Geothermal Heat Us | Already utilized the geothermal fluid in Oserian firm |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | KenGen is currently undertaking production drilling in Olkaria I for a planned 140 MWe plant by 2012. |




Conceptual Model of the Olkaria Geothermal Field

Direct-Use in Oserian Greenhouse utilizing Geothermal Heat

Annex-1-2  The Evaluation Sheet of the Eburru (Kenya) Geothermal Field (1)

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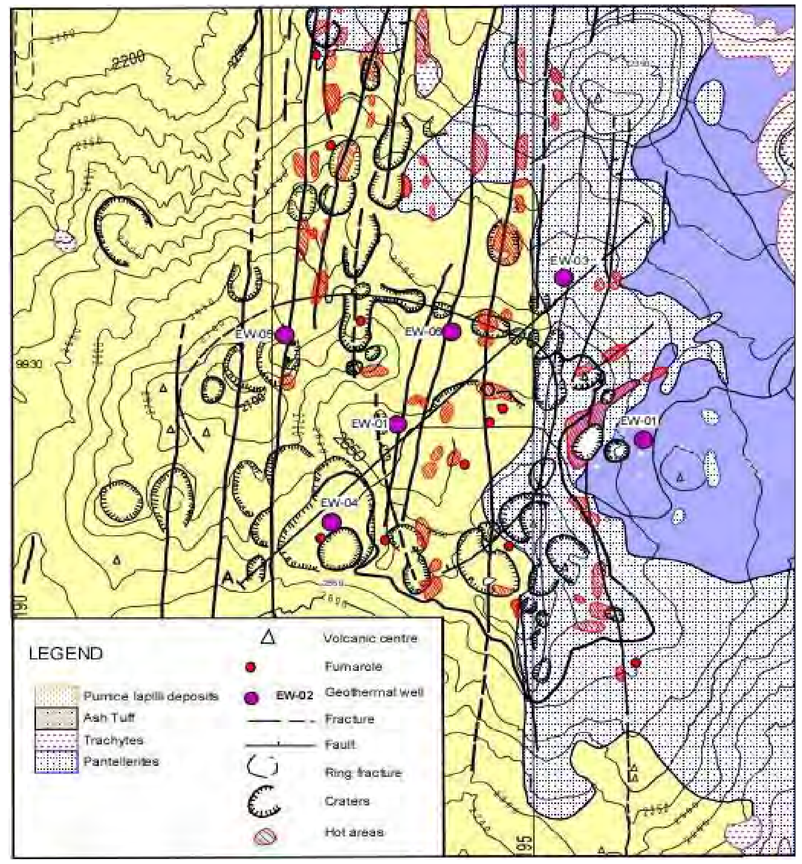
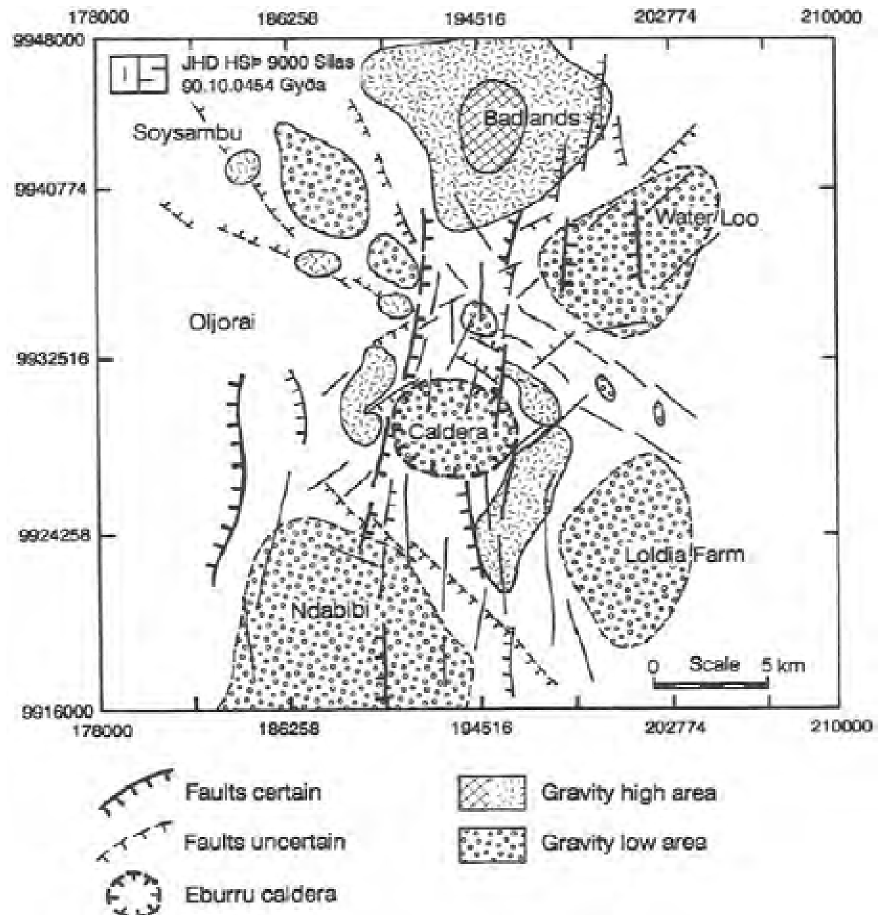
| Field Name | Eburru |
| Country | Kenya |
| Province/Location | Eburru volcano is located about 50 km north of Olkaria geothermal field.  Lake Elementaita is located about 20km north of Eburru. |
| Accessibility/Infrastructure | The Eburru area has a fairly well established infrasturucture and  for this reason a 2.5 Mwe binary pilot plant is planned for comminsioning in 2010. |
| Resource Characteristics<br>Geology | 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 escapement 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. |
| 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 phonolitic 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 vents 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 Structrure | 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 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 os six exploration wells in Eburru between 1989 and 1991. |
| Geochemistry | 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 temperture was 285oC and the total output from the two wells that discharged (EW-1 & EW-6) is 29 MWt (ofwona, 1996). |
| 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 geochemical 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 were 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. |



Geological map of Eburru geothermal field



(Source) (Simiyu, 1990)

Gravity Bouger map of Eburru field

Annex-1-2 The Evaluation Sheet of the Eburru (Kenya) Geothermal Field (2)

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| Gravity | The Eburru area has a complex gravity structrure. 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 mojor 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 MWe production capacity. High frequency anomalies are related to vertical intrusives at shallow depths, occuring at fault junctions. Analysis of these anomalies has led to a proper definition of a NW-SE structural and resistivity disciontinuity, 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 junctions.<br>Several intrusions exist at the intersectionsof 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 200oC. 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 sourht 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.<br>MT suveys done in 2006 revealed that the Eburru area is able to support up to >60 MWe. The results from the exploration wells indicate that the field had experienced temperatures of over 300oC possibly due to localized intrusive. |
| Well Drilling | 6 deep wells:<br>Three wells, EW-01, EW-04, and EW-06 discharge geothermal fluid. Only EW-01 produced steam.<br>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 ℃ respectively. |
| Well testing | Discharge tests showed that at 6.0 bars the well produces 82t/h mass 21 t/h steam with enthalpy of 1150 kJ/kg equivalent to 2.3 MWe. The well produced fluids at 265 ℃ and at a thermodynamic state close to saturated conditions. Drawn down tests indicated relatively low transmissivity of 0.35 x 10-8 m3/pas if major production comes from well bottom. Shut in tests indicated much higher transmissivity (5.2 x 10-8 m3/pas) 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 ℃ 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 1989-1991<br>- 6 exploration wells were drilled<br>- Estimated resource: 200 MWe (20-25 MWe in Eburru areas),<br>- 2.5 Mwe binary pilot plant to be installed in 2010 by KenGen |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential | |
| Resource Potential | Eburru-Badlands: 200MW (estimated), Reconnaissance and detailed surface exploration planned for 2011. |
| Restrictted by National Park | |
| Restricted by Power Demand | None |
| Rank of Development Priority | FS: Feasibility Study |
| Potential (Expected) Developer | GDC, KenGen, Private |
| Proposed Geothermal Development Plan | |
| Outline for Power Development | |
| Possible or Recommended Multi-purpose Geothermal Heat U | Supply of fresh water |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
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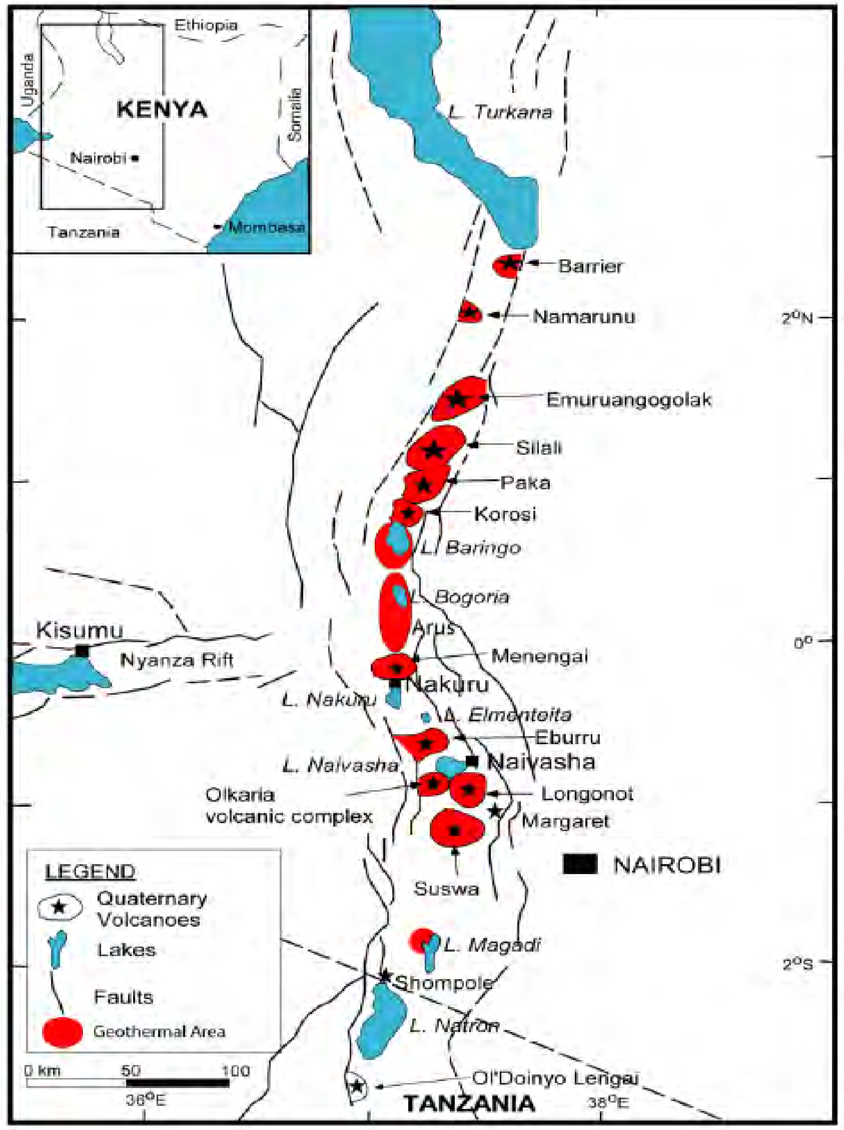
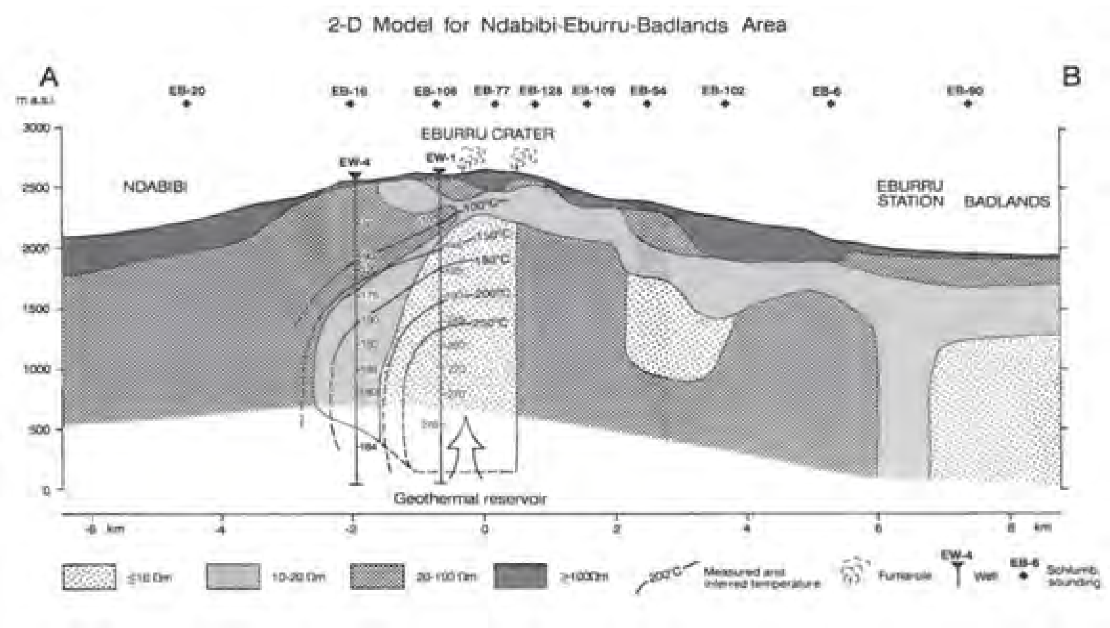


Location map of geothermal area in Kenya



(Source) (Onacha, 1990)

Resistivity section of Ndabibi-Eburru-Badlands field

Annex-1-3 The Evaluation Sheet of the Suswa (Kenya) Geothermal Field (1)

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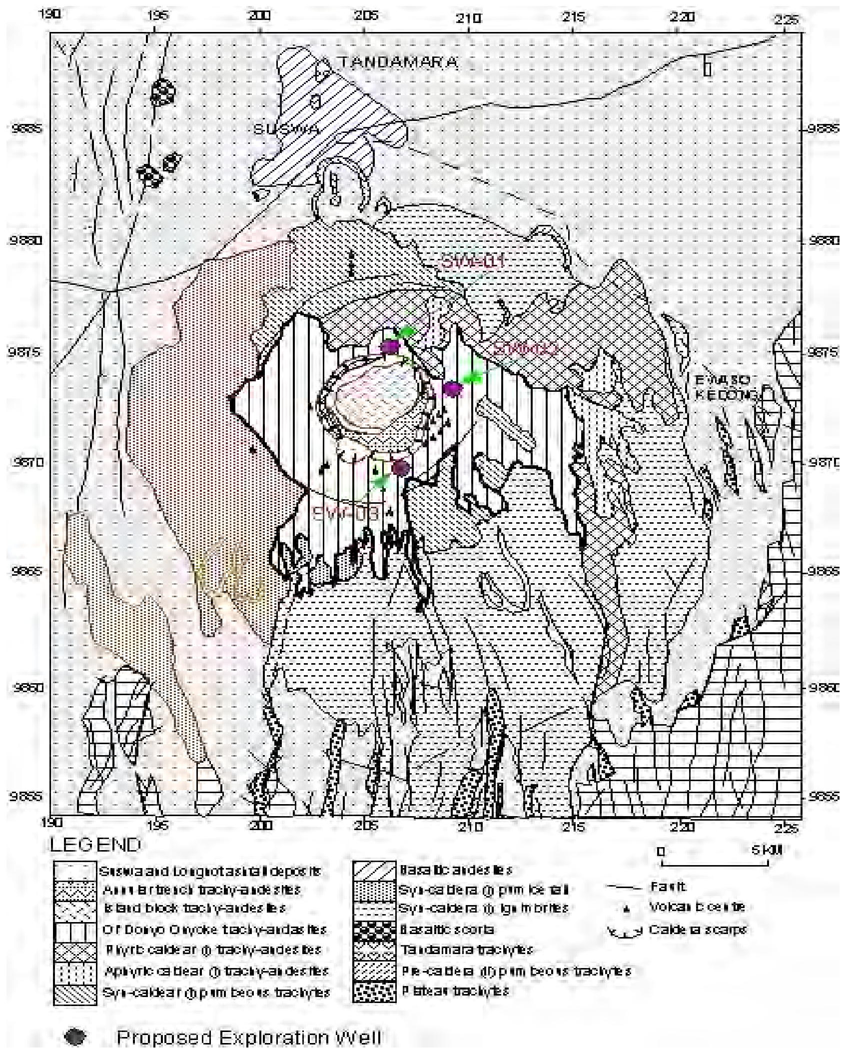
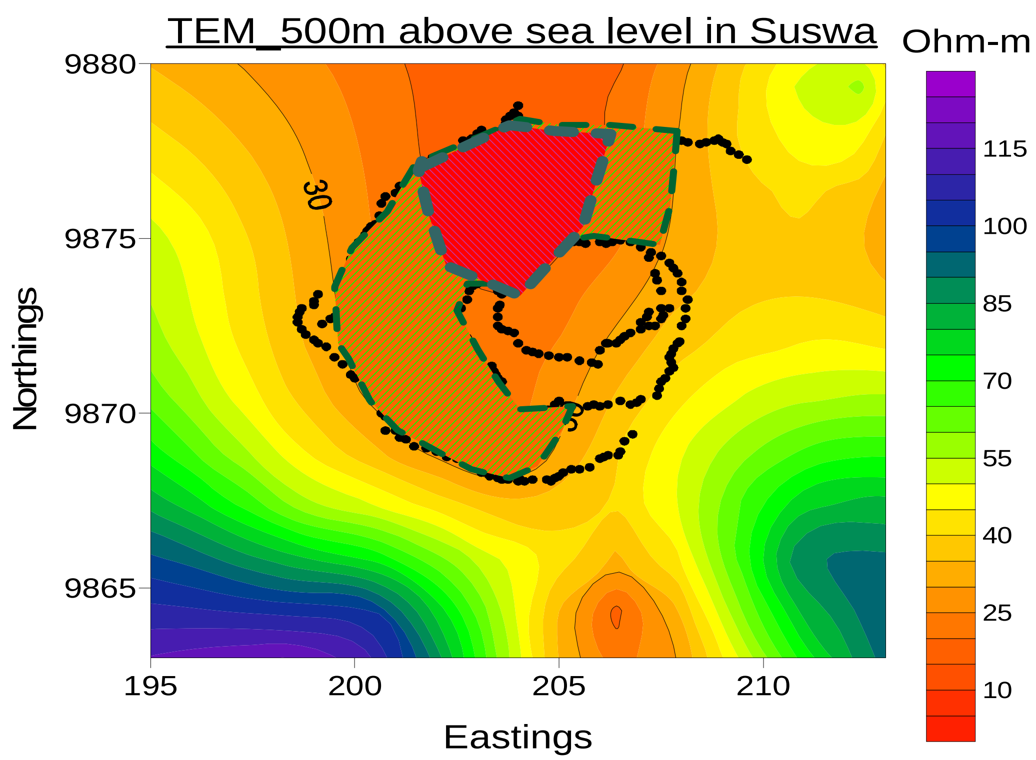
| Field Name | Suswa |
| Country | Kenya |
| Province/Location | Suswa is the southern-most caldera in the Kenyan Rift Valley. It contains a 12 x 8 km caldera with the rim at an altitude of 1890 m. Suswa is the closest active volcano to Nairobi, the capital of Kenya (50 km).<br>1.175 S, 36.35 E Summit elevation 2356 m Shield volcano |
| Accessibility | Suswa lies south of Longonot volcano and about 50 km WNW of the capital city of Nairobi. |
| Resource Characteristics<br>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 southern most 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 (Torfason, 1987a; Torfason, 1987b; KPC, 1992). The phonolitic nature of the lava implies medium level magma chamber, which could provide a heat source for a geothermal system.<br>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 acurate 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.<br>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 Oldonyo Nyoike peak then decreases gently further south.<br>Some small 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.<br>Generally low gravity values towards the west and east. |




Geological map of Suswa field




Extent of geothermal reservoir of Suswa

Annex-1-3  The Evaluation Sheet of the Suswa (Kenya) Geothermal Field (2)

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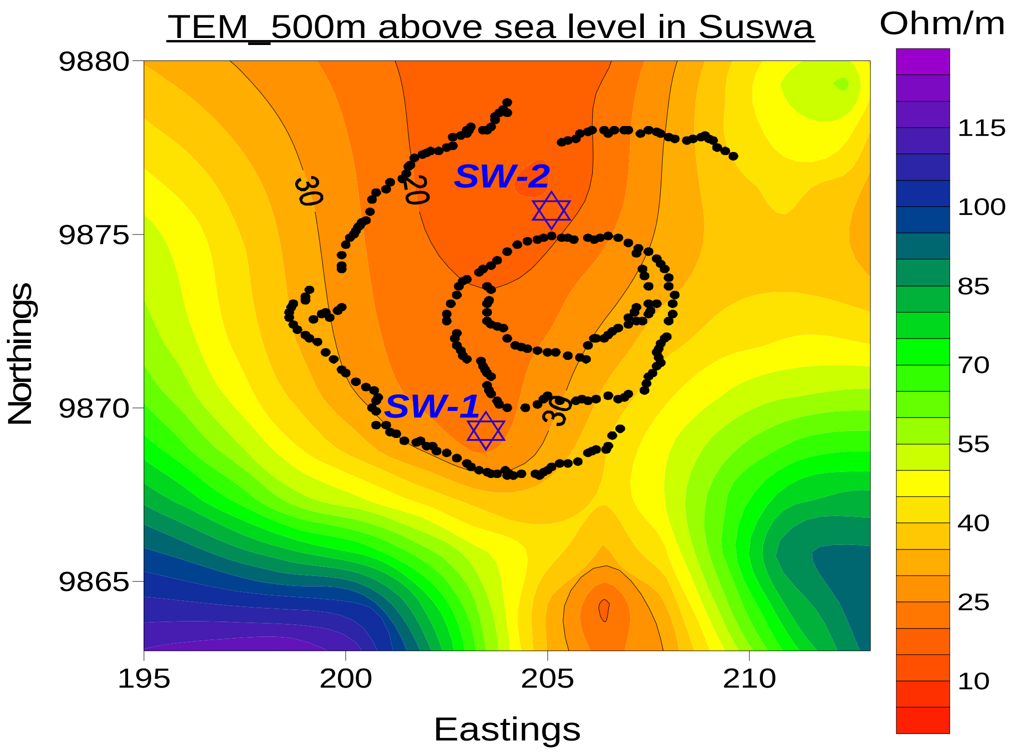
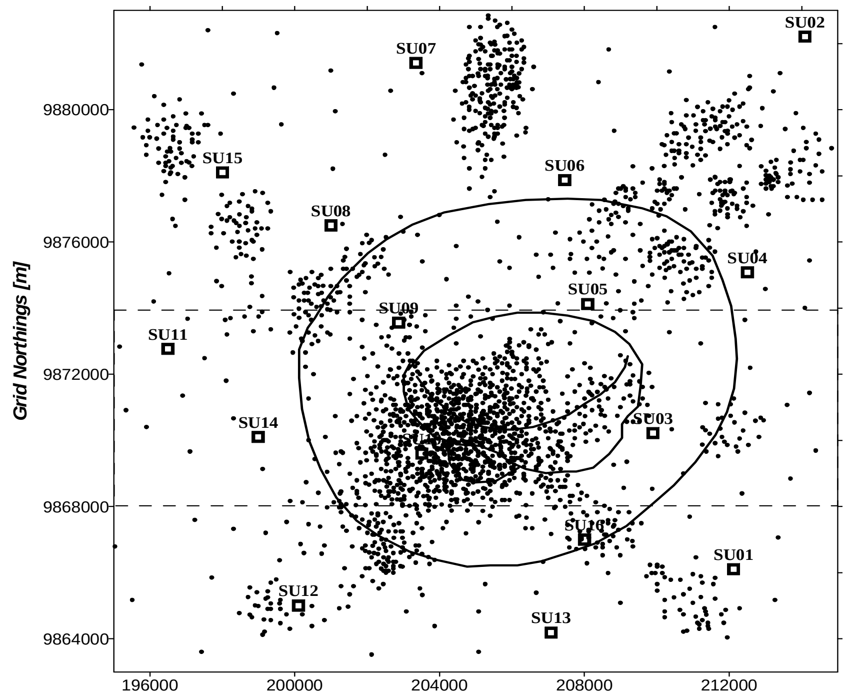
| Resistivity | Interpretation of DC Schlumberger soundings by Geotermica Italiana in 1987 identified 3 anomalous regions of low to intermediate resistivity. The first region was found on the western half of the outer caldera extending to the south and southwest. The second region was found on the eastern 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. |
| Well Drilling | |
| Temperature Survey | |
| Well testing | |
| Conceptual Model | 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 2500C 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 200oC. 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 masl. The prospect has a good recharge from both the west and east rift escarpments.<br>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. |
| Present Status of Development | 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. |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential | |
| Resource Potential | 600MW (estimated): Detailed surface exploration has been done. Exploration drilling to commence 2011. |
| Restrictted by National Park | |
| Restricted by Power Demand | |
| 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 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |



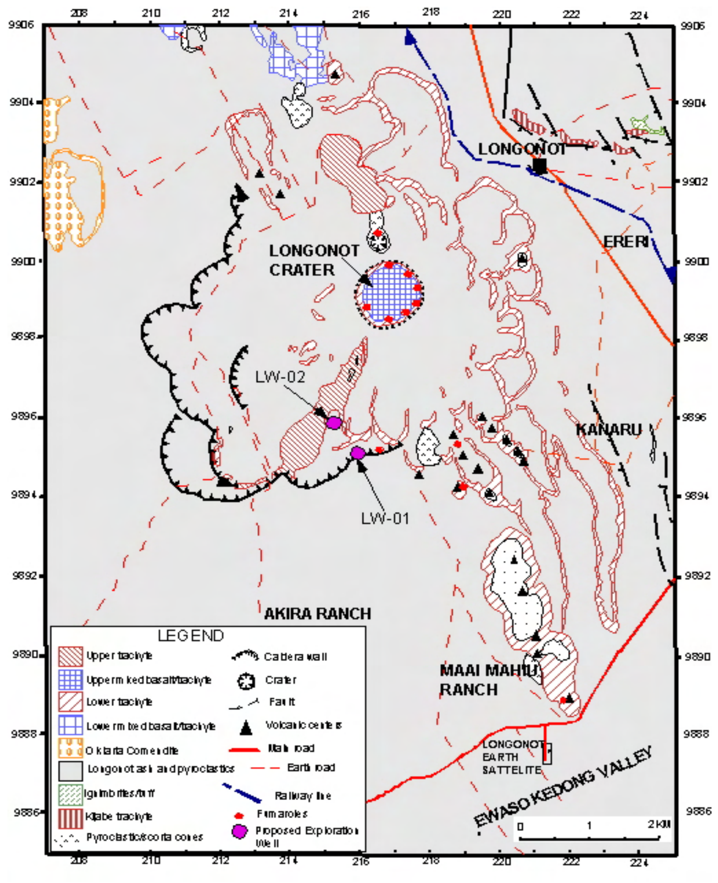

Planned points for exploratory well in the Suswa field




Hypocenter distribution map of Suswa field

Annex-1-4 The Evaluation Sheet of the Longonot (Kenya) Geothermal Field (1)

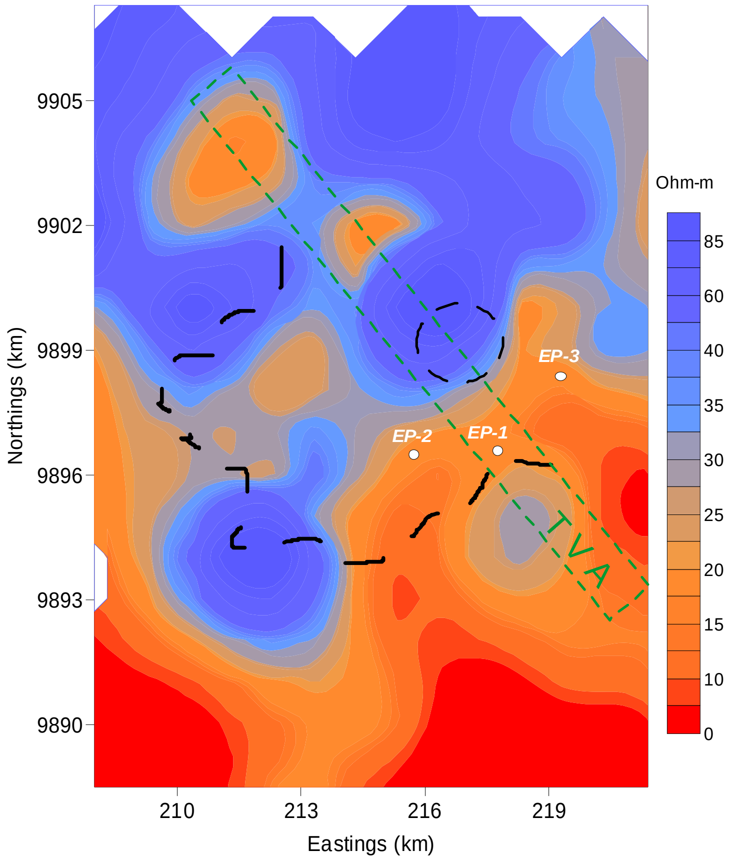
| | |
|---|---|
| Field Name | Longonot |
| Country | Kenya |
| Province/Location | Latitudes 0o51' S and 1o02' S and longitudes 36o22' E and 36o32' E.<br>Longonot Volcano Caldera is located east of Olkaria geothermal field on the floor of the rift valley. |
| Location | Longonot is one of the geothermal prospects with the Central Kenya Rift. The prospect is located on the Kenyan Rift Valley floor about 60 km southeast of Nairobi. It borders Olkaria volcanic complex to the west, Lake Naivasha to the north, Suswa volcano to the south and Kijabe hill to the east.<br>Longonot volcano occupies an area of about 350 km2 and consists of a cone with a gentle slope to the south and attains a maximum height of 2776 masl. It rises about 1000 m high relative to Akira plains which lie to the southwest and 880 m high relative to Lake Naivasha to the north. |
| Resource Characteristics<br>Geology | It consists of arcuate structures on the western and the southern parts which mark remnants of a caldera boundary. The area in and around Longonot is marked by active manifestations that occur in the form of fumaroles, altered grounds, warm grounds, sulphur deposition and silica deposition.<br>Geological studies indicate that Longonot Volcano is a Quaternary volcano, which is a divergent zone where spreading occurs resulting to the thinning of the crust hence eruption of lavas and associated volcanic activities. Trachyte, mixed basalt/trachyte, ignimbrites, base surge, pumice fall and ashes are the rock types associated with the volcano. |
| Volcanic activity (heat source) | Development of the precursor of Longonot caldera started 800,000 years ago with the development of a broad shield volcano. Volcanism continued and culminated in the caldera collapse about 9,000 years ago. Subsequent volcanism occurred in the center of the caldera and resulted in the building of a trachytic massif and deposition of thick pumice deposits within the caldera and on the flanks. It is estimated that the most recent volcanism at Longonot occurred about 200 years ago within the summit crater and along a north-northwest trending volcano-tectonic axis.<br>The geothermal potential of the area is associated with a shallow magma chamber that exists under the caldera and the summit crater. A heat source in the form of shallow intrusives is postulated to exist under the caldera and the summit crater. Xenoliths showing high alteration temperatures suggest hydromagmatic eruptions encountering geothermal aquifers with high temperatures. |
| Geological Structrure | The main structures in the area are tectono-volcanic axis, faults, caldera rims and lineaments. The general trend of the tectono volcanic axes is NNW-SSE and are marked by lava and pyroclastic cones which are aligned on the northern and the southern parts of the summit crater. |
| (Past Geological Studies included) | Many scientific investigations have been carried out in the area. But many of these were not specific to geothermal exploration. Under a UNDP, UK and Government of Kenya Technical Cooperation in the 1980s, extensive work was done on a geothermal resource assessment program of the Longonot-Suswa prospects. Further surface exploration work has been carried out in the mid of 2000's by KenGen on behalf of the Ministry. |
| Geochemistry | The Longonot geothermal prospect has positive indicators of a geothermal resource. Numerous manifestations occur within the summit crater and a few outside on volcanic centres to the south and on the southwestern caldera rim. They occur in form of fumaroles, altered grounds, warm grounds and sulphur and or silica deposition. Few manifestations are exposed in the area due to the thick pyroclastic cover.<br>The few indicators include low-pressured fumaroles with a few exceptions located inside the Longonot summit crater. Geochemical survey conducted involved fumarole sampling and soil gas survey with emphasis on carbon dioxide (CO2) and radon (Rn-222) gas compositions. Reservoir temperatures estimated using the gas geo-thermometers indicate a resource with geothermal fluids in excess of 3000C. These are conceived to be flowing from around the main summit crater towards the south and southwest. |
| Work done so far | A concerted effort was made in the 1980s to collect geochemical data. The Longonot area has limited surface activity that makes it difficult to explore using geochemical methods. |
| Geophysics | A sizable amount of geophysics data using the gravity, resistivity and micro-seismology techniques has been collected from the Longonot prospect. A detailed interpretation of geophysical data collected by KenGen was done in the mid of 2000's, aimed at evaluating the significance of the data for sitting deep exploration wells. |
| Gravity | Gravity low to the north of Longonot caldera including Kijabe Hill and the north-west of it<br>Gravity high to the south-east<br>Localised gravity high just north-west of Hyrax Corner<br>Gravity low to the west corresponding to the outer Longonot caldera. |



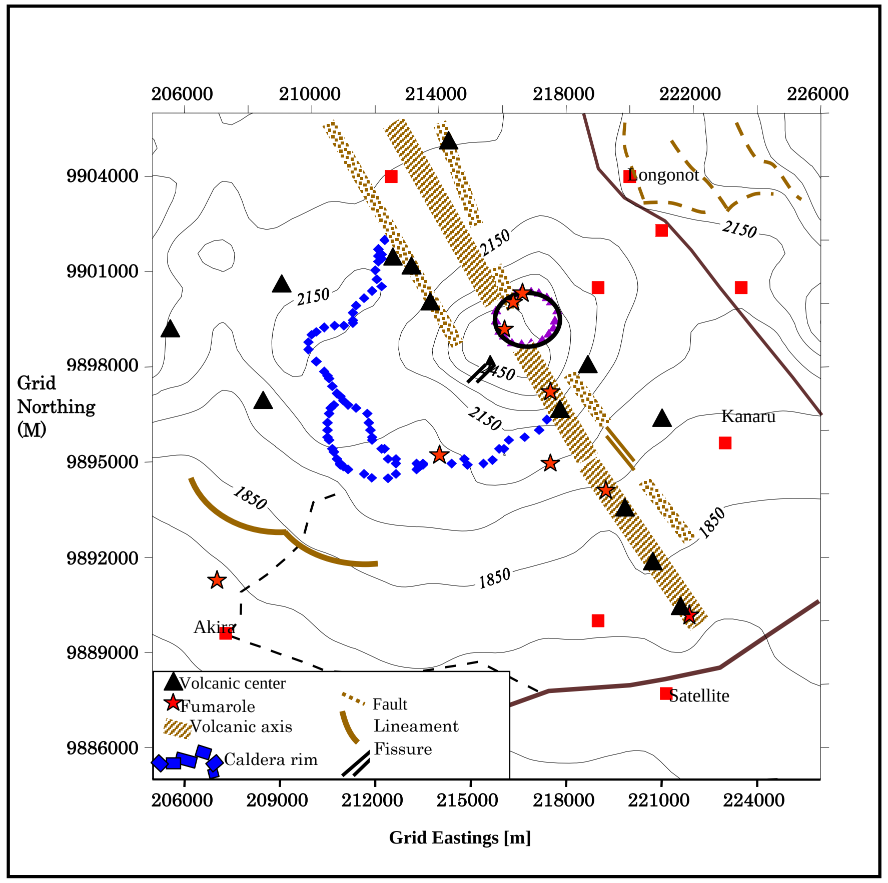

Geological map of Longonot field

Annex-1-4 The Evaluation Sheet of the Longonot (Kenya) Geothermal Field (2)

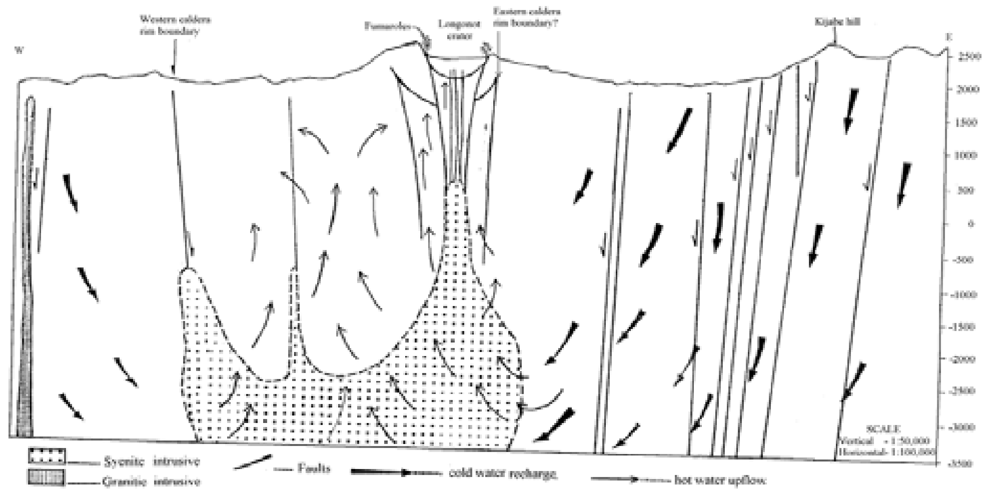
| | |
|---|---|
| Resistivity | Two shallow low (<10 ohm-m) resistivity anomalies were mapped. Interpretation of the data suggests a deep low resistivity anomaly exists in the area. The first anomaly lies to the south and southeast of the Longonot summit but within the outer caldera and covers about 70 km². It is shallower to the south of Longonot but deepens to the north. The second anomaly is found around the Akira offices further south and covers about 30 km². The northern sector of the study area shows high (>20 ohm-m) resistivity. The low resistivity anomaly is attributed to higher subsurface temperature, 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 MT interpretation.<br>Geophysics data has also mapped low 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 |
| Well Drilling | None |
| Temperature Survey | |
| Well testing | |
| Conceptual Model | The prospect area is faulted though the faults are completely covered by the Quaternary lavas and pyroclastics from Longonot and adjacent volcanic centres. The area is most likely recharged by the flank faults from the eastern part which channel the fluids deep to the heat source. Another recharge is through the concealed rift floor faults that run in a NNW-SSE direction, that channel the fluids from the northern part of the field. The regional hydrologic flow of the area is southwards and therefore the recharge from the north via the faults is quite possible. |
| Present Status of Development | KenGen conducted surface exploration work of Longonot geothermal prospects in 1 998 that involved geological, geochemical, geophysical and environmental surveys (KenGen, 1998). The presence of hydrothermally-altered lithics indicates that the geothermal system under the volcano must have attained temperatures of more than 250°C. Resistivity studies indicate an anomaly on the southern slopes of Longonot crater. These results have been used to site the first exploration well south of the volcano bound by the caldera structure.<br>Exploration wells are proposed in the area bound by the caldera rim where a heat source in form of intrusives is thought to be present, closer to the NW-SE Tectono-Volcanic Axis (TVA). The accessibility of the area is controlled to a large extend by the topography. The areas that are accessible and which are served by tracks include the eastern and the southeastern portions. Those areas that are poorly accessible and would involve quite some earth moving include the southern part of the summit crater and close to the steep edges of the crater. The difficult areas to access include the summit crater and its steep flanks and areas with lava flows exposed. |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential | |
| Resource Potential | 750MW (estimated): Detailed surface exploration have been done. Exploration drilling to commence mid-2010. |
| Restricted by National Park | |
| Restricted by Power Demand | |
| 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 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |



TEM resistivity map (altitude=1,300m) of Longonot field and planned well drilling site



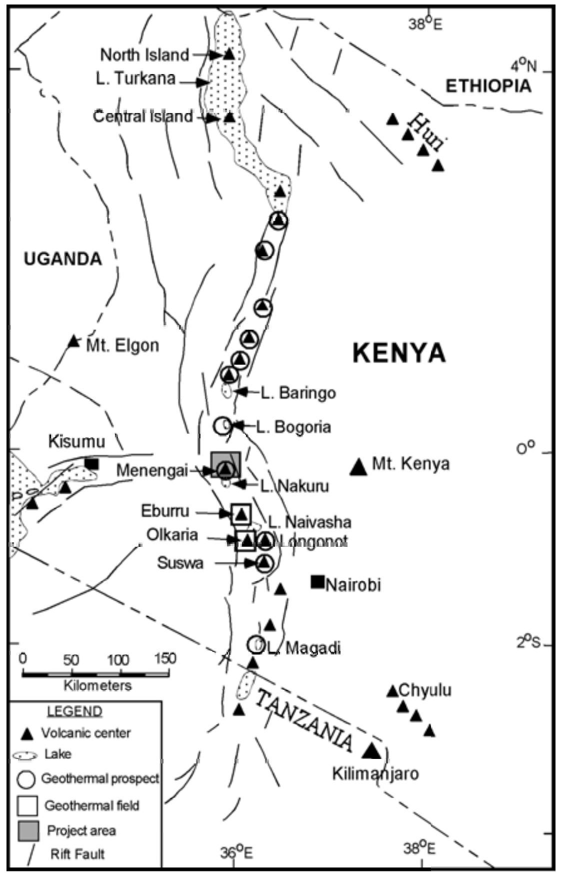
Mt. Longonot volcanic structure



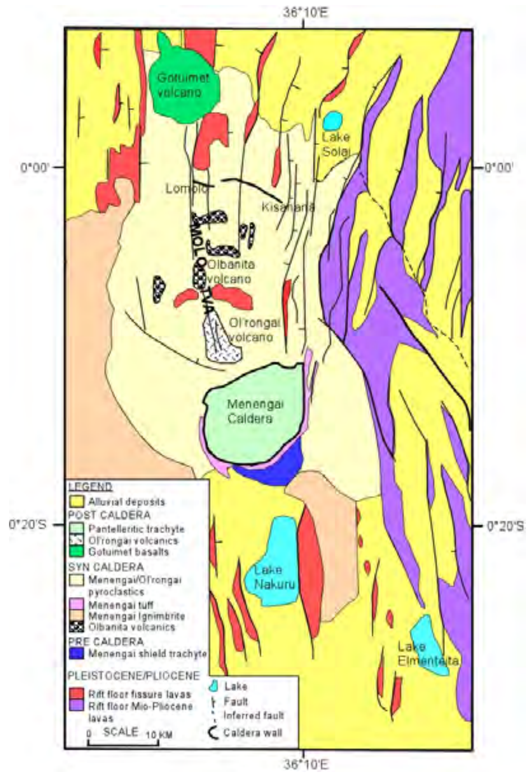
Geothermal fluid flow model of Longonot field

Annex-1-5  The Evaluation Sheet of the Menengai (Kenya) Geothermal Field (1)

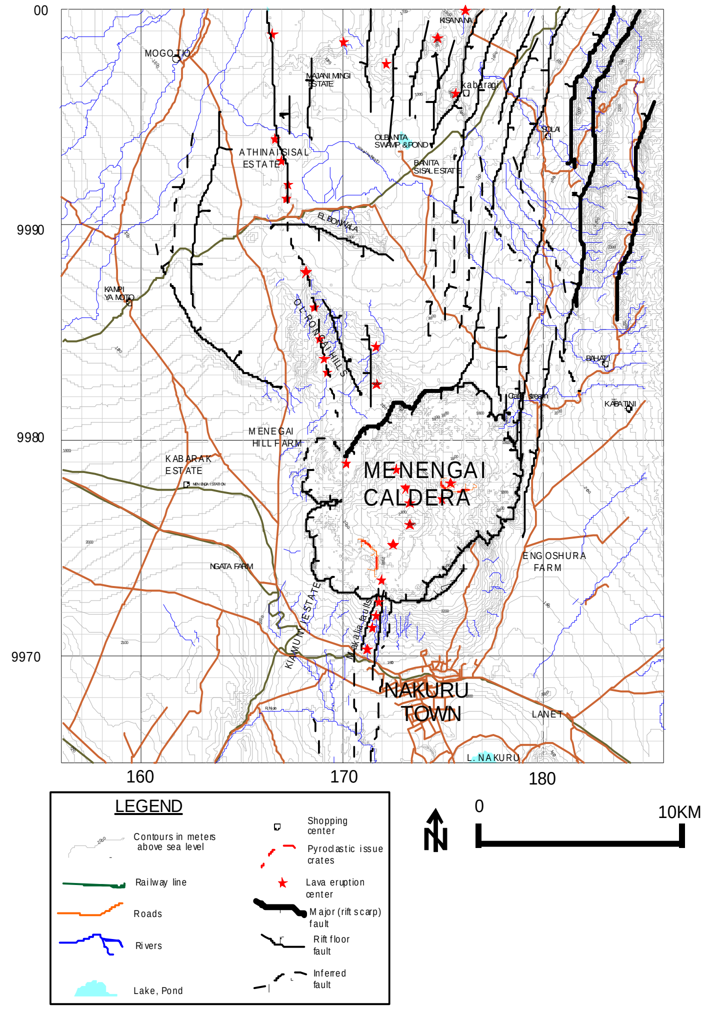
| | |
|---|---|
| Field Name | Menengai |
| Country | Kenya |
| Province/Location | Parts of six (6) administrative divisions that include Nakuru Municipality, Bahati, Njoro and Rongai divisions of Nakuru district and parts of Mogotio and Kisanana divisions of Koibatek District. |
| Location | The Menengai Caldera Geothermal Prospect is bound by the UTM co-ordinates 157000 E to 185000 E and 9966000 N to 0 (Equator). The area encompasses Menengai volcano, Ol'rongai volcanic field, the Olbanita plains and parts of the Solai graben. The prospect area measures 29X30 km2 and extends from the immediate north of Nakuru Town in the south to Kisanana in the north. |
| 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 extension tectonism 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 little effects of movements and have been eroded resulting in gentle scarps characterize the western margin. The eastern margins however depict wider belts, with sharp scarps implying recent active movements. This is further confirmed by the presence of a detachment fault (bounded by transcurrent faults) that runs for hundreds of kilometres. The rift trough is cut by numerous normal faults that clearly represent continued extensive tectonism under the rift floor. Two rift floor tectono-volcanic axes (TVA) that are important in controlling the geothermal system in study area include the Molo and the Solai TVA. |
| Volcanic activity (heat source) | The surface is covered by volcanic rocks mostly erupted from centres within the area. Most of the area around the caldera is covered by mainly pyroclastics erupted from centres associated with Menengai volcano. Young lava flows infilling the main caldera are post caldera in age. Older (Pleistocene) lavas mainly trachytic and phonolitic in composition are exposed in the northern parts and are overlain by eruptives from Menengai volcano. Some alluvial deposits are found in low-lying narrow grabens where they are deposited as thin reworked layers. One isolated exposure of diatomaceous bed was noted on the caldera floor, probably indicative of prehistoric climates and existence of shallow fresh lakes in this part of the rift.<br>The Menengai caldera represents a collapse directly above a partially emptied magma chamber. The 88 km2 oval depression indicates a vast magmatic body underlying the volcano. The continued eruptions (intra and post-caldera) which include the fresh young lavas, suggest that the magma body could still be active. |
| Geological Structrure | The location of Menengai prospect on the rift floor where the hydrogeologic regime comprises of recharge from the higher rift scarps and the intense rift floor fracture/faulting resulting from extensional tectonics of continental rifting, provide for a good structural set-up that allows water from the rift scarps to penetrate deep into the crust. The water then flows towards the hot magmatic intrusives under the rift floor and the normal faults provides for conduits for the hot fluids to percolate from depth into possible geothermal reservoirs at shallower depths. The regional Molo TVA may be such an important conduit of deep fluids thus an important geothermal controlling feature in the area |
| (Past Geological Studies included) | Inventory of hydrothermal features, geological mapping and Petrographic studies<br>Petrochemical and XRD analysis of surface alteration minerals |
| 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 1000 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. |
| 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 | 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 (Simiyu and Keller, 1997, 2001). Resistivity investigations revealed anomalies in areas north of the caldera (Geotermica Italiana, 1987). On the basis of these previous surface exploration activities at Menengai geothermal prospect, three sites were proposed for exploration wells. |
| Gravity | Gravity data interpretation by KRISP (Simiyu and Keller, 1997) along a regional profile that runs across Menengai show gravity high with an amplitude of 40 mgal and an EW wavelength of 35 km. This anomaly was modelled as an intrusive body, about 13 km wide and coming to within 4 km depth below the surface. Mariita (2003) carried out a filtering analysis of the gravity data from the area and found out that when the filter wavelength passed is increased, wavelengths and amplitudes of the anomalies change implying deeper roots of the causative structures. The individual gravity highs of Ol'rongai and Olbanita volcanic centres and Menengai caldera merge giving the impression of a continuous gravity high along the Molo TVA. |
| Resistivity | KenGen in 1998 carried out a re-interpretation of all the resistivity data and their results confirmed the earlier findings by Geotermica Italiana (1987). A distinct low resistivity anomaly (<15 Ωm) occurs to the west of the Menengai crater and the western anomaly extends into the Ol'rongai estate to the NW of Menengai in the Solai-Kisanana area. At 1000 m.a.s.l. the three distinct areas previously identified by Geotermica Italiana are clearly seen. |




Location map of Menengai field



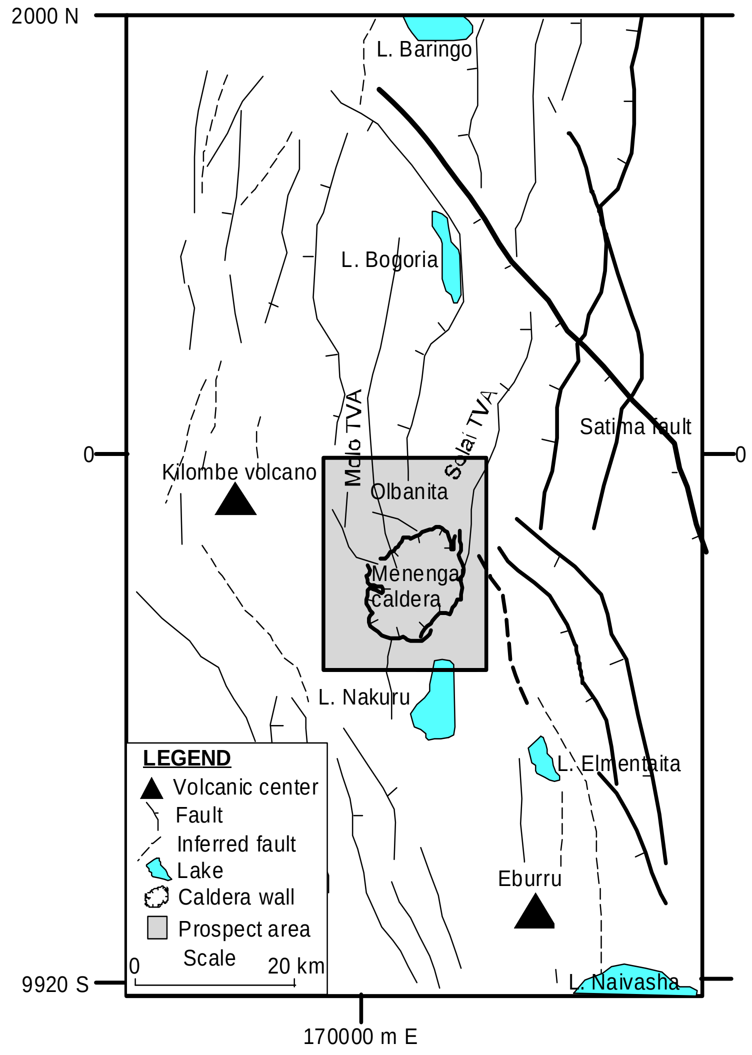

Geological map of Menengai field and around



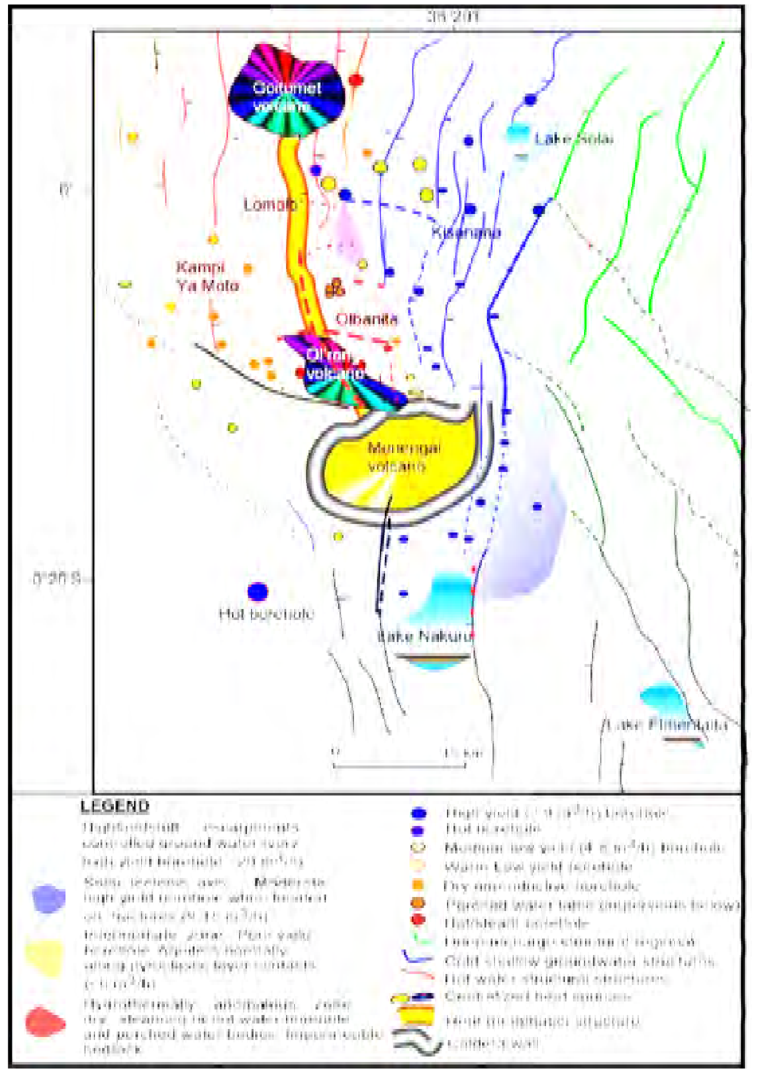

Map of Menengai field

Annex-1-5 The Evaluation Sheet of the Menengai (Kenya) Geothermal Field (2)

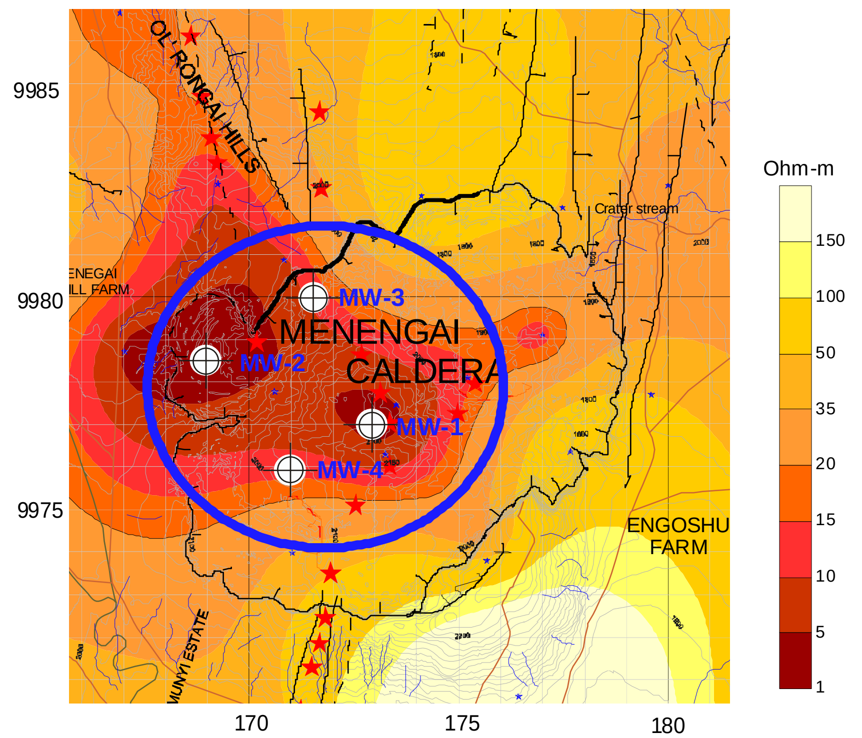
| | |
|---|---|
| Well Drilling | None |
| Temperature Survey | |
| Well testing | |
| Conceptual Model | A high temperature geothermal system exists under Menengai caldera within the prospect. It is postulated that the geothermal reservoir is at temperatures of more than 250°C as inferred from gas geothermometry. 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 dyke intrusions. It is modelled that the reservoir primarily exists within but with extensions to the west and north of the caldera.<br>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 c |
| 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 warrant further exploration by drilling deep geothermal wells. It is proposed that four exploratory wells; MW-1, MW-2, MW-3, and MW-4 be drilled.<br>But before commencement of exploratory drilling, a full EIA study for the prospect area should be carried out .<br>Whilst, 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 | |
| Power Sector Situation | |
| Power Output Potential | |
| Resource Potential | 1200MW (estimated): Detailed surface exploration done. Exploration drilling to commence mid-2010. |
| Restrictted by National Park | None |
| Restricted by Power Demand | |
| Rank of Development Priority | A |
| Potential (Expected) Developer | GDC (state-own company) |
| Proposed Geothermal Development Plan | |
| Outline for Power Development | The 840MWe power generations in Menengai prospect will be conducted in 6 phases (140MWe x 6 phases).<br>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 | |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |




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



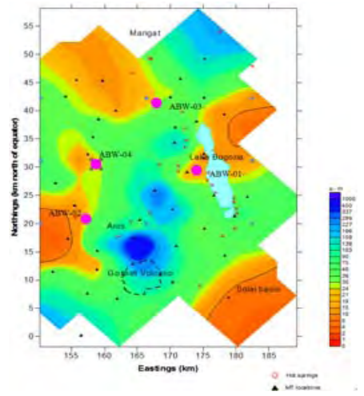

Fluid flow structure of Menengai field



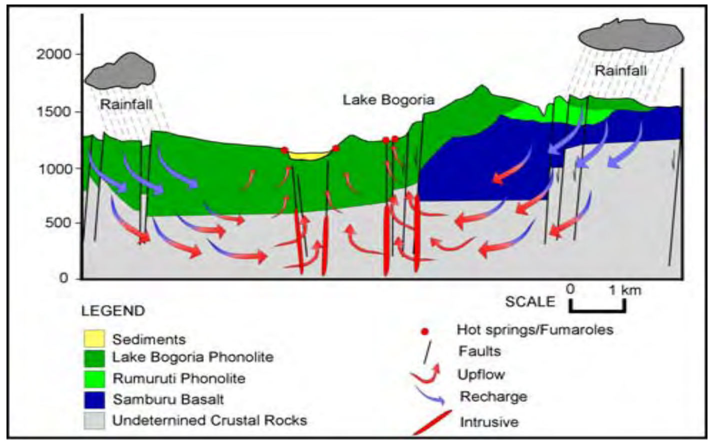

MT resistivity map (altitutde=2,000m) and planned well site
of Menengai field

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

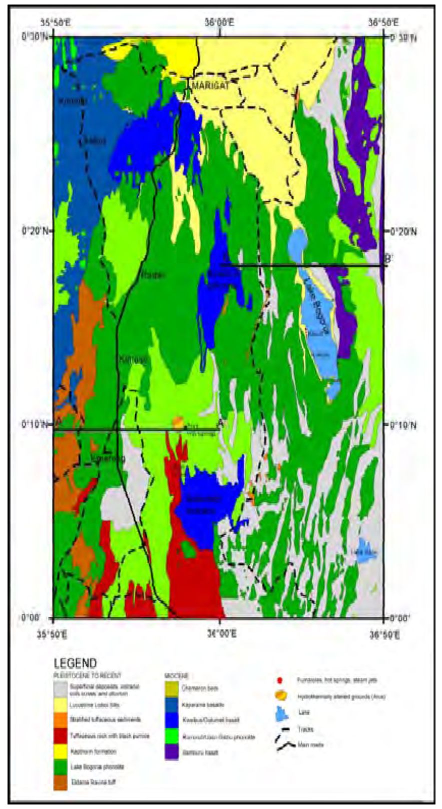
| | |
|---|---|
| Field Name | Arus Bogoria |
| Country | Kenya |
| Province/Location | The area referred to as Arus and Lake Bogoria prospects is located within the Kenya Rift valley immediately south of Lake Baringo prospect and north of Menengai prospect. It is situated mainly within the Baringo and Koibatek Districts and also includes parts of Nakuru District. The area is bound 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 to murram tracks and therefore is fairly accessible. Nakuru-Kabarnet tarmac road run across the prospect area near the western boundary from north to south. The seasonal tracks serve most of the area making it easily accessible, though with difficulty during the rainy seasons. Electric power and telephone service lines serve most of the farms, hotels and market centres that are in the area. GSM coverage appears intermittently within the prospect area. |
| Resource Characteristics<br>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 mostly 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 on the eastern side with the half graben changing into full graben accompanied by basalt-trachyte volcanism. The formation of the graben structure started about 5 million years ago and was followed by fissure eruptions in the axis of the rift to form flood lavas by about 2 to 1 million years ago. During the last 2 million years ago, volcanic activities become more intense within the axis of the rift. During this time, large shield volcanoes, most of which are geothermal prospects, developed in the axis of the rift. The volcanoes include Suswa, Longonot, Olkaria, Eburru, Menengai, Korosi, Paka, Silali, Emuruangogolak, and Barrier Complex. Other geothermal prospects, of which Arus and Lake Bogoria prospects are, occur between these central volcanoes (Omenda et al., 2001). |
| Geological Structrure | 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.<br>The most prominent of the NW trending faults is the line of Sattima-Aberdares and Marmanet Faults. Its complement to the north comprising the Lariak-North Arabel and other shorter minor faults forming a belt of discontinuous fractures. Progressively towards the northwest, both fault zones display an en echelon displacement to the west. |
| (Past Geological Studies included) | The first detailed geological mapping in the Kenya rift including Arus and Lake Bogoria area was done in the late 1960's by the Kenya Geological Survey. Geological work in the area with bias in geothermal exploration was carried out by Geotermica Italiana Srl (1987) in their Menengai-Bogoria reconnaissance report, but dwelt mainly on Menenga caldera. Further surface exploration work has been carried out in the mid of 2000's by KenGen on behalf of the Ministry. |
| Geochemistry | From the study done in the middle 2000's, geochemical exploration provides greater understanding of the location, nature and the origin of the thermal waters in a geothermal system. In addition, an insight into the recharge mechanism for the reservoir is envisaged. The information is fundamental for the assessment of the relative merits for future exploration and exploitation of a potential geothermal field. Geothermal surface activities in an area can be broadly classified into three types, which include: (i) Hot water in form of springs and mud pools, (ii) Steaming grounds, alteration zones and fumaroles and (iii) Non-manifestation areas where no surface expression of geotherma activity is observed. |
| 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 Geotermica Italiana covered the area from Menengai Caldera in the south to Lake Bogoria to the north. It involved sampling of water points and a few soil gas surveys targeting mainly carbon dioxide gas. High flows of discharging fluids were recorded around Lake Bogoria springs and temperature estimates using solute geothermometry from the springs and boreholes ranged from 145-190°C for borehole and spring water. Gas geothermometry gave temperatures between 209-214oC for the Arus steam jets using $CH_4/H_2$ and $CO_2$-$CH_4$-CO gas functions.<br>In the middle of 2000's, geochemical surface exploration was programmed to take one hundred and eighty working days, it was estimated to be adequate to sample all the fumaroles, springs, boreholes, and expedite soil gas surveys in the study area. The work involved (i) Sampling of all boreholes and springs within the Arus-Lake Bogoria prospects, (ii) Fumarole gas sampling, steam condensates and soil gas survey targeting mainly Radon-222/220 and c |
| Geophysics | Since the early 1970's both passive and active source seismic investigations were applied to understand the formation and structure of the Kenyan part of the East African rift valley. The United States Geological Survey carried out seismic studies at Lake Bogoria and Olkaria in 1972 and located earthquakes of magnitude 2 or less that were restricted mainly within the fields along fault zones (Hamilton and Muffler, 1972). In 1986/87 a micro-earthquake network was setup in the Lake Bogoria region in an area of bout 25 km diameter in the Molo graben, Ndoloita graben and Kamaachj horst comprising of 15 recording stations. Results from the survey appeared to suggest that most of the activity was associated with larger, older faults of the rift flanks rather than younger grid faults crossing cutting the rift.<br>In the early 2000's, mMethods that were employed during exploration of Arus-Bogoriawere, Magneto telluric (MT), Transient Electromagnetic (TEM) and Gravity. |



Location of Proposed Exploration Wells in Arus and Lake Bogoria prospect

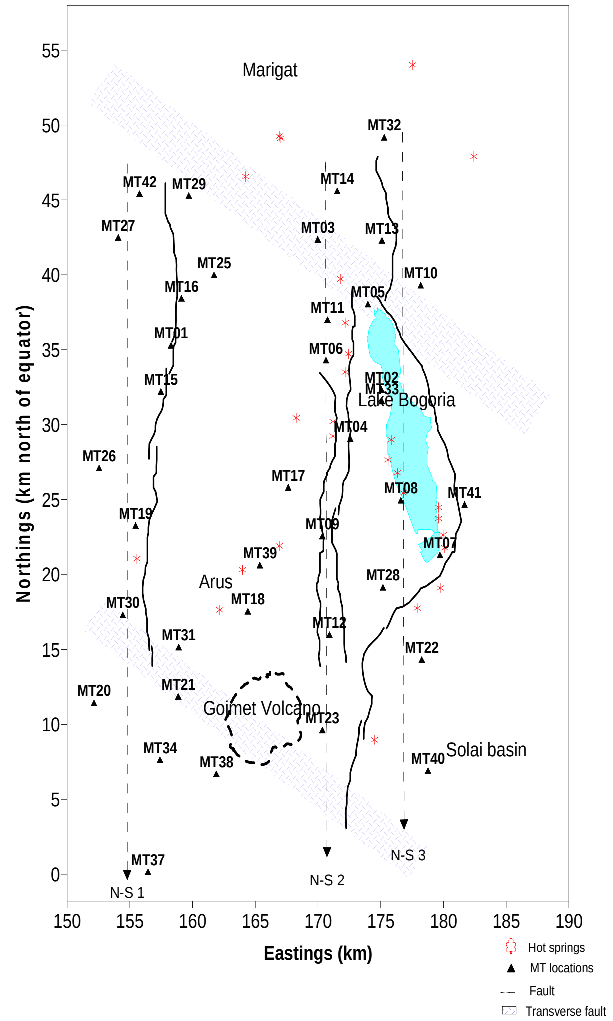


Conceptualized Model of the Lake Bogoria Geothermal Prospect



Geologic Map of the Arus-Bogoria Geothermal Prospect

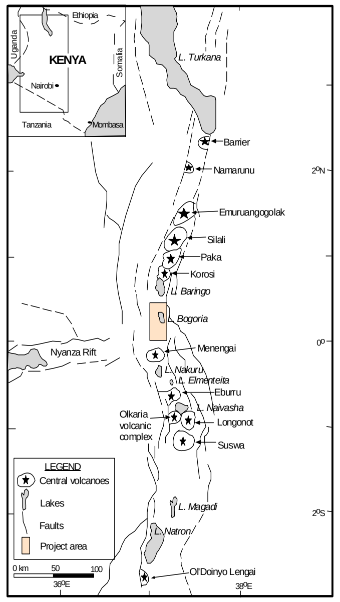

Hot Spring at the western edge of Lake Bogoria



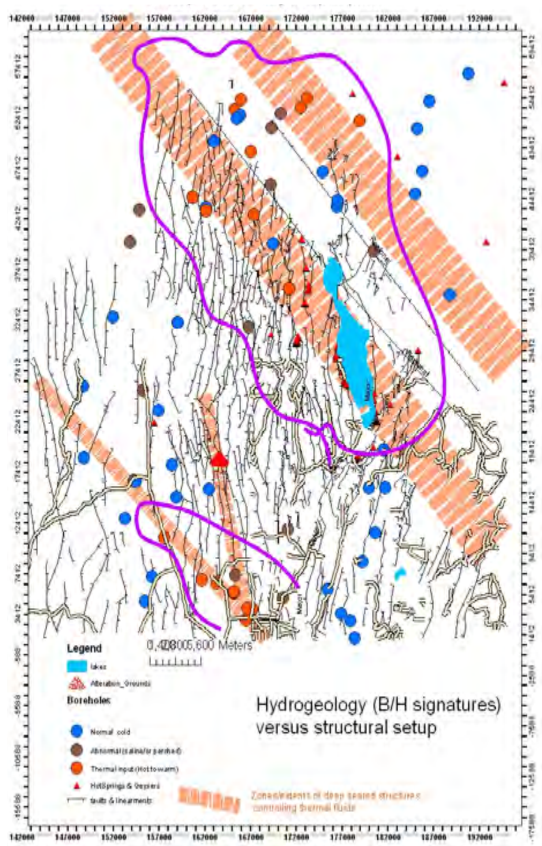
Location of MT soundings and interpreted profiles across the Arus-Bogoria region

Annex-1-6 The Evaluation Sheet of the Arus Bogoria (Kenya) Geothermal Field (2)

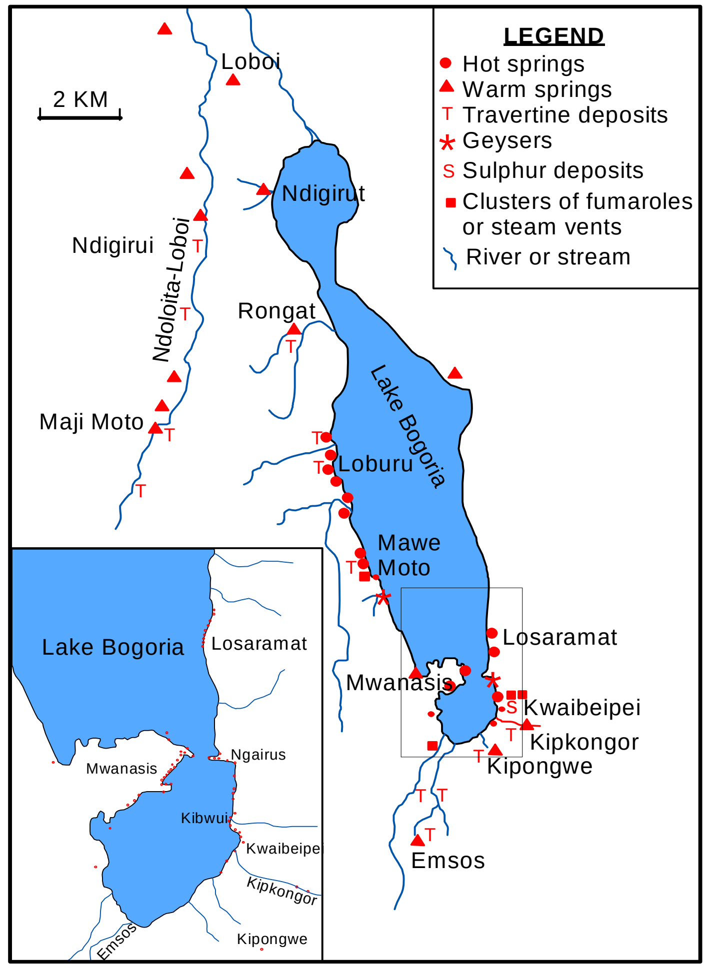
| | |
|---|---|
| Gravity | The gravity measurements were carried out using Lacoste and Romberg gravimeter model G-767. One hundred twenty data points were collected in the Arus and Lake Bogoria prospect. These were merged with data collected by UNDP and earlier workers for better coverage.<br>Various plot maps of gravity were prepared from the data set comprising of over 150 gravity stations using Bouguer density of ranging from 2.0 gcm-3 to 2.7 gcm-3 using Nettleton's method. It was found that to get the best fit for the region an average Bouguer density of 2.5 gcm-3 had to be used. Iso-maps maps were then prepared. |
| Resistivity | **TEM**: A total of 47 TEM soundings (Figure 3.3), covering an area of about 1575 km2, were carried out in the Arus-Bogoria prospect area using a central loop TEM array. The results are presented in this report by resistivity iso-maps at various heights above sea level.<br>**MT**: An 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. |
| Well Drilling | |
| Temperature Survey | |
| Well testing | |
| Conceptual Model | Fault controlled geothermal systems exist in both Arus and Lake Bogoria geothermal prospects. The estimated reservoir temperatures predicted to be medium to high (180 - 248ºC) and are ideal for electricity generation as well as direct utilisation.<br>The geothermal system around Lake Bogoria is possibly restricted to the regions around the Lake, more so the southern half. It is postulated that the geothermal system around the Lake involves deep-water circulation through the eastern and southeastern rift master faults. The main recharge path would be via the Sattima-Marmanet fault system. The water would then be heated by the general high geothermal gradient in the area and localized hot bodies possibly associated with deep-seated intrusives as manifested by the occurrence of dikes on the surface. The absence of a clear centralized heat source implies that the geothermal systems are small and restricted to the fault zones. It is also postulated that the system is of medium temperature. No clear cap rock can be described for the system near Lake Bogoria. |
| 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 in the Arus-Lake Bogoria prospect to confirm and characterize the geothermal systems. |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential<br>Resource Potential<br><br>Restrictted by National Park<br>Restricted by Power Demand | 400MW (estimated): Reconnaissance and surface exploration has been done. detailed detailed surface exploration planned for 2010. |
| Rank of Development Priority | B |
| Potential (Expected) Developer | |
| Proposed Geothermal Development Plan<br>Outline for Power Development | |
| Possible or Recommended Multi-purpose Geothermal Heat Use | Some of direct applications that can be utilized in the Arus and Lake Bogoria geothermal prospects include spa pools, greenhouse heating, agricultural produce drying and industrial processes. Most of these direct use applications utilize geothermal fluids in the low to moderate temperatures and the reservoir can be exploited by conventional water wells drilling rigs. The direct application currently available within the prospect area is a spa pool at Lake Bogoria Hotel. The water, which is at 38ºC is channeled directly into the swimming pool at one end and flows out at the other end. |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |

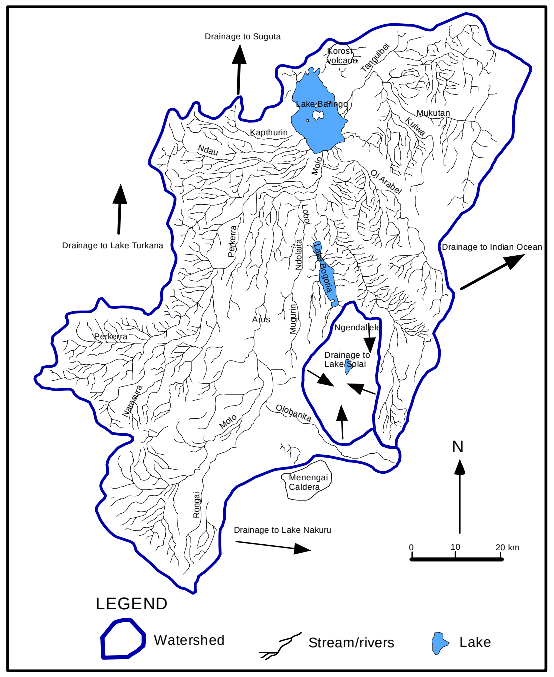



Map of the Kenya Rift showing the locations of major central volcanoes and the Arus and Lake Bogoria geothermal prospects

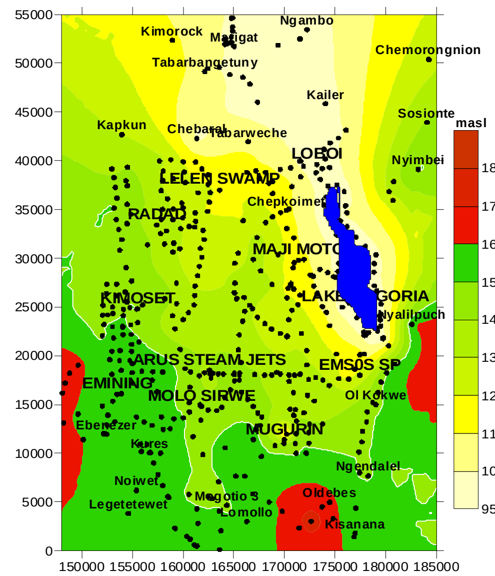



The Structural controls of the hydrogeology and hydrothermal activity in the Arus and Lake Bogoria prospect

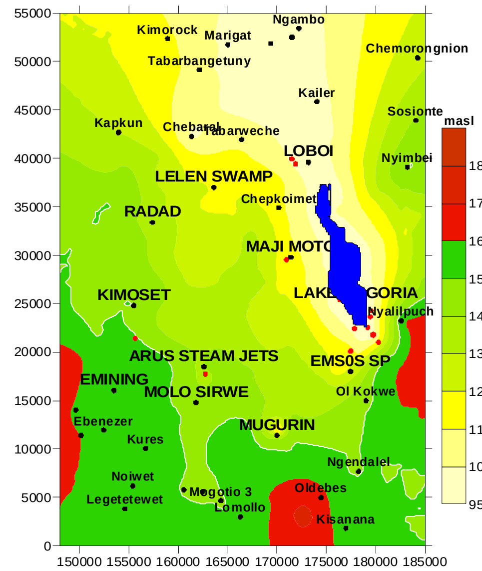



Map of the drainage system in the Arus and Lake Bogoria geothermal prospects



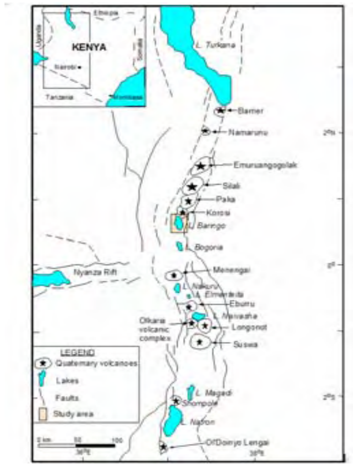

Arus-Lake Bogoria soil gas sampling points



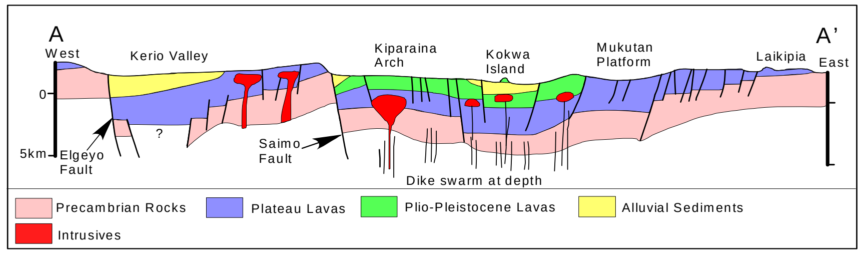

Arus-Lake Bogoria prospects borehole and springs locations

Annex-1-7 The Evaluation Sheet of the Lake Baringo (Kenya) Geothermal Field (1)

| | |
|---|---|
| Field Name | Lake Baringo |
| Country | Kenya |
| Province/Location | 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 0o30'N and 0o45'N and longitudes 35o59'E and 36o10'E. Lake Baringo is a prominent feature occupying most of the central part of the area.<br>The surface adjacent to the lake is flat to gentle N-S running grabens filled with fluvial and lacustrine deposits. N-S running sharp cliffs representing intense tectonism are also common as one moves away from the lake eastward. |
| Accesibility | The area has few all weather roads that include Marigat-Lake Baringo and part of the Nakuru-Kabarnet road. A system of secondary roads made of murram or earth form an extensive network serving the entire area except for some of the steepest hills, slopes and densely vegetated areas. The area is served by a network a fixed line telephone communication at most shopping centres and at several hotels within the area. GSM telephone communication can be accessed at some locations in the prospect area. |
| Resource Characteristics<br>Geology | Hydrothermal activity in the Lake Baringo prospects is manifested by extensive occurrence of fumaroles, hot spring, altered grounds and thermally anomalous groundwater boreholes. One of these boreholes, the Chepkoiyo borehole, which was drilled in April 2004, self discharged water at 98oC (local boiling point). The chemistry of the discharged fluids indicated possible input from a geothermal reservoir.<br>The geology of the area is dominated by intermediate lavas (trachytes and trachy-phonolites) in the west and east sectors of the prospect area and basalts in the north. The southern sector is, however, dominated by fluvial and alluvial deposits. |
| Volcanic activity (heat source) | Kenya Rift International Seismic Prospect (KRISP, 1987; Henry et al, 1990) studies indicate a thinned crust comprising of volcanic material in this part of the Kenya Rift where the prospect area is located. The heat source for this system is most likely dike swarms associated with the faults along which repeated fissure eruptions have taken place. |
| Geological Structrure | 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 form 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 m. |
| (Past Geological Studies included) | Detail surface investigations of this prospect were carried out between June 2004 and August 2004. |
| Geochemistry | Gas geothermometers recorded temperatures of 168°C to 310°C calculated using CO2, H2 and solute Na/K/Ca. High radon counts and high CO2 measured in the soil gas were observed around Loruk, the area west of Kampi ya Samaki, Rugus and southeast of Kiserian and could be indicative of enhanced permeability in these areas. |
| Work done so far | To the few sampling points that consisted of fumaroles and boreholes, soil gas and Radon-222 surveys were conducted throughout the prospect between June 2004 and August 2004. |
| 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 underlying volcanics, identification of structures that could be possible conduits for geothermal fluids and presence of heat sources.<br>Schlumberger resistivity done by MOE in the late 1980s<br>A few gravity measurements done by universities in the early 1990s<br>Aeromagnetic data collected by the National Oil Corporation of Kenya in 1987<br>Micro-seismic monitoring to the south of Lake Baringo carried by the University of Leicester in the early 1990s |
| Gravity | **Gravity**: Gravity highs are seen on higher altitudes along the northern and eastern flanks of the area, i.e. Korosi and the S-E of Lake Baringo. Other high gravity areas are those associated with volcanics appearing on the surface to the west near Loruk and Kampi Ya Samaki. A gravity high is seen to the S-W of the lake and runs approximately N-S, passing through the Chepkoiyo well and coincident with the fault along Marigat-Loruk road. Incidentally, the geothermal manifestations appear on these volcanics. A trend of gravity lows is seen running in a NE-SW through the southern part of the lake. The lowest gravity signal was recorded south of Lake Baringo on fluvial sediments.<br>**Magnetics**: The highest magnetic signal was recorded at the southeastern slopes of Korosi, around Komolion, NNE of the survey area. The lowest values are seen on the sediments around the lake. The region around Chepkoiyo well has signals of moderate values. Generally, the magnetic signatures in the western sector trend in a N-S direction and tend to mimic that of low resistivity at 500 masl. |
| Resistivity | **TEM**: At the elevation of 500 masl, it is observed that these resistivities are in most areas lower than 20 ohm-m for all the depths investigated. A trend of low resistivity (<5 Ohm-m) is seen running in an N-S direction west of the lake passing through the Chepkoiyo well. The other such low resistivity trends in an NE-SW direction through the Chepkoiyo well, Ol Kokwa Island and Rugus hills to the NE. Slightly higher resistivities (8-20 Ohm-m) exist to the south, north, N-E and further west of the lake.<br>**MT**: Planar resistivity variations of MT data at sea level, 2000 mbsl and 5000 mbsl, respectively. At the near surface, these anomalies mimic those of TEM in most areas around the lake. Low resistivity anomalies exist to the west, NE and SE of the lake. The shapes of the low anomalies also tend to follow the topography due to sediment deposition. Similar information has also been derived from seismic experiments by Tongue et al.(1994). At deeper levels, the western low resistivity anomaly still persists, spreading out to the north and northeast. |




Location of the Lake Baringo geothermal prospect within Kenya rift




Generalized Litho-Stratigraphic Cross Section through Lake Baringo Geothermal Prospect

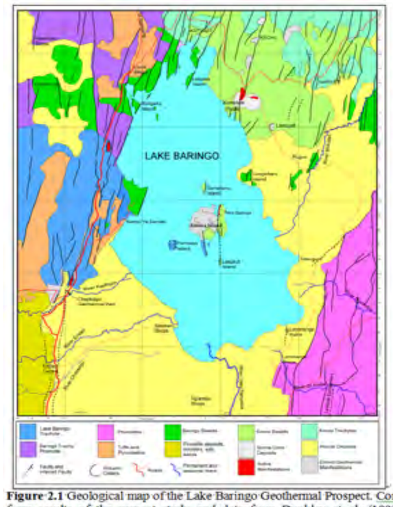



**Figure 2.1** Geological map of the Lake Baringo Geothermal Prospect. Compiled from results of the present study and data from Dunkley et al. (1993) and Hackman (1988).

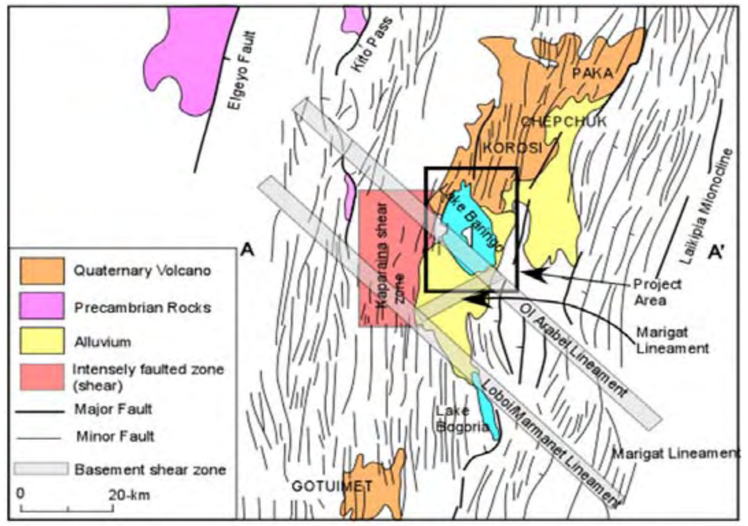
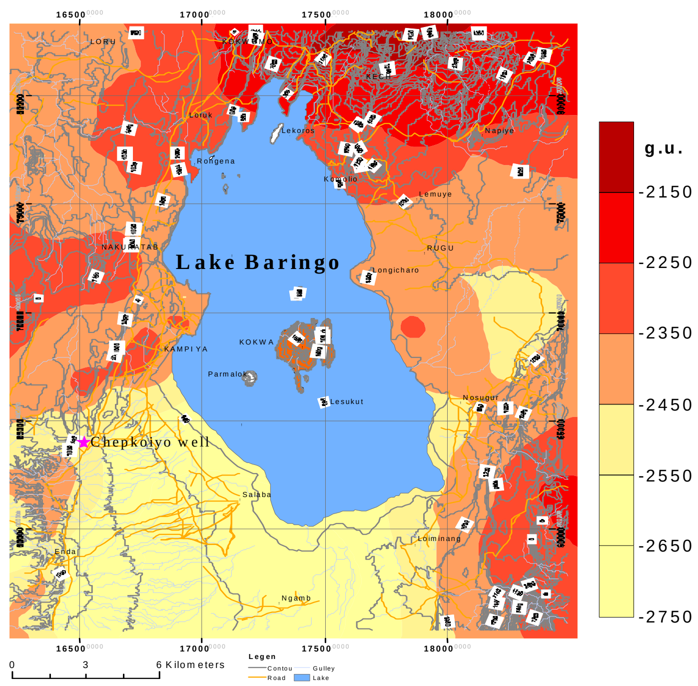
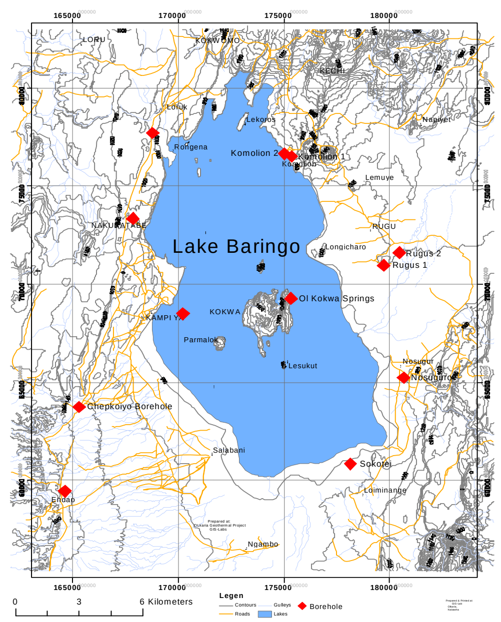



**Figure 2.2** Structural map of the area around Lake Baringo Geothermal Prospect. Major (Precambrian?) lineaments (Shear zones)



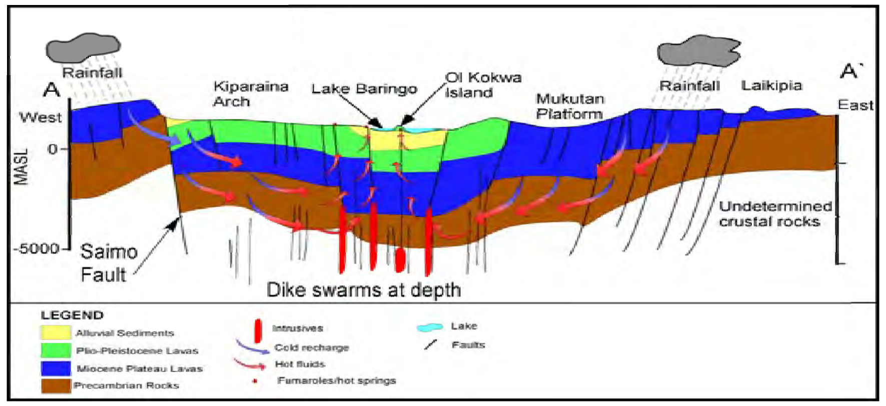

Bouguer Anomaly Distribution in the Lake Baringo Geothermal Prospect



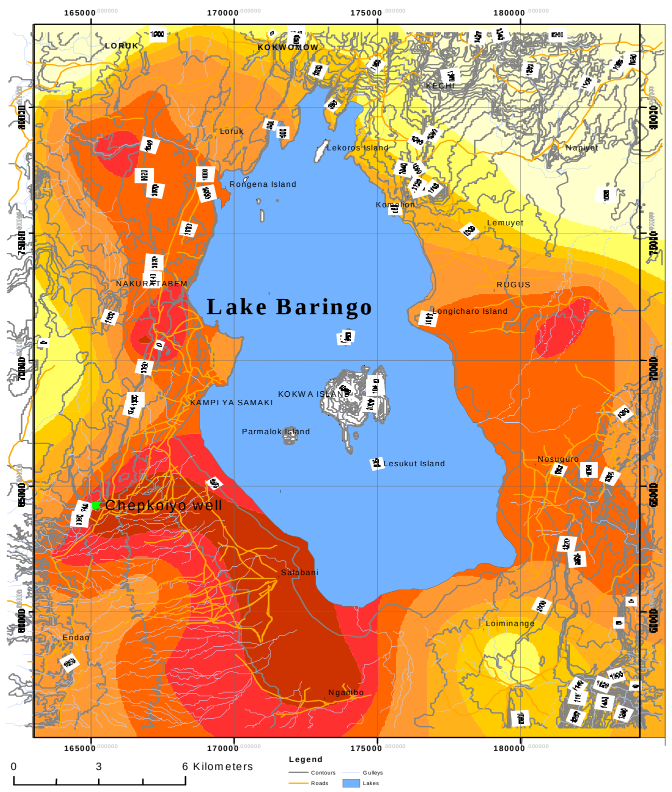

Shallow boreholes locations in the Lake Baringo Geothermal Prospect

Annex-1-7 The Evaluation Sheet of the Lake Baringo (Kenya) Geothermal Field (2)

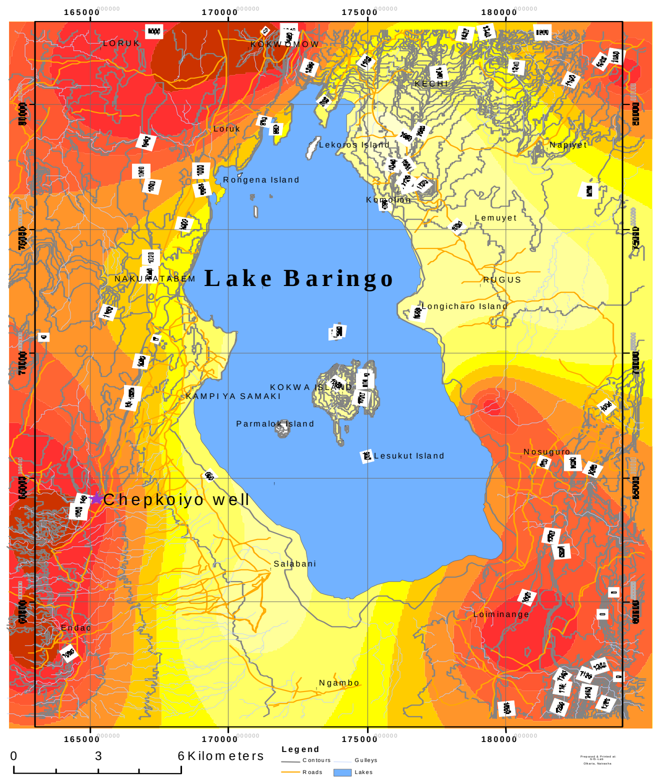
| | |
|---|---|
| Well Drilling | None |
| Temperature Survey | None |
| Well testing | None |
| Conceptual Model | • Geoscientific data indicate existence of a geothermal resource in Lake Baringo prospect, which is characterised by intermediate to high temperatures.<br>• The heat source for the geothermal systems are dyke swarms and shallow intrusive bodies associated with faults and the reservoir rocks are the Plio-Pleistocene lavas.<br>• Gas geothermometers recorded temperatures of 168°C to 310°C calculated using CO2, H2 and solute Na/K/Ca.<br>• High radon counts and high CO2 measured in the soil gas were observed around Loruk, the area west of Kampi ya Samaki, Rugus and southeast of Kiserian and could be indicative of enhanced permeability in these areas.<br>• Over 1049 MWt natural heat loss occurs in the Lake Baringo geothermal prospect. Out of this amount, 90% is lost along the main fault zones to the west of Kampi Ya Samaki and through Komolion and Ol Kokwa Island. |
| 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 extensional rift tectonics. It is therefore expected type of systems are mainly deep 'circulatory systems' for the western central, and eastern parts. The northern parts (around Komolion, Kechii and surrounding areas) are probably outflows associated with systems within the Korosi volcano. The systems are therefore restricted mainly to fault zones and are discrete.<br><br>The following further work are neccessary:<br>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.<br>2. Additional MT and TEM soundings would be necessary to increase density of sounding locations and thus, improve the geothermal models. The S-E of the lake and at Ol Kokwa Island need further investigation area to confi<br>3. Seismic studies on focal mechanisms and swarm activity location determinations are needs to be done in the Lak<br>4. Mercury is one of the most volatile elements carried in geothermal steam from deep geothermal reservoirs and as<br>5. Down-hole temperature and pressure profiles of boreholes, which are accessible, needs to be carried out.<br>6. A full Environmental Impact Assessment study for the prospect area should be carried out before commencemen |
| Natrural/Social Environmental Condition | The area to the west of Lake Baringo along the 4 km wide N-S trending zone, comprising of faults and fractures, represented by deep conductive zone running through the Chepkoiyo well is a good candidate for direct utilization. The area is particularly suitable for the creation of a climatized environment, all year round, with optional temperature (heating and cooling), desired humidity conditions, and eventual addition of CO2 of geothermal origin, which stimulates the production of biomass in greenhouses. |
| Power Sector Situation | Small-unit generation of electricity, through medium-low temperature geothermal waters (90-160°C), is particularly suitable for a rural economy, especially when distributed in areas isolated from the national electricity network. The geothermal systems in Lake Bogoria prospect could be small and discrete and therefore small-scale utilization of the geothermal resource both for electricity generation (using direct or binary systems) and direct uses which include cooling and tourism are feasible. |
| Power Output Potential<br>Resource Potential<br>Restrictted by National Park<br>Restricted by Power Demand | 200MW (estimated): Surface exploration done. Detailed surface exploration planned for 2010. |
| Rank of Development Priority | B |
| Potential (Expected) Developer | |
| Proposed Geothermal Development Plan<br>Outline for Power Development | |
| Possible or Recommended Multi-purpose Geothermal Heat U | The island is also an ideal locality for direct uses because it is isolated from the mainland and construction of overhead or submarine power lines to supply the island is extremely expensive. The island is inhabited by over 1500 people, over 5000 livestock, has several schools, shopping centres and tourist hotels and therefore the demand for cheap energy source is high and ever increasing. |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | Other than exploratory drilling,<br>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.<br>2. Additional MT and TEM soundings would be necessary to increase density of sounding locations and thus, improve the geothermal models. The S-E of the lake and at Ol Kokwa Island need further investigation area to confirm, or otherwise, the existence of a geothermal resource.<br>3. Seismic studies on focal mechanisms and swarm activity location determinations are needs to be done in the Lake Baringo region to identify possible faults for drilling targets.<br>4. Mercury is one of the most volatile elements carried in geothermal steam from deep geothermal reservoirs and as such can be a powerful tracer element, more so when used in conjunction with both Rn-222 and CO2. It is recommended that in addition to Rn-222 and CO2 surveys, mercury measurements be conducted in the area and in all future exploration campaigns.<br>5. Down-hole temperature and pressure profiles of boreholes, which are accessible, needs to be carried out.<br>6. A full Environmental Impact Assessment study for the prospect area should be carried out before commencemen |
| | |
| Location Map | |
| Other Figures | |



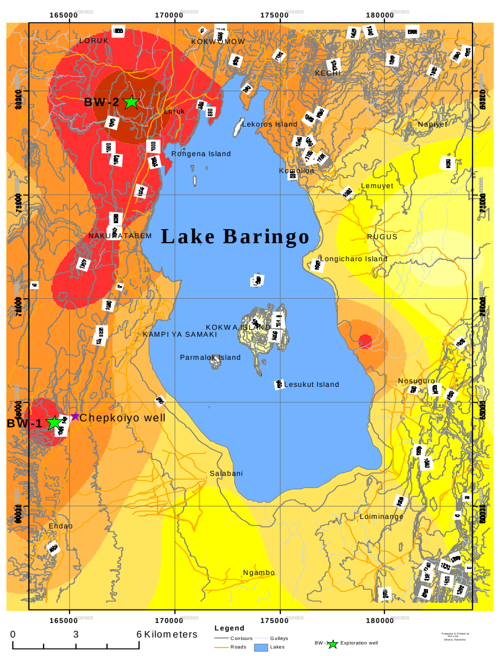

Simplified Geothermal Model of Lake Baringo Geothermal Prospect




Resistivity Distribution at 500masl from TEM measurements in the Lake Baringo Geothermal Prospect




Resistivity Distribution at sea level from MT measurements in the Lake Baringo Geothermal Prospect



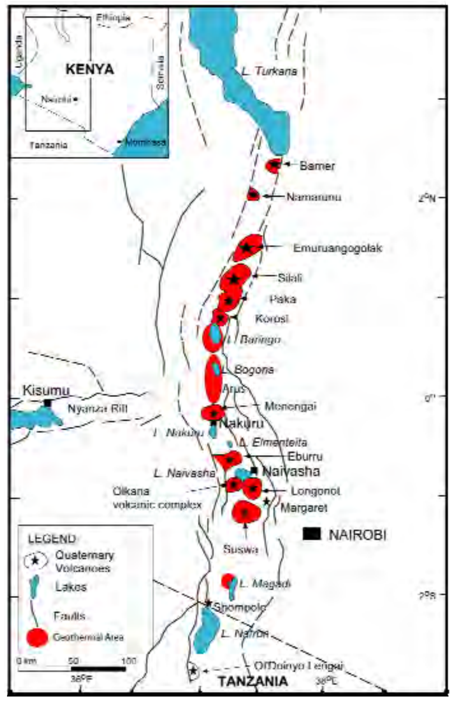

Proposed Location for Exploratory Wells (BW-1 and BW-2) in the Lake Baringo Geothermal Prospect

Table 4.1 Chemical composition of water samples from Baringo boreholes

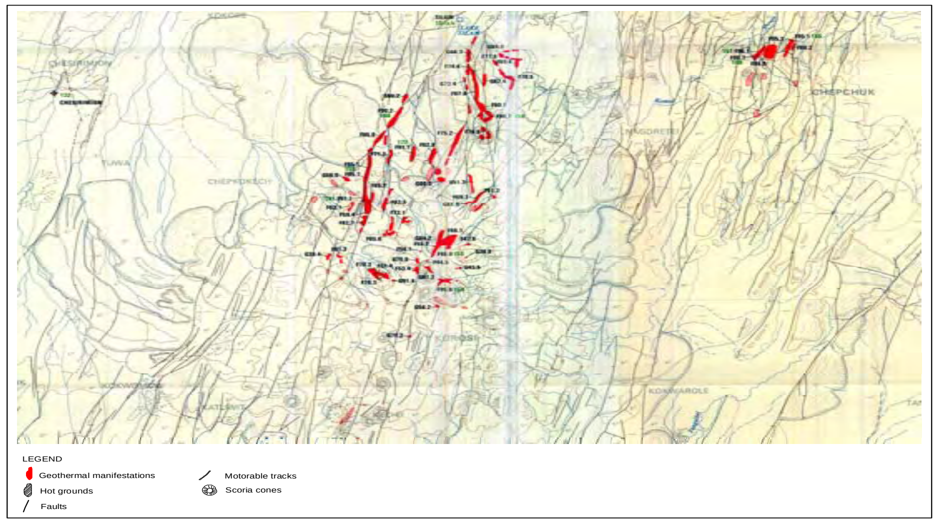
| NAME | Temp | pH | Cond | TDS | $H_2S$ | $CO_2$ | $SO_4$ | Cl | F | Li | $SiO_2$ | B | Na | K | Ca | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chebarsiat | 30.5 | 8.3 | 590 | 396 | 0.14 | 242 | 39 | 32 | 0.6 | 0 | 108 | 0.1 | 129 | 2.5 | 4 | 2 |
| Chepkerelionin | 28.4 | 7.8 | 770 | 505 | 0.07 | 385 | 6 | 46 | 0.5 | 0 | 62 | 0.1 | 85 | 2.3 | 72 | 50 |
| Koroto 1 | 27.1 | 7.4 | 790 | 539 | 0.03 | 502 | 23 | 21 | 0.5 | 0 | 55 | 0 | 64 | 2.5 | 101 | 119 |
| Koroto 2 | 29.3 | 7 | 940 | 626 | 0.03 | 787 | 2 | 17 | 0.5 | 0 | 54 | 0 | 56 | 1.3 | 132 | 64 |
| Rorobai | 32.1 | 7.5 | 850 | 566 | 0.07 | 490 | 42 | 21 | 1.4 | 0 | 35 | 0 | 156 | 8.2 | 47 | 31 |
| Endao | 29.3 | 7.2 | 640 | 425 | 0.11 | 424 | 17 | 19 | 1 | 0 | 36 | 0 | 88 | 8.7 | 67 | 19 |
| Marigat | 29.5 | 7.5 | 360 | 238 | 0.11 | 204 | 30 | 9 | 0.9 | 0 | 23 | 0.1 | 26 | 4.1 | 57 | 91 |
| Akorian | 30.3 | 7 | 520 | 341 | 0.17 | 246 | 17 | 21 | 3.0 | 0 | 34 | 0 | 77 | 9.3 | 68 | 20 |
| Kosile | 30.8 | 7.2 | 480 | 314 | 0.17 | 138 | 19 | 13 | 1.5 | 0 | 42 | 0 | 52 | 2.4 | 60 | 22 |
| Barsemoi | 29.3 | 7.3 | 820 | 551 | 0.07 | 510 | 5 | 21 | 0.8 | 0 | 92 | 0 | 101 | 2.6 | 106 | 48 |
| Chebarsiat 2 | 26.5 | 7.5 | 870 | 580 | 0.05 | 471 | 36 | 30 | 0.7 | 0 | 49 | 0.1 | 65 | 4.6 | 113 | 54 |
| Tibingar | 29.3 | 7.1 | 800 | 537 | 0.05 | 427 | 3 | 18 | 0.5 | 0 | 38 | 0.2 | 610 | 1.7 | 132 | 53 |
| Loruk | 47.5 | 8.2 | 1550 | 1027 | 0.26 | 436 | 341 | 159 | 15.6 | 0 | 88 | 0.6 | 342 | 17 | 12 | 24 |
| Chebarsiat 3 | 31.9 | 8.3 | 750 | 499 | 0.2 | 233 | 24 | 126 | 0.6 | 0 | 73 | 0 | 104 | 4.3 | 16 | 32 |
| Chepkoi | 37.9 | 7.8 | 710 | 454 | 0.05 | 268 | 32 | 42 | 4.4 | 0 | 88 | 0 | 141 | 5 | 21 | 24 |
| Yatoi | 34.9 | 8.3 | 780 | 507 | 0.11 | 391 | 21 | 16 | 0.9 | 0 | 60 | 0 | 168 | 10 | 8 | 167 |
| Komolion 1 | 31.1 | 7.8 | 1820 | 1209 | 0.02 | 682 | 19 | 101 | 4.9 | 0 | 46 | 0 | 441 | 27 | 37 | 58 |
| Komolion 2 | 30.9 | 7.6 | 540 | 366 | 0.03 | 781 | 161 | 10 | 4.7 | 0 | 29 | 0.4 | 85 | 18 | 30 | 24 |
| Lake Baringo | 30.3 | 9 | 680 | 461 | 0.1 | 242 | 17 | 53 | 5.9 | 0 | 59 | 0.1 | 139 | 13 | 42 | 35 |
| Rugus | 31.4 | 8.1 | 9460 | 4730 | 0.03 | 2057 | 2623 | 1095 | 35.0 | 0 | 28 | 0.9 | 2443 | 12 | 6 | 155 |
| Chemeron (Eu) | 37.5 | 7.6 | 800 | 399 | 0.2 | 120 | 20 | 102 | 16.1 | 0 | 45 | 0.1 | 142 | 1.9 | 26 | 37 |
| Lokodowiabet | 32.5 | 8.3 | 800 | 537 | 0.09 | 304 | 24 | 65 | 2.3 | 0 | 58 | 0 | 157 | 7.3 | 14 | 42 |
| Sokotei | 32.7 | 8.5 | 41200 | 30640 | 0.18 | 5346 | 17111 | 3813 | 24.5 | 0 | 5 | 0.6 | 9786 | 20 | 29 | 45 |
| Chepkoiyo well | 97 | 9.3 | 8430 | 5010 | 1.7 | 3245 | 175 | 329 | 57.4 | - | 318 | - | 2078 | 62 | 1.45 | - |

Annex-1-8 The Evaluation Sheet of the Lake Korosi (Kenya) Geothermal Field (1)

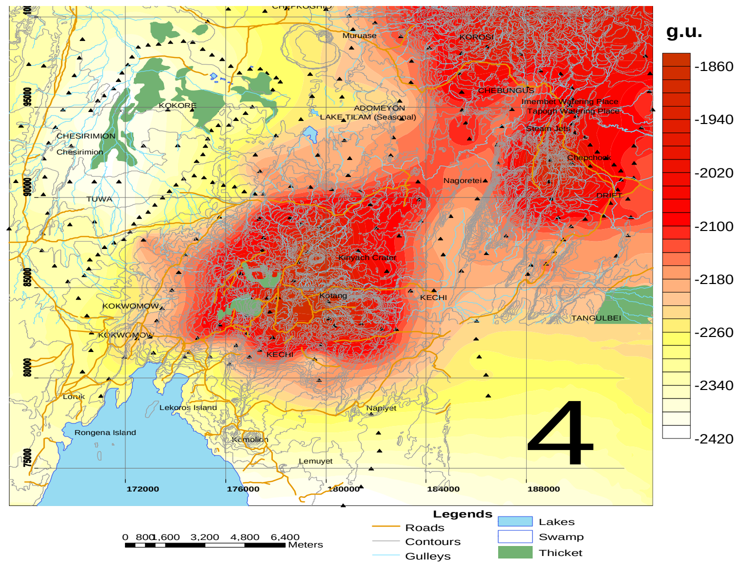
| | |
|---|---|
| Field Name | Korosi |
| Country | Kenya |
| Province/Location | Korosi - Chepchuk area is located in Baringo district of the Kenyan Rift Valley and is neighboring Lake Baringo to the south and Paka volcano to the north at approximately 00o 45'N, 36o05' E. The volcano occupies an area of about 260 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 Nairobi-Maralal road. The other branch continues northwards and passes through Nginyang, Kapedo, and Lomelo. These two well-maintained murram roads provide access to the eastern and western sectors of the prospect area and from them a number of poorly defined and rough tracks that are impassable during the rainy seasons branch. A rough track extending in an E-W direction between Nginyang and Tangulbei provides access to the northern flanks of both Korosi and Chepchuk volcanoes.<br>The area is served by a network a fixed line telephone communication at most shopping centres within the area. GSM telephone communication can be accessed at some locations in the prospect area, though satellites phones can be accessed everywhere within the prospect area. |
| Resource Characteristics<br>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. |
| Volcanic activity (heat source) | Korosi is a multi vent complex composed predominantly of trachyte lavas, which have built up a low volcanic shield, upon which lesser amounts of basalt, mugearite and pyroclastic deposits have erupted.<br>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 NNE-trending faults. The majority of the lavas were erupted from the northern part of the summit area and flowed down to the northern flanks of the volcano. Radiometric dating of the Upper Trachyte lavas indicates an age of 104±2 ka.<br>Heat source is associated with shallow magmatic bodies under the volcano and intrusive dykes along NNE structures. The location of the prospect areas allow for recharge of waters from the wet rift flanks into the deep hot intrusives. The areas have extensive faulting which can allow upflow of hot geothermal fluids to shallow depths. |
| Geological Structrure | The 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 last 100,000 yrs BP. The structural setup of the area is defined by dominant NNE and N trending fault swarm within the axial region. The dominant fault trend at Korosi is somewhat discordant with rift boundaries at that latitude which is more in NE trend. The fault zone defines a micro-graben within the axis of the rift; the boundaries of which are marked by the Nakaporon fault in the west and Nagoreti fault in the east. The latter fault also defines the western boundary of the Chepchuk volcanic edifice.<br>The Korosi volcanic massif is located entirely within the micro-graben marked by the Nakaporon and Nagoreti faults but with a bias to the west resulting in some of the Korosi volcanic products overflowing the walls of the east-dipping Nakaporon fault. The occurrence of cinder cones and other volcanic centres are controlled by the major N and NNE trending faults. |
| (Past Geological Studies included) | The detailed geological mapping to confirm the reported geological features, surface geology, structures, hydrothermal indicators and their distribution was already carried out in KenGen surface exploration study (2005-2006). |
| Geochemistry | Fumarole steam chemistry indicate reservoir temperatures in the range of 200- 280 oC 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 oC) and around Korosi (244 – 259 oC). |
| 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 geothermometry in KenGen surface exploration study (2005-2006). |



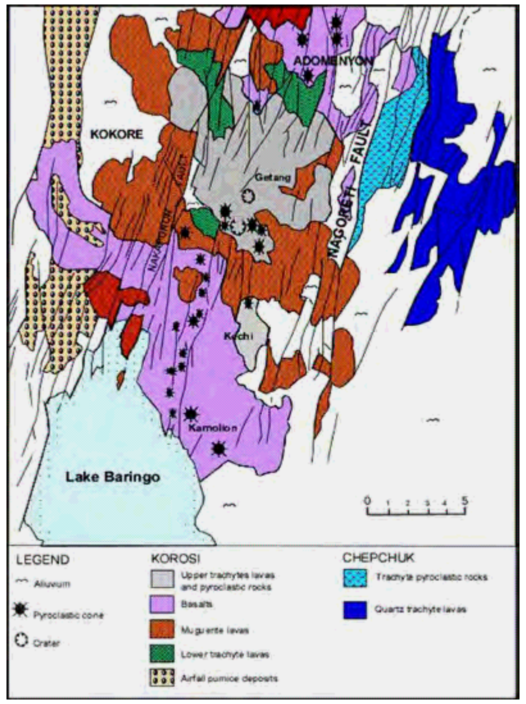

Location of Korosi Geothermal Prospect

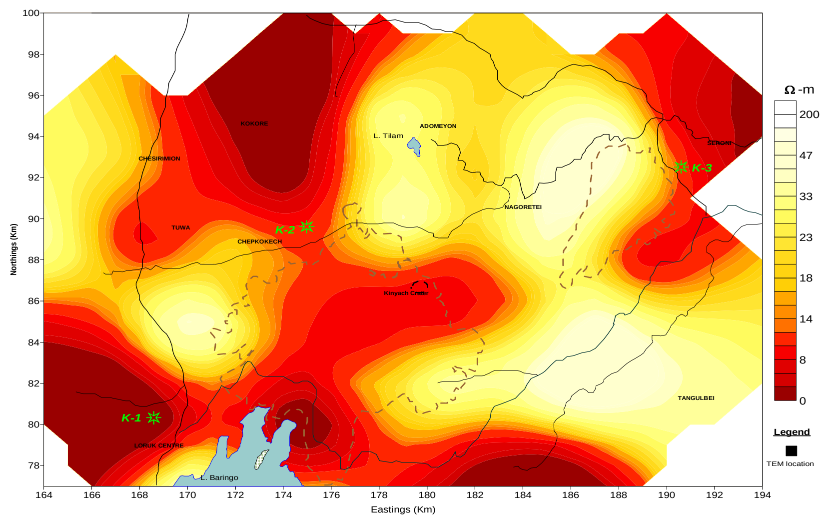



Structural map of the Koroshi Geothermal Prostect
indicating areas of high thermal manifestations




Bouguer Anomaly Distribution in the Korosi-Chepchuk area
The triangular symbols indicate the locations of the gravity stations.

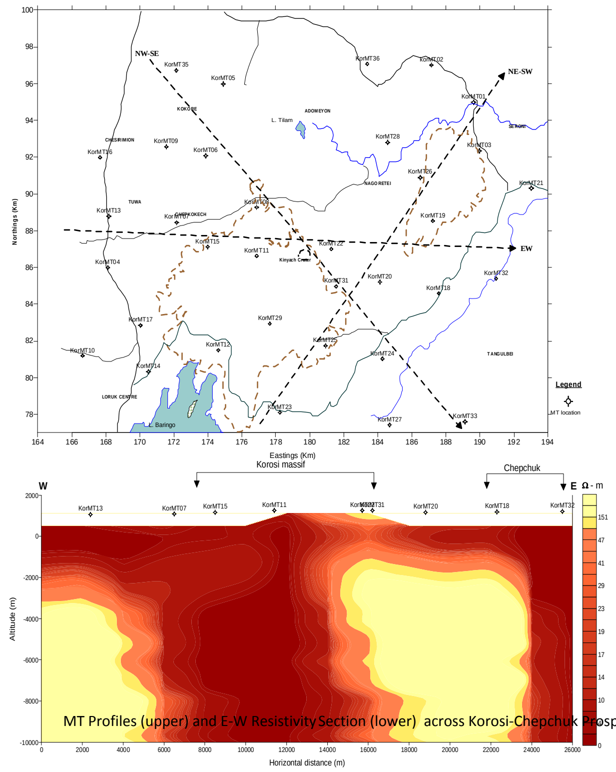


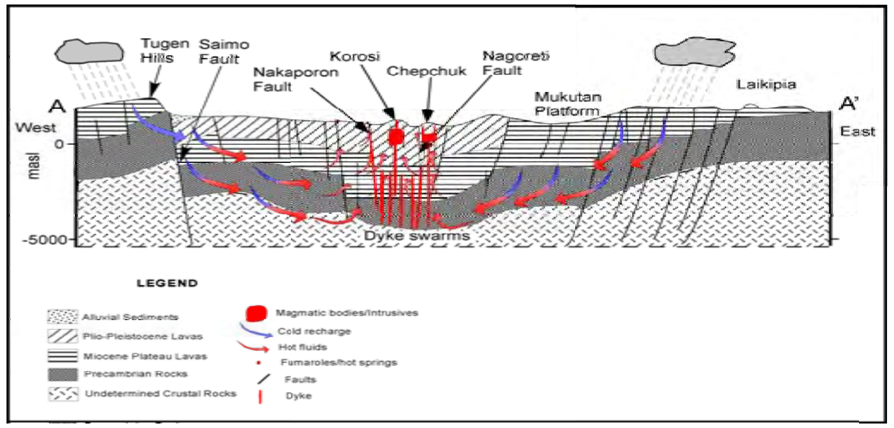

Location of the three proposed exploratory wells at Korosi--Chepchuk prospect superimposed on a
TEM resistivity distribution at 450 masl map

Annex-1-8 The Evaluation Sheet of the Lake Korosi (Kenya) Geothermal Field (2)

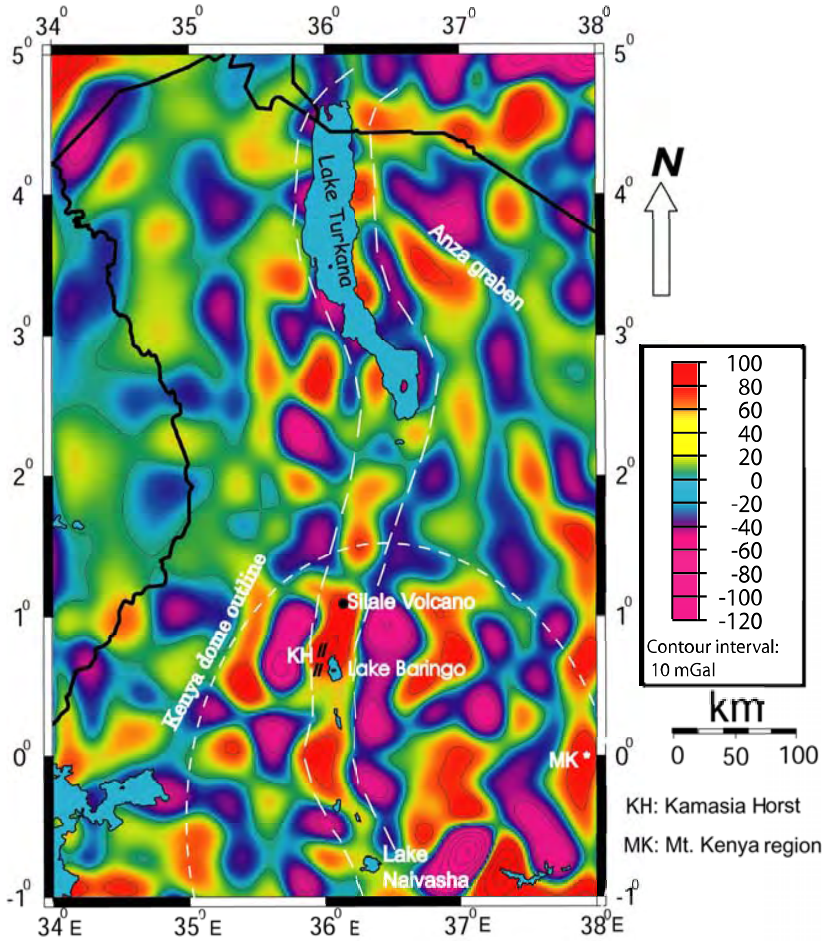
| | |
|---|---|
| Geophysics | Gravity and Ground Magnetic surveys, Transient-ElectroMagnetic (TEM) measurements, Magnetotelluric (MT) measurements and Micro-Seismic data collection were carried out in KenGen surface exploration study (2005-2006). 44 TEM soundings, 36 MT soundings, 280 Gravity stations and 280 Ground magnetic stations were covered. Results of these investigations have been used to infer the depth and extent of the possible heat source and geothermal reservoir and ti 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).<br>These data were examined along with gravity anomalies and a qualitative interpretation carried out over the Korosi-Chepchuk prospects. Magnetic anomalies seen here were not different from those over those coinciding with volcanic centres at Suswa, Olkaria, Eburru and Menengai. These anomalies are interpreted as being caused by changes in the susceptibility of rocks due to demagnetization 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 NE direction, connecting the volcanic centres of Korosi, Chepchuk and Paka. The gravity and magnetic signatures suggest shallow magmatic 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 volcano. Intersections of major structures such as Ol Arabel lineament with the NE-SW and N-S structures that run along the rift floor appear to play a significant role on resistivity distribution in this prospect. MT resistivity cross-sections show low resistivity anomalies at depth that could be related to heat sources. |
| Well Drilling | None |
| Temperature Survey | None |
| Well testing | None |
| Conceptual Model | Seismic studies done at the Kenyan North Rift in the early 1990s indicate that the crust thins north of Lake Baringo area and is estimated to be 20-25km thick. Observations from both geological and geophysical studies indicate that dense bodies exist under Korosi volcano. The bodies are expected to provide heat for the geothermal system under Korosi. Intrusions of magma along the NNE structures have also resulted in an emplacement of additional shallow heat sources. It is postulated that the geothermal system at Korosi is still active and that a reservoir exists under the massif with a bias towards the north.<br>Sources of hydrothermal fluids in the Korosi geothermal system are the groundwater from the eastern rift flanks and the Tugen Hills. The high hydraulic gradient between the high recharge areas and the floor allows for deep recharge into the geothermal reservoirs. The fluid flow is enhanced by the highly fractured Plio-Pleistocene lavas that are dominant in this part of the rift.<br>The reservoir rocks are postulated to be Plio-Pleistocene lavas and the associated pyroclastics. The cap rocks are envisaged to be the widespread Korosi tuffs and pyroclastics at depth, which are expected to provide for proper sealing. |
| Present Status of Development | ◆ A high temperature geothermal resource do exist in the Korosi and therefore deep wells (~2000 m), should be drilled in the prospect to confirm the characteristics and potential of the geothermal reservoir(s). The central northern portion of Korosi volcanic massif is proposed as the target area.<br>◆ The heat source for the geothermal resource at Korosi is associated with shallow magmatic bodies associated with the Upper Trachytes and to a less extent the intrusive dykes associated with the Young Basaltic magmatism.<br>◆ The reservoir rocks in the prospect are hypothesized to be either Loyamarok Trachy-phonolite or Baringo Trachyte together with associated volcanic rocks. |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential | |
| Resource Potential | 450MW (estimated): Reconnaissance and surface exploration done. Detailed surface exploration planned for 2010 and exploration drilling in 2011. |
| Restrictted by National Park | |
| Restricted by Power Demand | |
| Rank of Development Priority | B |
| Potential (Expected) Developer | |
| Proposed Geothermal Development Plan | |
| Outline for Power Development | |
| Possible or Recommended Multi-purpose Geothermal Heat Use | |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |



MT Profiles (upper) and E-W Resistivity Section (lower) across Korosi-Chepchuk Prospect



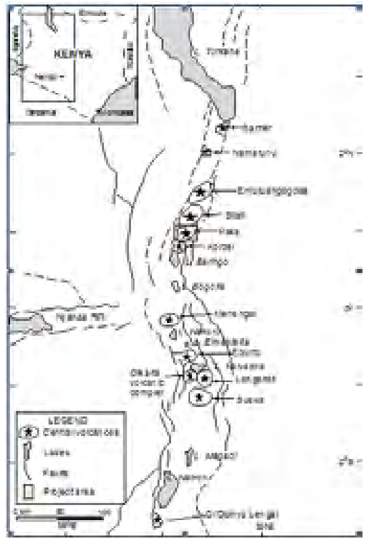
The conceptualized geothermal model of Korosi and Cheptchuk Geothermal Prospects



Band-pass filtered gravity map of the northern part of the Kenya rift.
(Mariita, 2003)

Annex-1-9 The Evaluation Sheet of the Paka (Kenya) Geothermal Field (1)

| Field Name | Paka |
|---|---|
| Country | Kenya |
| Province/Location | Paka is situated approximately 25 km north of Lake Baringo at 00o 25' N and 36o 12' E. It is one of the promising prospects in the North Rift. The area covered by this survey extended about 400km2 around the volcano massif. |
| Accessibility/Communication | The prospect is accessed via Nakuru-Marigat road, and a drive through rough earth tracks through east of Nginyang, shopping centre. The road communication within the prospect area is very poor. |
| Resource Characteristics<br>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 1697masl is surrounded by plains to the north, south, west and east. At the summit well preserved caldera about 1.5km in diameter, which is filled with young basaltic flows.<br>Several craters dotting the massif are aligned in a NNE direction (plate 1). The volcano is cut on its central and eastern flanks by a swarm of NNE trending faults.<br>Paka is a small shield volcano constructed largely by trachyte lavas and pyroclastic deposits. Basalt, hawaiite, mugearite, lavas were erupted from a series of fissure and fault zones located on the lower northeastern and southern flanks. |
| Volcanic activity (heat source) | Volcanic activity commenced by 390 ka and continued to within 10 ka. Broadly contemporaneous trachytic and basaltic activity occurred on a number of small satellite centres peripheral to the main volcanic edifice. The oldest exposed rocks are the Lower Trachytes, which constructed an early volcanic shield. Subsequent fracturing of the shield by the NNE-trending faults was accompanied by eruption of the Lower Basalts from fissure sources on the eastern flanks of the volcano.<br>The magma chamber in Paka is still active as indicated by the eruptions of the young basalt lavas within the caldera and along fissures to the north of the volcano.<br>The main heat source for the geothermal system at Paka is possibly a trachyte or trachyte-basaltic body underlying the volcano.<br>Heat source; Existence of a centralized volcano with young eruptions implying still active and hot magma bodies at Paka. Young trachytic lavas implying a shallow (high viscosity) magma that has had sporadic infusion of basaltic material (post caldera basalts) in recent times ~ 10,000yrs ago. Pyroclastic eruptions at Paka also implies an evolved silicic magma body at very shallow depths (~ 6-10km)<br>From the geophysical study, two heat sources are estimated in the depth: one E-W trending below the caldera sur |
| Geological Structrure | 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 graben bound by the eastern and the western fault boundaries respectively. This zone shows a right stepping en echelon arrangement along the volcano and forms one of the regional fault pattern, which extends southwards to Chepchuk and northwards into the southern flanks of Silali. On the southern flanks of Paka, the general direction of the faults is N-S, but to the north of the summit, it shows arcuation into a NNE to a NE trend. |
| (Past Geological Studies included) | Detailed surface investigations in Paka were carried out between September 2006 and April 2007 period by a team of KenGen Scientist and Engineers. Detailed geological and hydro-geological surveys were carried out to determine the volcanological structure of the Paka and surrounding. |
| Geochemistry | In some of these areas maximum temperatures exceed the local boiling point with the maximum temperature recorded being slightly over 97oC. Occurrences of Sulphur were observed in the fumaroles in the Eastern crater and it is an indication that the faults deep seated, and tapping directly from the magma.<br>On the southern upper parts of the flanks patches of hot grounds, some of which are weak fumaroles are scattered, but follow a N-S linear trend. These areas show alteration to reddish and whitish kaolinite and alunite clays respectively.<br>To the northern part of the area, an isolated geothermal activity in form of warm grounds occurs in the crater at Murulen.<br>Geothermal activity on Paka is dispersed over a broad NNE-trending zone covering an area of 48 km2 extending from high Paka mountain southern flanks northwards across the summit area and over the northern flanks. The activity on the summit rim on the eastern side of the Paka Massif is extensive. Altered grounds are observed to the north of the Paka Volcano in the Nading area. |
| Work done so far | Sampling of water borehole, fumaroles and steaming grounds sampling, soil gas and radon surveys:<br>Geochemical analyses of fluids from natural outlets including fumaroles, a borehole water and soil gas was carried out to predict the possible physical qualities of possible geothermal reservoir at the subsurface. |




Location of Paka Geothermal Prospect

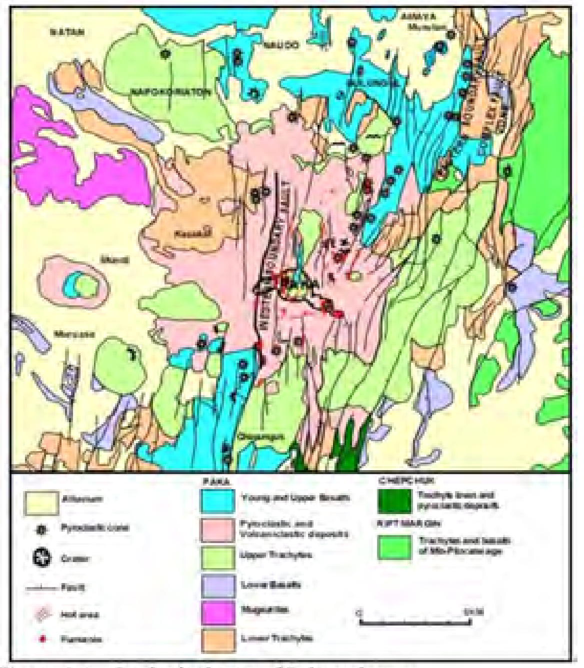



Figure 2.1. Geological map of Paka volcano.

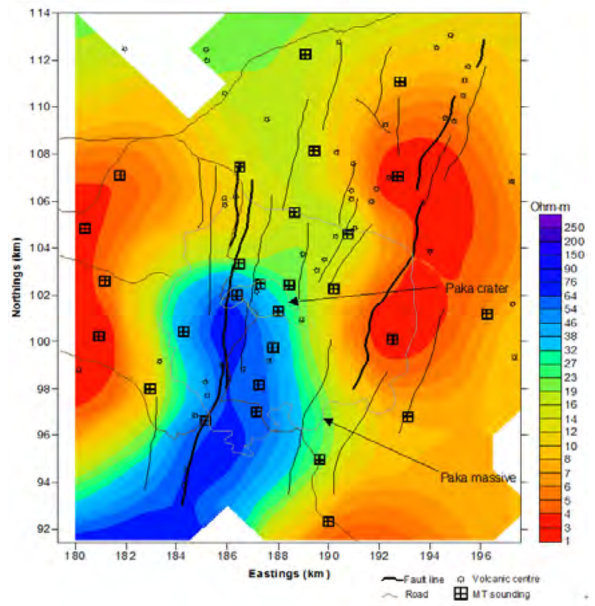



Figure 3.5: MT resistivity distribution at 1000 mbsl in Paka prospect

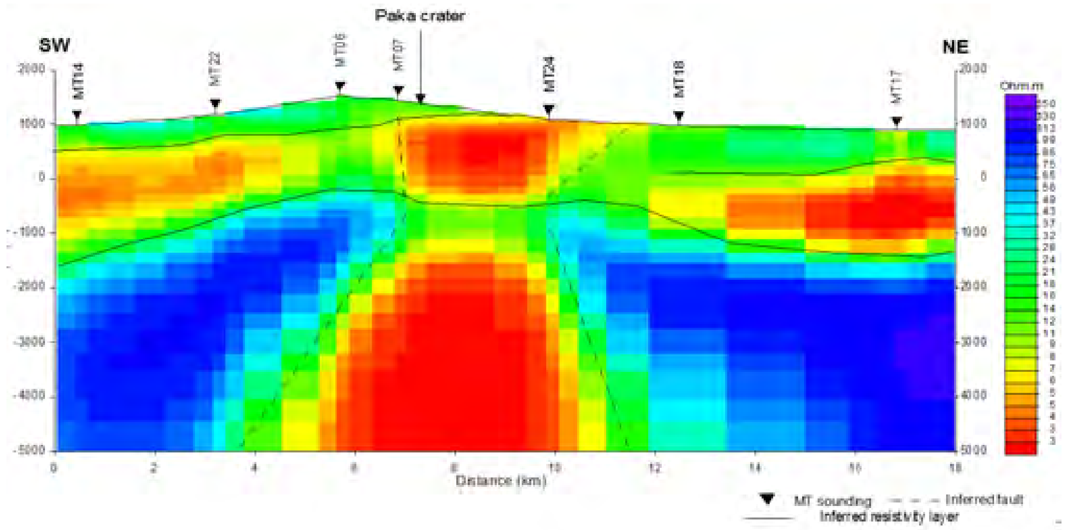



Figure 3.10: NE-SW 2D MT resistivity cros-section

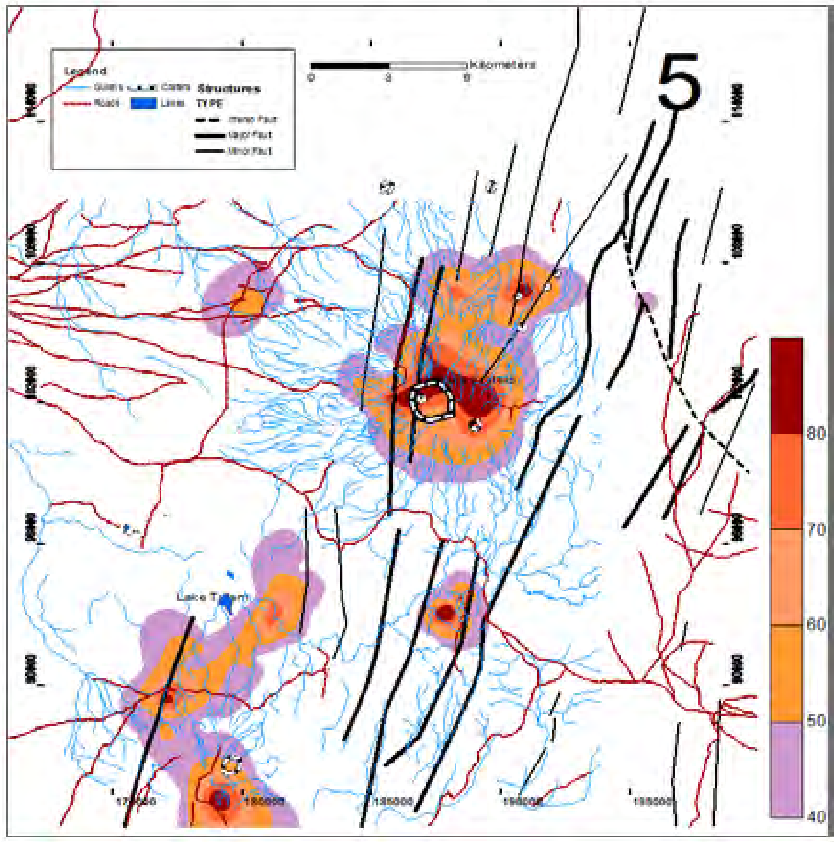
Annex-1-9 The Evaluation Sheet of the Paka (Kenya) Geothermal Field (2)

| | |
|---|---|
| Geophysics | 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 | |
| Resistivity | 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 and could be one of the main heat sources for the geothermal activity in the prospect. This shows that a geothermal reservoir may exist on the Mt Paka peak area at a depth of one kilometer. Shallow (600masl) resistivity isomap show extensive low resistivity alluvial formation covering all valleys and lower slopes of the Paka massif. Thus major leakage from the geothermal system occur 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 steaming grounds and fumaroles. |
| Temperature Survey | An attempt was made to apply various geothermometry functions to the thermal waters that were sampled in this geothermal prospect. The Na-K 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 in 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 and possible permeability, thus reservoir control at the subsurface. Reservoir temperatures of between 180oC-300oC are expected based upon geothermometry.<br>Two heat sources at depth are offset to the east of the main massif and are controlled by a NW and a NNE deep structures. Consequently upflows and the main reservoirs are expected to be situated over the eastern and NNW of the main massif. The recharge is mainly from the eastern (Laikipia scarp) at depth. Some recharge also may be coming from south and west at depth. Ouflows are mainly on the volcano massif, especially in the summit craters and northwards along the NNE graben faults. This is due to enhanced vertical permeability due to fracturing of the capping formation. The capping formation is thick alluivial deposits composed of volcaniclastics and pyroclastics in the lowlands surrounding the Paka massif. |
| Present Status of Development | Deep exploratory drilling is recommended at Paka to confirm the geothermal reservoir and enable direct measurements into the subsurface, and determination of petro-physical state of the reservoir. |
| Natrural/Social Environmental Condition | A base line environmental survey 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 east Pokot community who survive mainly on livestock on the arid rocky country that 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 | |
| Resource Potential | 500MW (estimated): Reconnaissance and surface exploration done. Deatailed exploration planned for 2010 and exploration drilling in 2011. |
| Restrictted by National Park | |
| Restricted by Power Demand | |
| Rank of Development Priority | B |
| Potential (Expected) Developer | |
| Proposed Geothermal Development Plan | |
| Outline for Power Development | |
| Possible or Recommended Multi-purpose Geothermal Heat Use | |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | It therefore recommended that the three localities (PW1, PW2 & PW3) should be drilled to depth of 2.5km to determine the detail petro-physical characteristics of the geothermal reservoirs in the prospect. |
| Location Map | |
| Other Figures | |

Table 4.3: Aqueous geothermometry temperatures from Paka geothermal prospect.

| Date | Site | Na-K (F, 1979) | Na-K (G, 1988) | Na-K-Ca (F & T, 1973) | Tqtz P&F 1982 |
|---|---|---|---|---|---|
| 22.11.2006 | Nginyang SDA | 348 | 351 | 266 | 126 |
| 14.11.2006 | Orus | 182 | 200 | 164 | 79 |
| 9.11.2006 | Dabalikow | 250 | 263 | 209 | 101 |
| 16.10.2006 | Kokwototo | 270 | 281 | 221 | 97 |
| 04.10.2006 | Chemolingot D.O's Office | 348 | 351 | 265 | 97 |

Figure 5.1 Temperature distribution at Paka (one metre depth)



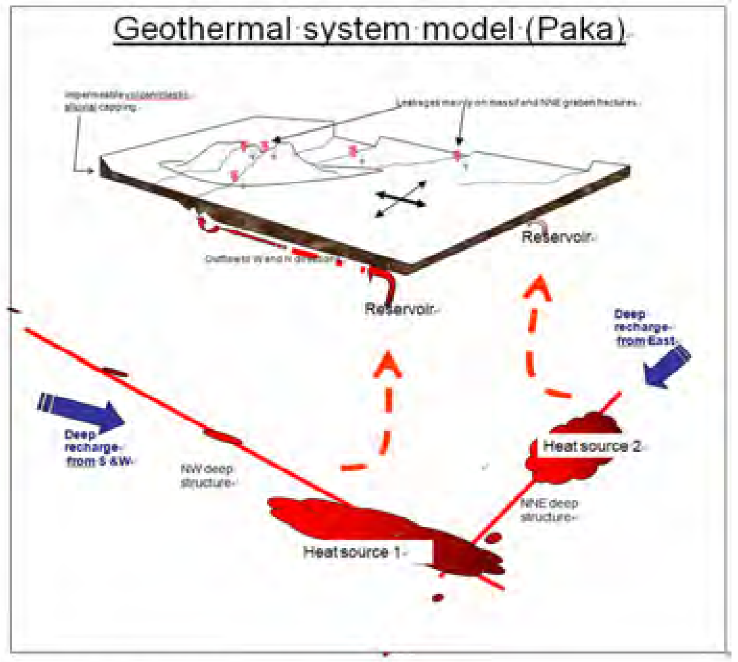
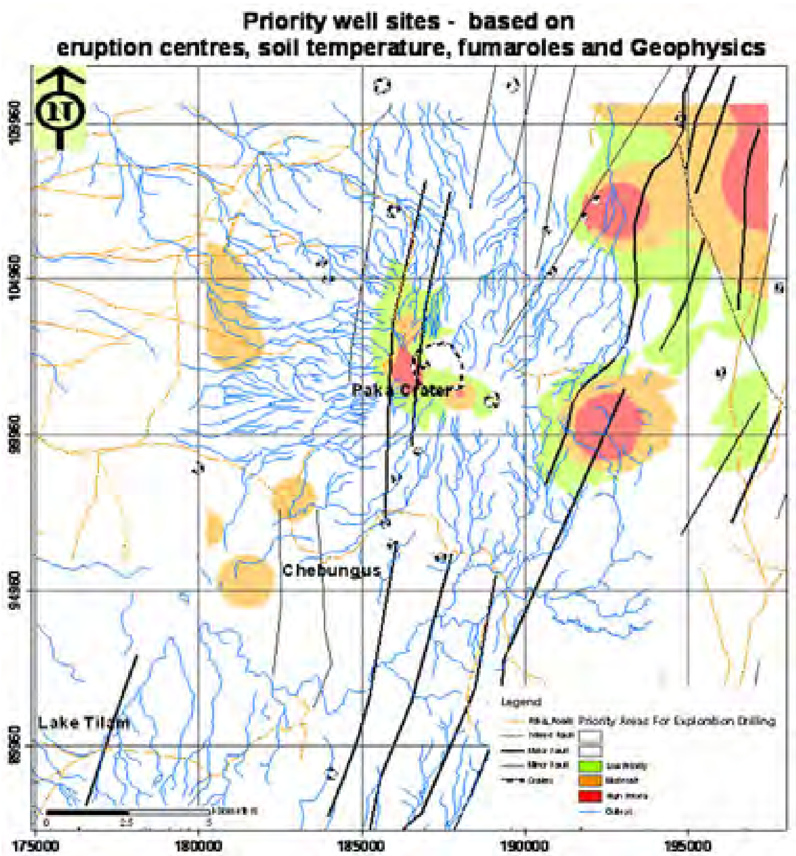
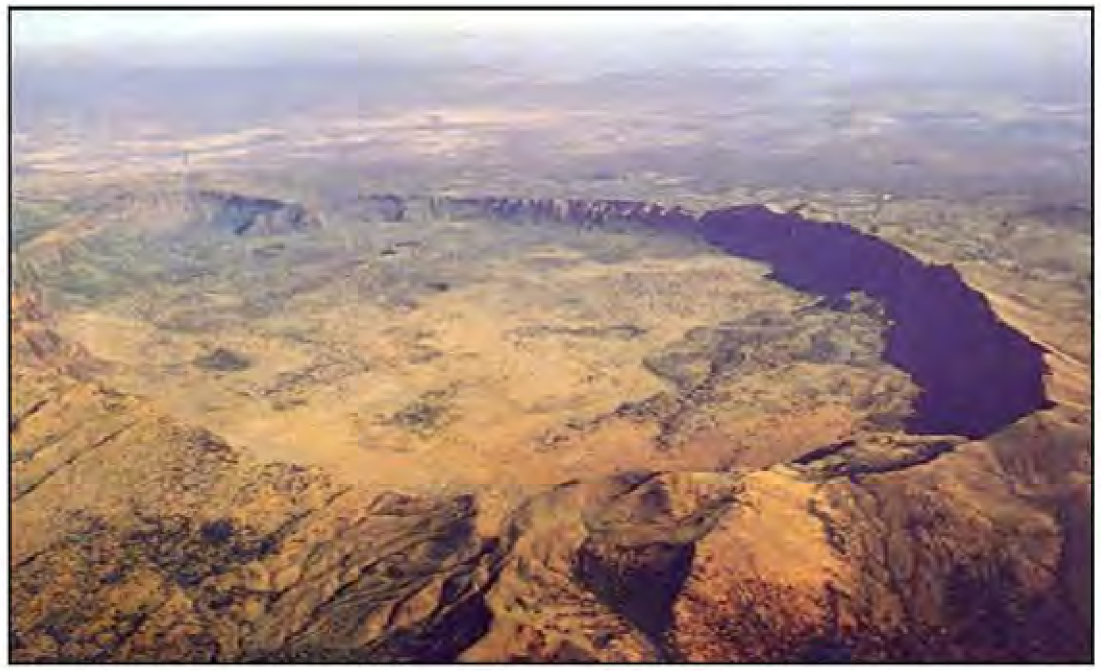




Figure 7.2 Conceptual model of the geothermal systems at Paka



Annex-1-10 The Evaluation Sheet of the Silali (Kenya) Geothermal Field (1)

| | |
|---|---|
| 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.<br>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.<br>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 Emuruangogolak.<br>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 o C. The series of springs (Kapedo) to the western side discharge at temperatures of 45-55ºC 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 infilling associated with two major periods of explosive activity. This activity ceased around 133–131 ka and was probably the result of fracturing and decompression of a high level magma chamber by regional extension and the injection of basaltic dykes below the volcano. Later eruptions (c. 120 ka) along the western flanks migrated eastward with time and culminated in the eruption of viscous trachyte lavas from a circumferential fissure zone. The emplacement of a basic dyke swarm to shallow crustal levels beneath Silali resulted in the formation a broad volcanic rift zone within which large volumes of fluid basalts were 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 pr |
| Geological Structrure/Geographical Features | Early eruptions of Silali volcano formed a 500 m high lava shield. Construction of the shield was followed by eruption of Kapedo tuffs from pyroclastic cones on the western flanks. Eruption of Kapedo tuffs was followed by major eruption of summit trachytes which cover most of the western slopes. Lava was erupted from a fault, rather than from a cone.<br>Eruption of Katenmening basalts 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.<br>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. |



The impressive 5 x 8 km summit caldera of Silali volcano is seen in an aerial view from the SE. Formation of the 300-m-deep caldera is related to the incremental eruption of basaltic and trachytic lava flows about 63,000 years ago. N-S-trending rift valley faults cutting across the volcano can be seen at the lower left. Some of the youthful parasitic cones on the caldera floor and flanks of Silali, the largest volcano of the northern Gregory Rift, may be little more than a few hundred years old.

Annex-1-10 The Evaluation Sheet of the Silali (Kenya) Geothermal Field (2)

| | |
|---|---|
| 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 ℃. 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 coincident 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 Drilling | 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 outflows 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:<br>• Geological mapping of the rock formations, structural mapping, hydrogeological and volcanological studies of the volcano,<br>• Geophysical measurements that shall include resistivity (MT and TEM)<br>• Geochemical sampling for fumarole steam, water points and soil gas survey,<br>• Heat loss measurements,<br>• GIS data acquisition<br>• Environmental baseline data collection |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential<br>Resource Potential<br><br>Restrictted by National Park<br>Restricted by Power Demand | 800MW (estimated): Reconnaissance has been completed. Detailed Surface exploration to commence mid-2010 and exploration drilling planned for 2011.<br>Silali is one of the largest potential in the northern Kenya Rift. |
| Rank of Development Priority | B? Silali is ranked 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<br>Outline for Power Development | |
| Possible or Recommended Multi-purpose Geothermal Heat Use | |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |

Kapedo hot springs discharging 1,000 L/s of hot water at 55$^{o}$C.

Annex-1-11 The Evaluation Sheet of the Emuruangogolak (Kenya) Geothermal Field

| | |
|---|---|
| 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.<br>Parasitic pyroclastic cones situated on the upper western flanks of Emuruangogolak and represent Pre-caldera I Pyroclastic Activity.<br>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.<br>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.<br>The most recent lava flow on Emuruangogolak is a trachyte block lava, erupted from a small cone lyin |
| Geological Structrure | |
| (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℃ to 350 ℃. 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 | |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential | |
| Resource Potential | 650MW (estimated): Reconnaissance planned for 2010 and detailed surface exploration in 2011. |
| Restrictted by National Park | |
| Restricted by Power Demand | |
| 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 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |

Annex-1-12  The Evaluation Sheet of the Namarunu (Kenya) Geothermal Field

| | |
|---|---|
| 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. |
| Location | |
| Resource Characteristics<br>Geology | |
| Volcanic activity (heat source) | 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 Structrure | |
| (Past Geological Studies included) | |
| Geochemistry | Fumaroles at temperatures ranging from 30 to 100 ℃ occur at the foot of eastern and western fault scarps. Fluid geothermometry indicates a reservoir at temperatures of more than 200 ℃. 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 | |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential<br>Resource Potential<br>Restrictted by National Park<br>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<br>Outline for Power Development | |
| Possible or Recommended Multi-purpose Geothermal Heat Use | |
| Scope for Power development | |
| CO2 emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |

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

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|---|---|
| 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 Structrure | |
| (Past Geological Studies included) | |
| Geochemistry | Developing a geothermal model for the prospect is complicated by lack of geophysical data and conflicting geochemical information. Low $H_2$ and $CH_4$ 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 ℃) 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 | |
| Natrural/Social Environmental Condition | |
| Power Sector Situation | |
| Power Output Potential | |
| Resource Potential | 450MW (estimated): Reconnaissance planned for 2011 and detailed exploration for 2012. |
| Restrictted by National Park | |
| Restricted by Power Demand | |
| 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 | |
| $CO_2$ emmission Reduction ('000 tonne/year) | |
| Proposed Geothermal Development Schedule | |
| | |
| Location Map | |
| Other Figures | |