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GEOTHERMAL EXPLORATION IN THE KENYA RIFT

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ABSTRACT

Initial regional exploration for geothermal resources in Kenya indicated that the Quaternary volcanic complexes of the Kenya Rift provide the most promising prospects. Thus, detailed exploration for geothermal power has been concentrated within the Rift Valley. Exploration for geothermal energy has been ongoing since the 1950s and today a 45 MW power plant is operational at Olkaria. The Least Cost Generation Expansion Programme (LCGEP) has identified geothermal power to be the least costly source of power in Kenya. Based on this programme, the National Power Development Plan (NPDP) requires a total of 576 MW of geothermal power to be installed by the year 2017. Consequently, the Kenya Electricity Generating Company has drawn a Geothermal Resource Assessment Programme (GRAP) to meet this requirement. The GRAP requires that detailed surface studies and drilling of at least three exploratory wells be carried out in each of the geothermal prospects in order to prioritise them for development.

1. INTRODUCTION

The Kenya Rift Valley (Figure 1) is an integral part of the East African Rift System which extends for over 3000 km from Southern Mozambique through Tanzania, Kenya and Ethiopia to join the Red Sea and Gulf of Aden rifts at the Afar triple junction. The evolution of the rift is structurally controlled; the rift faults exploit the weak collision zone at the contact between the Archean Tanzania craton to the west and Proterozoic Orogenic belts to the east (Smith and Mosley, 1993; Smith, 1994). Initiation of rifting occurred during early Miocene and continued to the present with most of the Quaternary volcanism concentrated within the axis of the rift. The Kenya Rift straddles a local region of upwarping which is termed the Kenya Dome. The rift can be divided into three sectors; namely the North rift with north and north-northeast trending structures, the Central rift with northwest and west-northwest trending structures, and the Southern rift with north and north-northeast trending structures.

Quaternary volcanic rocks in the Kenya rift varies from nephelinitic through phonolite to trachytic and sometimes to peralkaline salic suites, with basalt accompanying all stages but tending to change from alkali to transitional types (Clarke et al., 1990). The Central rift zone, from Olkaria to Eburru, comprises peralkaline volcanism of comendite and pantellerite lavas and ash. South of this zone, the lavas are mainly basalts, trachytes and phonolites, and north of this zone, the lavas are mainly basalts and trachytes.

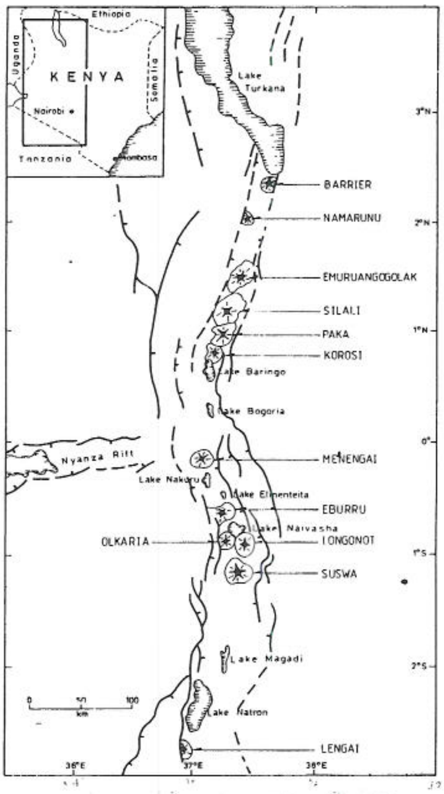

Figure 1: Quaternary volcanic complexes of the Kenya Rift

Exploration for geothermal energy started as early as the fifties when two wells were drilled at Olkaria. In 1960 more geophysical work was carried out between Lake Bogoria and Olkaria. This survey identified several areas of low resistivity, suitable for geothermal prospecting. In 1970, the UNDP and the Kenya Power and Lighting Company (KPLC) carried out an extensive exploration programme in the Rift Valley. This survey identified Olkaria as the best candidate for exploratory drilling. By 1976, six deep wells had been drilled and in 1981 the first 15 MW generating unit was commissioned. To date, there is a 45 MW Power Station at the Olkaria East field. Continued exploration has tentatively sectioned the Olkaria Geothermal field into six fields which can be developed separately.

The Kenya Electricity Generating Company (KenGen), UNDP, the British Geological Survey and other bodies have continued to explore for geothermal energy in the Kenya Rift Valley. The Kenya Electricity Generating Company has so far carried out detailed surface work at Olkaria, Eburru, Suswa and Longonot but has not drilled exploration wells in the last two prospects.

The Least Cost Generation Expansion Plan (KPLC, 1997) has identified geothermal power to be the least costly source of power for Kenya and requires 576 MW of geothermal electric power to be installed by the year 2017. In view of this, a Geothermal Resources Assessment Programme (GRAP) has been drawn to achieve this target. Although about 13 geothermal prospects of the Rift Valley have been identified, exploration drilling has been done in Olkaria and Eburru only. Therefore, the geothermal potential of the Rift valley is not well known. The proven resources at Olkaria and Eburru are about 173 MW and 20 MW of electricity respectively. With further exploratory drilling at Olkaria, there is a possibility of another 64 MW, which will bring the total proven power for Olkaria to 237 MW and the total proven geothermal power to 257 MW. There is, therefore, an additional 319 MW that will have to be developed elsewhere so as to satisfy the NPDP requirements.

2. GEOTHERMAL PROSPECTS

The Quaternary volcanic complexes are associated with geothermal manifestations in the form of hot grounds, fumaroles and hot springs. These have, therefore, been the targets for geothermal exploration. In the Central rift, hot springs of low temperature occur on the eastern escarpment near Longonot and around Lake Elementaita. To the north, hot springs are more common but some are not directly related to Quaternary volcanic complexes. These occur around the Arus and Bogoria area and also along the Suguta valley where large amounts of hot water are discharged.

2.1 Olkaria

The Olkaria volcanic complex is not a central volcano but a series of Quaternary volcanic domes and lava flows. The youngest lava, Ololbutot lava flow, is dated (charcoal/carbon found below the flow) 180 ± 50 yr BP (Clarke et al., 1990). The rocks are highly evolved and petrochemistry data indicates that there has been some partial melting of the crust. With the exception of a few comenditic lavas, the whole of Olkaria is blanketed by ash from mainly the Olkaria Hill, Longonot and Suswa volcanoes. The peralkaline rocks extend from the surface to about 1400 m a.s.l. Below these, in the eastern part, the dominant rocks are mainly trachytes and thin basaltic lavas and tuffs. To the west, the dominant rocks at depth are pyroclastics and tuffs.

Most workers in the region have concluded that the ring structure defined by most of the domes in this area mark the rim of a large caldera which has been filled by later volcanic materials (Naylor 1972; Clarke et al., 1990; Muchemi, 1992). The main structural trends are the NW-SE and NNW-SSE trending rift faults; the N-S, NNE-SSW and the NE-SW trending rift floor faults (Figure 2). Recent volcanic activity is associated with the near N-S trending faults and the rim of the inferred caldera structure. This has led many workers to believe that the source of these lavas constitute the most recent heat source for the Olkaria geothermal field (Clarke et al., 1990). N-S oriented dykes which outcrop along the Olnjorowa gorge are thought to form east-west fluid barriers. Geothermal manifestations occur on the margins of the caldera, along Ololubutot fault and along the Olkaria fault zone. The manifestations occur mainly as fumeroles and hot grounds. Native sulphur occurs in two fumarolic areas to the west of the Olkaria complex.

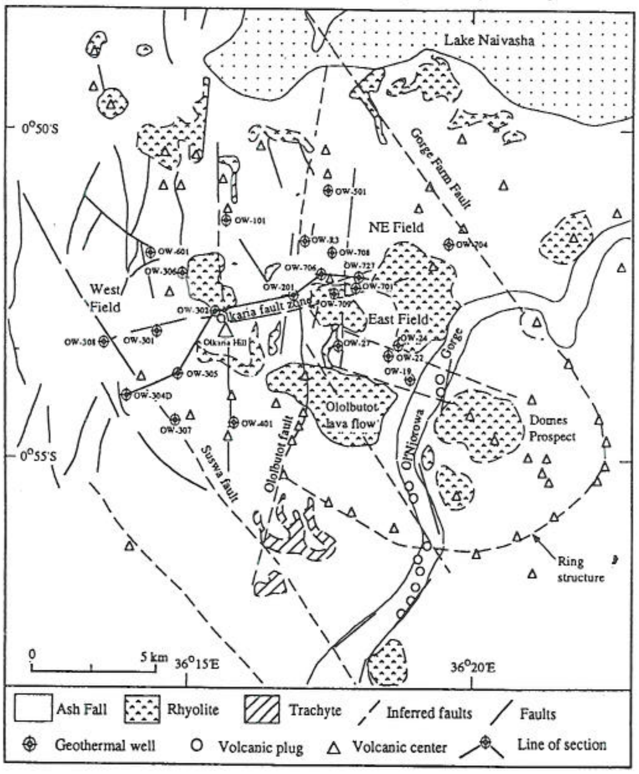

Figure 2: Geological and structural map of the Olkaria geothermal field

The resistivity structure of Olkaria has areas of low resistivity to the east and to the west. The eastern low resistivity area coincides well with the Olkaria North East and the Olkaria east field and extends to the Olkaria Domes field (Onacha, in prep.). An east-west downhole temperature cross section shows higher temperatures to the east and to the west in general agreement with the resistivity structure.

To date, a total of 87 geothermal wells have been drilled and 29 of these wells are connected to the Olkaria East field Power Station. The fluids are mainly sodium-chloride type with some shallow bicarbonate waters to the west. Currently exploratory drilling is being carried out in the southern and eastern part of the complex within the inferred caldera.

2.2 Eburru

The Eburru volcanic complex consists of two major volcanic centers oriented in an E-W trend with the eastern one being the youngest. It is in this young volcanic center that geothermal manifestations are found. The surface rocks comprise mainly Quaternary pantelleritic lava flows and volcanic ash. Trachytic lava flows occur on the slopes of the eastern volcano and on the plains. Basalts occur mainly on the plains. Rhyolites and pyroclastics are the main rocks above 1400 m a.s.l. Below this, the dominant rocks are trachytes with minor basaltic, rhyolite and pyroclastic flows. An intrusive of syenitic composition was intersected by four of six wells drilled with the shallowest part occurring at 800 m a.s.l.

The eastern volcanic center is cut by numerous NS trending fractures that form a micrograben (Figure

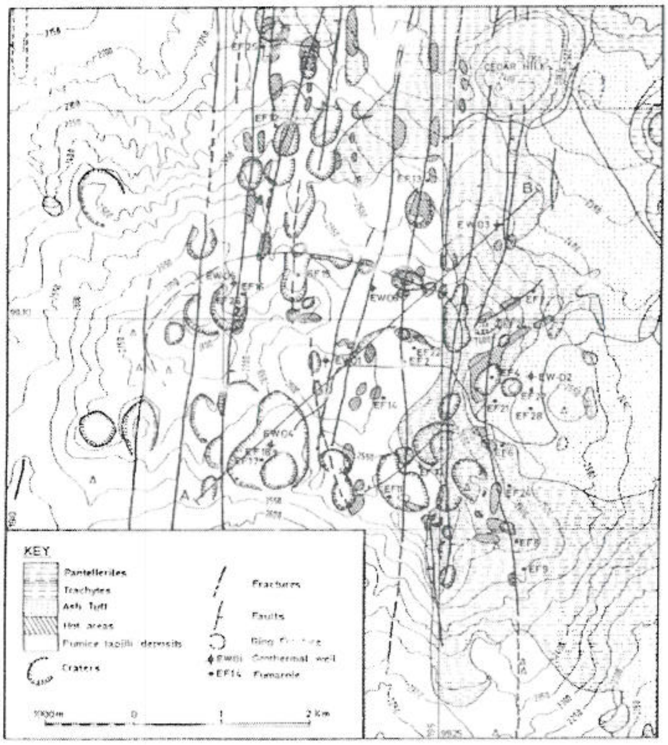

Figure 3: Geological and structural map of the Eburru geothermal field

3). Along the main faults many phreatic craters and phreatomagmatic craters occur. Some of these craters describe a circular structure, which is inferred as the margins of a caldera. Gravity data also support the presence of a circular structure (Simiyu, 1990). The top of the volcano is dominated by a depression which had earlier been thought to be a summit crater. However, this is the remnant of a caldera that has been modified by later volcanic activity along the rim. Geothermal manifestations occur mainly along the NS trending faults. Major areas of surface geothermal activity occur where the NS trending faults cut the ring structure. The low resistivity structure defines a small area of about 2 km^2 within the caldera. This area is connected to an extensive area of low resistivity (<10 ohmm) to the north of the Eburru volcanic complex by a narrow region of low resistivity that is confined within the micrograben (Onacha, 1990).

To date, six geothermal wells have been drilled and one well produces steam and two others produce hot water. The fluid chemistry data indicate that the wells discharge a mixture of chloride and bicarbonate waters (Omenda and Karingithi, 1993).

The available data indicate that the Eburru prospect can support a 20MW power station. Further well testing is being carried out to find out whether the output can be boosted by combining conventional geothermal power generation with binary systems.

2.3 Suswa

Suswa is 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 (Figure 4). The outer caldera has a diameter of about 10 km and the inner caldera has a diameter of about 4 km. The surface rocks comprise mainly trachytes, ignimbrites and phonolites (Omenda, 1997).

The plains around the mountain consist of mainly older plateau trachytes. To the north, the Tandamara suite, which comprises cinder cones in the plains, has lava flows of basaltic trachyandesite and trachyandesite composition. The volcano suite indicates a zoned magma chamber which possibly constitutes the heat source (Omenda, 1997). The main faults and fractures are the N-S and the NNW-SSE trending faults. Geothermal manifestations occur around the outer and inner caldera where near N-S structures intersect the calderas. The trough surrounding the island block also has numerous manifestations.

Detailed scientific studies have been carried out in this field and three wells have been sited. Exploration wells are planned for drilling in the year 2000.

2.4 Longonot

Longonot volcanic complex is dominated by a central volcano with a summit crater. The volcano rises to about 2776 m a.s.l. The surface is covered by peralkaline and trachytic pyroclastic rocks (Figure 5). Trachytic lava, mixed trachyte-basalt lavas, and basalts occur to the south, in the crater and to the North of the volcano. These lavas occur along a NW trending fracture zone that is referred to as the Longonot tectono-volcanic axis. There is also a NE trending structure that cuts the volcano. The present Longonot volcano sits on the eastern rim of this caldera. Petrochemistry analysis of the lavas indicate that all the lavas originate from a single magma chamber below the caldera (Clarke et al., 1990).

Geothermal mainfestations occur along the Longonot tectono-volcanic axis, the southern rim of the caldera and at the inner rim of the crater. Detailed work carried out in this area show that a geothermal reservoir possibly exists within the caldera. The resistivity structure shows an area of low resistivity that starts within the caldera and extends to the south outside the caldera (Onacha, 1998). Three exploratory wells have been sited and drilling will commence in 1999.

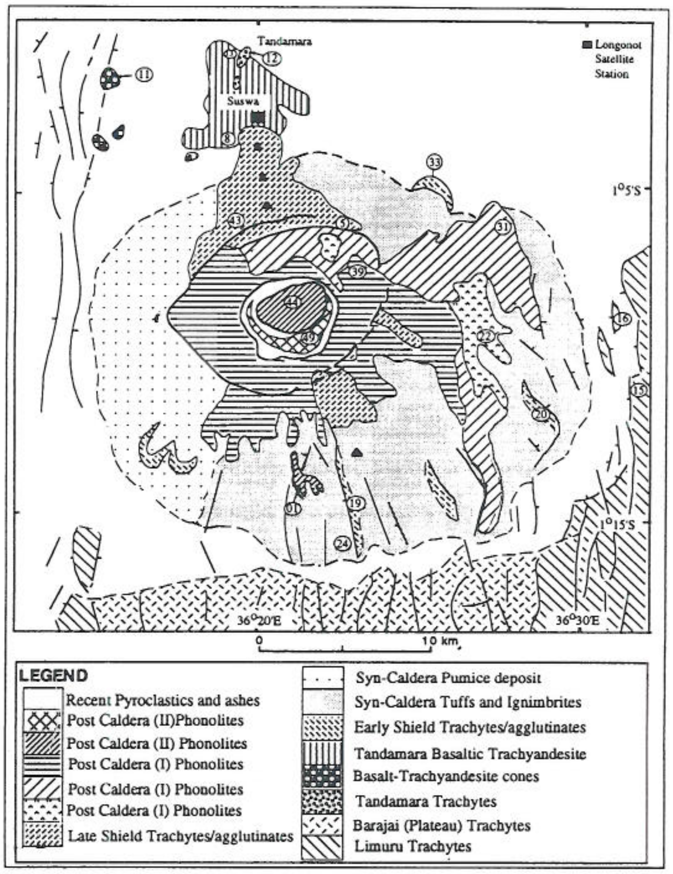

Figure 4: Geological map of Suswa volcano

2.5 Menengai

The Menengai-Olbanita area is located within a region of intra-continental triple junction where the Nyanza rift joins the Kenya rift. Menengai complex is dominated by a central volcano with a large caldera of about 12 km in diameter. The caldera has steep sides up to 300 m high where older shield lavas are exposed. The rest of the area outside the caldera is covered by pyroclastics and tuffs. The volcanic suite comprises phonolites, trachyphonolites and trachytes. The floor of the caldera is covered by post caldera collapse trachytes. The northern rim of the caldera is cut to the west by N-S trending faults which form a micrograben and to the east by north-northeast trending faults that form the Solai techtono-volcanic axis. Geothermal manifestations occur on the floor of the caldera and a long the NS trending faults.

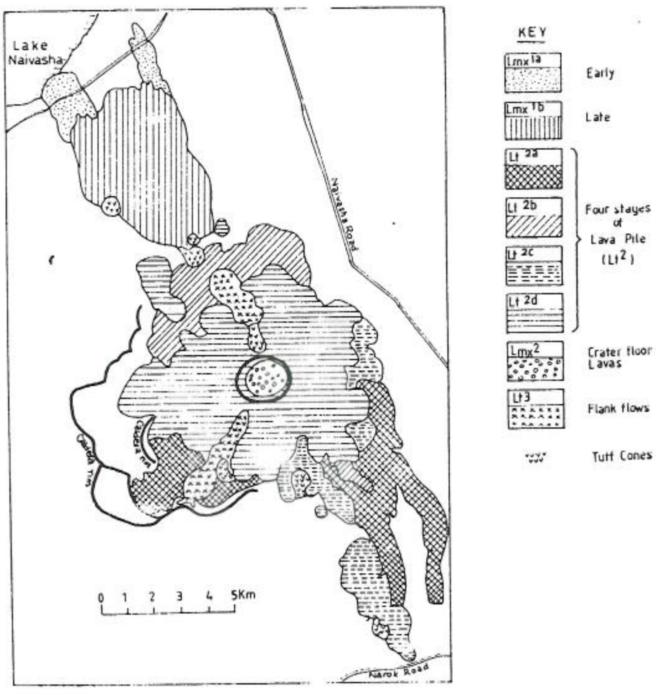

Figure 5: Geological map of Longonot geothermal field

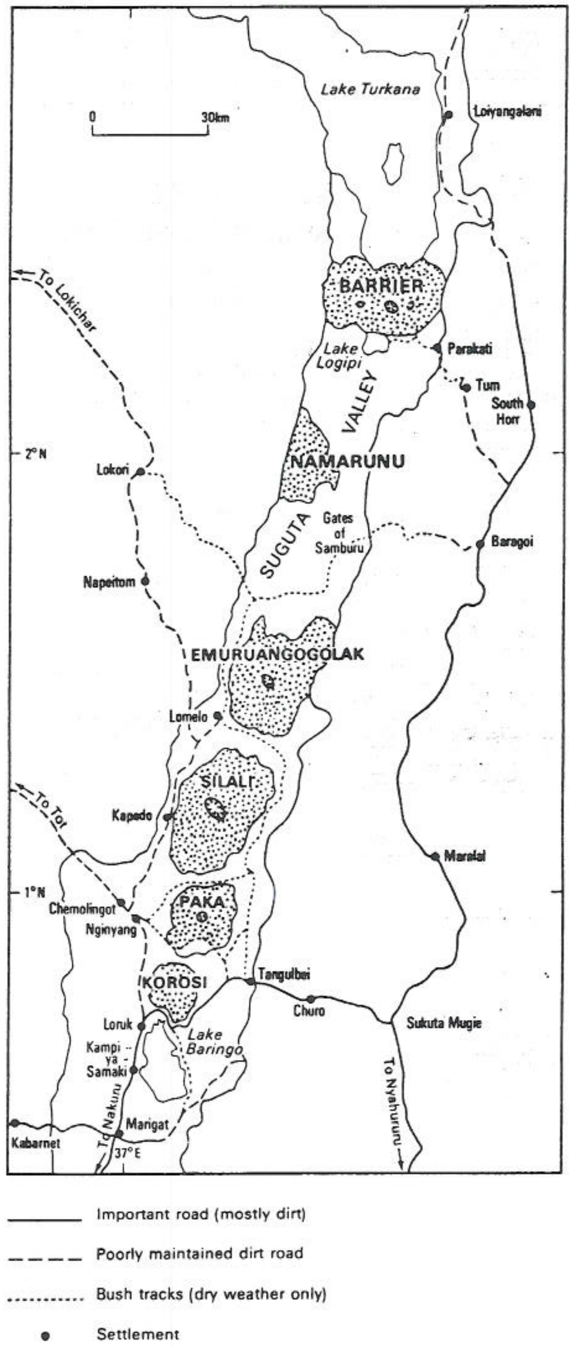

Figure 6: Quaternary volcanic complexes of the north rift

2.6 Olbanita

The Olbanita volcanic complex consists of the remnants of an old caldera 8 km north of Menengai. The surface is covered mainly by pyroclastics and tuffs with minor occurrences of trachytes and basalts. Although there are few surface geothermal manifestations, shallow boreholes in this area have encountered steam with a gas geothermometry indicating a reservoir temperature of 190°C.

2.7 Arus and Lake Bogoria

The rocks in this area are mainly Pleistocene flood trachytes and phonolites. However, two basaltic shield volcanos, Kwaibus of Lower Pleistocene and Goitumet of Upper Pleistocene also occur in the area. This area is cut by numerous N-S and NNE-SSW trending faults. The Arus area has no obvious relationship with a central volcano or a caldera but there are fumeroles and hot springs with a measured temperature of 96°C. Lake Bogoria is a saline lake which is fed entirely by hot springs which occur on the shores and on the floor of the lake.

2.8 Korosi

Korosi is a trachyte-basaltic volcanic complex situated just north of Lake Baringo (Figure 6). The complex, which rises to about 500 m above the rift floor, is a multivent complex composed predominantly of trachyte lavas which have built a low volcanic shield, upon which lesser amounts of basalts, mugearite and pyroclastic deposits have been deposited (Dunkley et al., 1993). Korosi is cut by a zone of *en-echelon* NNE-SSW trending faults which steps progressively eastwards across the volcanic complex. The faulting has superimposed a horst and graben topography upon the volcanic shield. Geothermal manifestations occur along the N-S and NNE-SSW trending faults and to a lesser extent in the craters. Surface temperatures of up to 95.7°C have been recorded in this area (Dunkley et al., 1993).

2.9 Paka

This is a central volcano that rises to about 1697 m a.s.l. and is about 600-700 m above the floor of the rift valley. The summit of the mountain is dominated by a NW-SE trending fault bounded ridge (Dunkley et al., 1993). This ridge is a constructional feature formed by a series of coalesced eruptive centres, upon which several craters and a circular caldera of a diameter of 1.5 km have developed. Numerous N-S and NNE-SSW trending faults cut the complex. Geothermal activity is dispersed over a broad north-northeast trending zone covering an area of approximately 32 km^2. The activity is bounded on the west by the Western Boundary fault, to the west of which there are no surface manifestations. The eastern limit of thermal activity is less well defined, but is constrained by a number of west-facing faults cutting the northeast flanks of the volcano. The maximum surface recorded temperature is 97.8°C.

2.10 Silali

Silali volcanic complex is a broad shield volcano that rises 760 m above the rift floor that is elongated in a N-S direction with basal dimensions of 36 km by 25 km and an aerial extent of 850 km^2. The volcano is composed predominantly of basalt and trachyte lavas with minor volumes of hawaiite, mugearite, benmoreite and phonolite lavas. Mixed magmas are also present. The Silali volcano rises to an altitude of 1528 m a.s.l. and has a well preserved caldera with a long axis of 7.5 km and a short axis of about 5 km. The walls of the caldera rise to about 340 m. The lower northern and southern flanks are cut by a N-S to NNE-SSW trending volcanic rift zone that is 10 km wide and up to 30 km in length. This zone is characterised by numerous faults, tension cracks, fissures and minor graben, and is intimately associated with extensive basalt lava fields which mantle the flanks of the shield.

Geothermal manifestations occur within the caldera, along the NNE-SSW trending faults and along the Suguta valley. In addition to fumeroles, hot grounds and hydrothermal alteration, numerous hot springs occur. The hot springs occur along the Suguta river, where they are the main sources of water for the river, and to the north at the edge of the shield where they are associated with NNE-SSW trending faults. At Kapedo, a small water driven generator has been installed but does not use this heat. The Kapedo springs have a maximum of 55°C. The Lorusio springs, which are located to the north of Kapedo, have a maximum of 82.2°C. The springs at the northern flanks of the shield have a maximum temperature of 38.2°C.

2.11 Emuruangogolak

This is a large basalt–trachyte volcano situated in the narrowest part of the inner trough of the Rift Valley. The volcano reaches an elevation of 1328 m a.s.l. on the summit and has a shield–like form that is elongated in a NNE-SSW direction. A large part of the volcanic pile consists of an old trachyte shield. These older trachytes are covered by younger basalts to the north and south and younger trachytes around the summit. The summit region of the shield is occupied by a caldera with a long axis of 5 km and a short axis of about 3.5 km. Post caldera trachytes have filled the caldera and overflown and covered some parts of the rim. The remaining rim has walls about 70 m high.

Surface geothermal activity is almost exclusively confined to the summit caldera. These occur along the NNE-SSW trending faults. The highest measured temperatures in fumeroles is about 96°C. Hot springs also discharge at the flanks of the shield along the Suguta and Kamuge rivers.

2.12 Namarunu

This is a basalt–trachyte volcanic complex which is not associated with a central volcano. Dunkley et al., (1993) discussed the complex to be mainly composed of down-faulted Pliocene volcanic sequences, similar to that of the adjacent rift margins upon which later Quaternary volcanic activity has been superimposed. The summit region of Namarunu is composed of faulted and dissected trachytic volcanic rocks and is bounded on the east by strongly faulted flanks which step steeply to the floor of the inner trough. Along the base of the eastern flanks, there is a NNE-SSW line of young basaltic scoria cones, tuff cones and tuff rings, from which lava flows have been erupted onto the floor of the Suguta valley.

Geothermal activity in this area occurs around the cones and the eastern margins of the inner trough and is mainly in the form of hot grounds and numerous hot springs. The maximum recorded surface temperature is 60.3°C.

2.13 Barrier

The Barrier volcanic complex forms an E-W trending whaleback ridge which forms a natural dam which separates Lake Turkana and the Suguta valley. The complex comprises four distinct volcanic centers. From west to east these are: Kalolenyang, Kakorinya, Likaiu West and Likaiu East. The complex consists of basanite, basalt, hawaiite, mugearite, benmoreite, trachyte and phonolite. Trachytic pyroclastics cover much of the western slopes of Kakorinya and the summit area of Likaiu West.

Geothermal activity has only been observed on Kakorinya, the youngest volcanic center of the complex. Fumaroles and hot hydrothermally altered ground occur in the caldera and on the upper western and southern flanks. The highest measured temperature is 98.6°C and was measured inside the caldera. Lake Longipi, which is situated to the south of the volcanic centre, is fed by numerous, weak alkaline hot springs and seepages which issue along the base of the southern flanks of the volcanic complex.

3. EXPLORATION PROGRAMME

To meet the geothermal energy component in the next 20 years, it is necessary that detailed surveys and drilling of exploration wells be done in many of the prospects. This information will assist to formulate the best and the most economic development scenario. At present, surface studies at Olkaria have been completed and part of the field has been developed by KenGen, and the western area will be developed by an Independent Power Producer (IPP). Fine tuning of the model is, however, necessary so that the knowledge and experience obtained in Olkaria can be used in other fields. Exploration drilling is currently being done in an area to the east of the current power station (Olkaria Domes field) and in the Olkaria South East field.

Detailed surface studies are planned to be carried out in Menengai, Olbanita, Arus, Bogoria, Korosi, Paka, Silali, Emuruangogolak, Namarunu and Barrier Volcano. The British Geological Survey has carried out geological and geothermal mapping of the northern rift prospects. However, geophysical, geochemical and detailed structural studies aimed at siting exploration wells is yet to be done.

For all the fields, it is estimated that only three exploration wells will be required to prove the resource. After the completion of exploration drilling in Olkaria, exploration drilling will be done in Longonot in 1999, followed by Suswa in the year 2000. After this, exploration drilling will move to the north rift, starting with Menengai and progress gradually northwards until all fields will have been explored.

It is envisaged that KenGen will carry out the exploration and development stages for the Kenya government, but both KenGen and IPPs will carry out the power station construction. To interest the IPPs to invest in this sector, the Kenya Government may have to fund the exploration survey and prove the field to between 50-100%. This, therefore, calls for additional finances, manpower and equipment for fields beyond Longonot.

4. ENVIRONMENTAL CONSIDERATIONS

The development and exploitation of geothermal resources may have a potential impact on the environment. The Kenya Electricity Generating Company, in recognition of this fact, established in 1985 a full environmental section that is charged with the responsibility of monitoring all geothermal development activities that could impact on the environment. The section also prepares Environmental Impact Assessment reports which give recommendations on how these activities can be carried out with minimum impact on the environment. Where inevitable damage occurs, especially while making access roads and drill sites, the section rehabilitates the sites by planting grass, shrubs and indigenous trees.

In the current exploration programme, the section is involved from the surface exploration stage by collecting baseline data on flora, fauna, assessing susceptibility to soil erosion and carrying out demographic studies. Conditions for mitigating impact during drilling and well testing are then given. A full Environment Impact Assessment study will then be done before the power station is constructed. Some of the fields to be investigated under this programme are in densely populated areas and others are within National Parks. In some areas, the prospects are near fresh water rivers and streams in regions where water is a scarce commodity. For example, Olkaria is largely in a National Park, close to flower farms and near Lake Naivasha, which is a fresh water lake. This, therefore, requires stringent environmental conservation measures.

Currently, all the discharge fluids at Olkaria are being injected into deep wells for the purpose of disposal and also to maintain reservoir pressures. All the drill sites and other excavation sites, are being rehabilitated by the planting of indigenous grasses, trees and shrubs. Results from two test flower gardens located downwind of the power station indicated that the amount of H_2S emitted from the power station is too low to have any effect on the flowers. Also there has been no indication of any adverse effects on personnel and wild animals in the park. The water abstracted from the lake is metered at the intake and great care is taken to make sure that the water is optimally used. In particular mud and aerated water are used during the drilling of wells so as to minimize the use of water.

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