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EVALUATON OF HEAT LOSS IN THE NORTHERN KENYA RIFT VALLEY.

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Key words: geothermal activity, heat loss, north rift, Olkaria, manifestations, volcanic complexes.

ABSTRACT

Evaluation of total natural heat flow from the ground is an important tool in ranking the potential of geothermal resources. It can provide an insight into the hydrology of the system and the transfer mechanisms operating within the subsurface. Fumaroles, steaming grounds, hot grounds and Hot Springs form the basis for the measurements which lead to evaluation of the natural heat transfer of a system. This paper is an analysis of surface heat transfer associated with steaming ground over six 'volcanic' complexes in the Northern Kenya Rift Valley, namely: Korosi, Paka, Silali, Emuruangogolak, Namarunu and the Barrier, stretching from Lake Baringo to Lake Turkana in the north, a distance of about 200 km. The analysis is based on a comparison with shallow temperature surveys over steaming ground in the Olkaria Domes area, where temperatures were measured at 0.15 and 1 m depth. This data was used to calibrate the heat flow characteristics of hot and steaming ground in the northern rift, with the assumption that the rock formations in both areas have similar physical properties and alteration characteristics. Negligible liquid discharges are associated with all six volcanic complexes and mainly conductive heat transfer involving hot and steaming ground was assumed.

Paka was found to have the largest steaming ground area, 2260 E 3 m^2, followed by Korosi, 1991 E 3 m^2, though relatively cooler than the rest, with Emuruangogolak having the smallest area. The total heat discharged by the six prospects within the northern part of the rift was found to be about 742±210 MWt.

It is evident that this part of the rift contains a considerable potential in terms of geothermal energy. A refining exercise which would include evaluation of hot grounds, steaming grounds, fumaroles and hot springs will definitely give a more accurate geothermal potential data. This refining exercise would be necessary for the country since she has not yet discovered any other source of energy and geothermal energy is relatively a clean energy source.

1: INTRODUCTION

The Kenya Rift Valley is one of the most spectacular continental rift zones and forms part of the East African Rift System. The Kenya Rift extends from north to south for a length of 750 km with varying width from 40 km to 70 km. At its highest point, the northern rift floor stands at 2000 m near Olkaria and descends to less than 300 m, above sea level, in the north at Lake Turkana. The rift forms a graben structure marked by sub-parallel faults and hosts a series of geothermal systems (Fig.1).

This paper attempts to analyse the natural heat discharge within the northern region of the Kenya rift valley, from Lake Baringo to Lake Turkana. Specific emphasis is laid on the volcanic complexes between the two lakes, which include: Korosi, Paka, Silali, Emuruangogolak, Namarunu and the Barrier (Fig.2). The analysis assumes similar rock physical characteristics that of the Olkaria Domes area which the author used to calibrate the data used in this exercise. Both Olkaria and the northern rift systems are associated with young trachytic magmatic events.

Mapping of the latteral extent of the hot grounds and measurements of ground temperatures in the northern part of the rift was carried out between 1988 and 1992. This was during a regional geothermal assessment programme in the northern sector of the Kenya Rift Valley by the British Geological Survey and the Ministry of Energy, Kenya. Heat transfer through fumaroles, steaming grounds, and hot grounds are related to deeper upward flow of thermal fluids and this can be used to rank geothermal systems.

2: GEOTHERMAL ACTIVITY

To check whether the complexes discharge superheated steam, boiling point temperatures (TBP) based on mean air pressure and boiling point temperature of water as a function of elevation was computed (Table 1). The theoretical temperatures together with the maximum temperatures observed at the surface of each geothermal prospect are plotted in Figure 3. It was found that some parts of Paka and some springs (Elboitong) in the Suguta valley have temperatures which are slightly above the local boiling point of water. In the second column of Table 1 are the average temperatures listed as they would occur in an ideal atmosphere with a critical lapse rate of about 3°C/Km; actual lapse rates are greater, about 5°C/km. As a result, the average temperatures listed are probably slightly higher for the Rift, but they would be within a few degrees of the actual mean temperature at the elevation given.
(Example: T° of Olkaria (2000 m asl) lies between 18° and 20° C).

2.1: Olkaria Domes area

This comprises of at least 80 smaller volcanic domes and flows spreading over a 100 km area (Fig. 4). Drilling to depths of 2 km indicates that the near surface silicic rocks overlying rift valley flood lavas are mainly trachytic in composition (Thomson et, al. 1990). Surface thermal manifestations at Olkaria consist almost exclusively of hot and steaming ground which encompass a total area of at least 3 km spread over 100 km of terrain (Fig. 5). This activity is similar to that of other manifestations in the northern part of the rift complexes.

2.2: The northern rift volcanic complexes

Korosi is the southmost complex in the northern rift valley where surface temperatures record a maximum value of 95.7°C. Paka, which is the next northwards has ground temperatures mainly in the range 50.2°C to 94.5°C recording a maximum of 97.7°C. (Dunkley et, al. 1993). Silali forms an elongated N-S shield volcano and has an areal extent of 850km². and a caldera which is 7.5 km long by 4.5 km wide.

Its activity is associated with trachytic volcanism controlled by NNE – NE trending faults and fissures. Hot ground and fomarole temperatures reach a maximum of 96.8°C in the eastern part of the caldera. Emuruangogolak, which is the fourth has its activity confined to the summit caldera where hot ground temperatures mostly exceed 80°C reaching a maximum of 96°C. Namarunu complex is thermally quiet with extensive areas of older hydrothermal alterations and silica is common on the upper flanks and summit. The silica veins are interpreted as conduits of former hot springs activity. Along the eastern side of Suguta Valley to the east of Namarunu , Elboitong hot springs form the hottest geothermal surface manifestations in Kenya with temperatures locally exceeding 100°C. The hot springs have temperatures increasing from 89°C in the north to 100.2°C in the southern part where the hottest and most vigorous activity occur (Fig. 6). The Barrier is the northmost volcanic complex with the youngest volcanic activity of basaltic eruptions from Andrews and Telekis cones which were active towards the end of the 19th Century. The highest temperatures are found in the caldera recording a maximum of 98.6°C where the local boiling point is 97.2°C. (Dunkley et, al. 1993)

3.0: THE HEAT LOSS ASSESSMENT

The term "steaming ground" is used to describe hot ground where heat is transferred to the surface by conduction and convection. The surface temperature increases and there is usually high temperature gradient between 50° and 350°C in the upper, say, 20cm. An imperial relationship between heatflow (H) and temperature (T) at a depth of 15cm which was derived in New Zealand (Dawson, G.B. 1964) was used in this exercise.

The assessment involved converting fumarole and steaming ground temperature and their areal extent as shown in the 1:50,000 maps into heat loss data. For the conversion, all the areas with thermal activity for each complex were studied and a classification derived producing a subdivision of all hot ground into three categories, which were finally used as the basis for the final evaluation.

3.1: Use of Calibration Data from Olkaria

Using sub-areas shown in Fig.5 and $\Delta T/\Delta z$ between 0 and 0.15m depth, together with an assumed thermal conductivity of 1W/mK, the heat loss for each area in the Olkaria Domes prospect (1F, 2F, 3F, and 4F) was calculated. Important for the re-assessment of the ground temperature data were two separate studies:

An MSc study by C.SERVENE (1996) found that for a 100,000m, large steaming ground over the Tokaanu geothermal system in New Zealand, there was a good linear relation between near surface T-gradient (0 to 0.2m depth) and T at 0.2 m depth indicating that upto 80°C most of the surface heat transfer was by conduction and that steaming ground was saturated with condensates even at shallow depth.

Studies of steaming ground over the south Olkaria area in 1993/4 are summarised in two KPC internal reports already cited. D. Kagiri (1994) defined hot ground by actual point surveys as the area where T at 1m depth was >50°C. C.O. Ofwona (1993), also got more or less the same values. On plotting the $\Delta T/\Delta z$ values between 0 and 0.2m depth against T at 0.2m depth, again a quasi-linear relationship, as noticed by SERVENE was repeated.

The studies in the Domes area Olkaria are summarised in Table 2 & 3. The result of the three independent assessments for the Olkaria Domes prospect are shown in Table 4, and shows that the estimates are in reasonable agreement. The 1st assessment used all available T-data, while the 2nd and the 3rd assessment used only Tmax for each sub-area, i.e. the information shown as in Fig. 7.

The mean heat loss (W/m2) for each category was then calculated for the northern rift complexes using the same procedure as for the Olkaria South and Domes prospect. To achieve the mean values of heat loss for the analysis, temperatures taken at 0.15m depth were plotted verses heat loss (W/m2) for the Olkaria Domes area (Fig. 9), then computed, Table 5.

4: RESULTS OF THE EVALUATION

These results were arrived at after extracting the surface thermal areas from 1: 50,000 maps showing the geothermal systems mentioned above. The thermal area data was then converted for each system to heat discharge data assuming a surface thermal conductivity of 1W/m K and the average heat loss as in the Domes area. The results which show that Paka geothermal system has the highest heat discharge (296 MWt) are listed below (Table 6). This table contains the main findings of the study which outlines a rough estimate of the total heat discharge through steaming and hot grounds within the study area.

5: DISCUSION AND CONCLUSION

This heat loss assessment is only a coarse estimate of the actual heat loss of the northern rift geothermal systems. Although the estimate of the total areas of hot ground is as accurate as the information given on the 1:50,000 maps, a better estimate could be achieved if the temperature measurements were taken at known and constant depths, say at the surface, at 0.15m and at 1m throughout each prospect. The accuracy of the estimate given in this paper is limited by the accuracy of the heat loss data from Olkaria South and Domes prospect. The assigned average value of a "mean" temperature for a large area could easily be an under- or over-estimation. This would result in inaccurate values of conductive heat loss estimate. Thus, the obtained heat loss through conduction can only be ascertained by use of an average value of thermal conductivity. The heat transfer at the surface is also a function of thermal diffusivity, bulk density of the rock matrix, the thermal capacity of the soil, and the degree of its saturation and porosity. In addition, corrections are required to assess the convective component for ground where temperatures are greater than 80°C. It was assumed that the northern rift has the same geology as the Olkaria South prospect. Regionally, this may hold, but locally there may be large variations. It was also assumed that the catchment areas which contribute to the recharge of the systems, whether shallow or deep, are similar. For the purpose of this paper, these assumptions may hold, but should be proved during the refining of this heat loss estimate. It should be noted that ground inhomogenities occur over large or even small areas. The natural heat loss from the northern Kenya geothermal systems is mainly through conduction of heat through the soil. This has been estimated to be 742 MWt with an error of about 31 per cent. Note that no hot spring heat discharge was included in this assessment as insufficient data were available during the compilation of this paper.

It is therefore recommended that:

- More detailed temperature measurements should be carried out along the profiles over the northern rift geothermal systems at 0, 0.15 and 1m depth for assessing the local temperature gradient.
- Thermal conductivity of the surface layer in this area should be determined to increase the accuracy of the conductive heat loss assessment.
- Since the relationship between heat loss (H) and temperature (T) at 0.15 m applied in Olkaria South and Domes prospect heat loss analysis was derived from studies of the Wairakei geothermal system (NZ), which is geologically and climatically different, a more representative relationship for H and T at 0.15 m should be derived for selected prospects in the northern Kenya rift.
- Mass flow measurements for all the hot springs should be carried out for all prospects as a refining exercise to establish the hot spring heat discharge.

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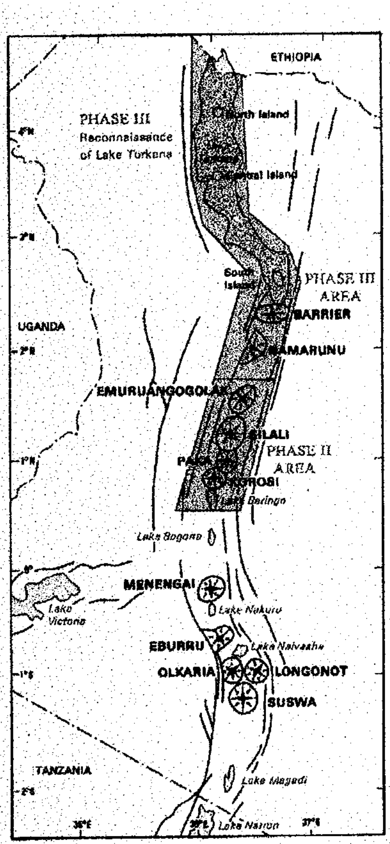

Fig. 1: Location map of the Kenya rift quaternary volcanoes.

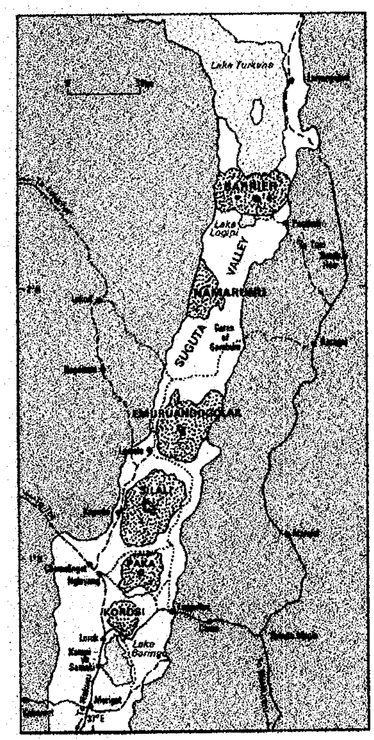

Fig. 2: Northern Kenya Rift geothermal systems.

Table 1: North Rift mean air pressure and boiling point of water as a function of height.

Elevation (km)	Average Temp. (°C)	Average Temp. (°K)	Constant	Av.Press . (mb)	TBP (°C)
0.0	27.0	300.2	8.81	1010.00	99.87
0.5	25.6	298.8	8.77	956.87	98.39
1.0	24.2	297.4	8.73	900.69	96.72
1.5	22.8	296.0	8.69	849.86	95.19
2.0	21.4	294.6	8.65	801.46	93.55
2.5	20.0	293.2	8.61	755.40	91.98
3.0	18.6	291.8	8.57	711.57	90.41

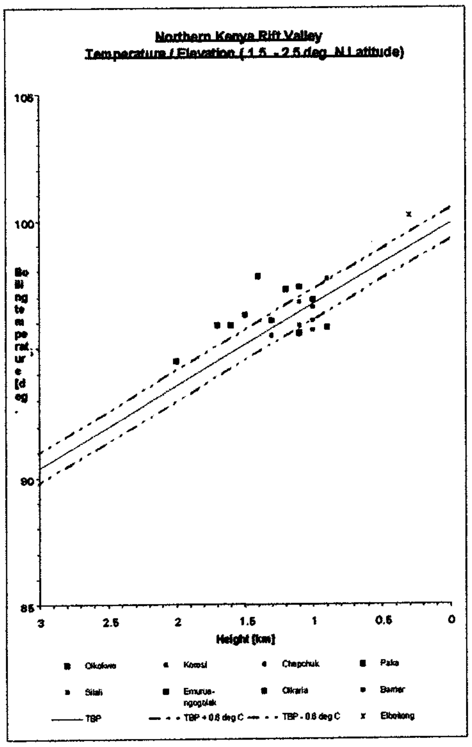

Fig.3: Boiling point curve of the North Rift Geothermal systems (1.5°-2.5° N-Lat.)

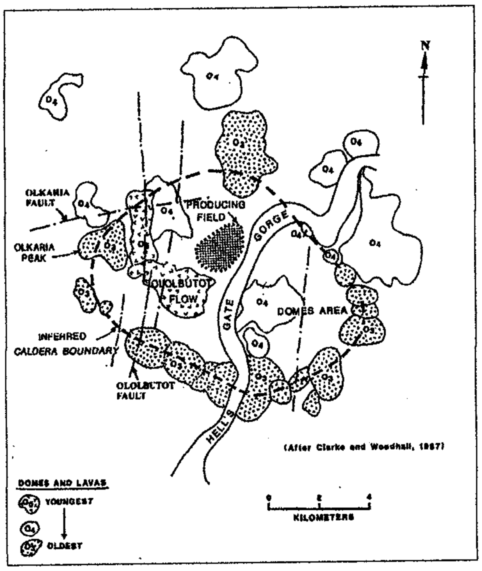

Fig. 4: Location of Olkaria south and Domes prospect.

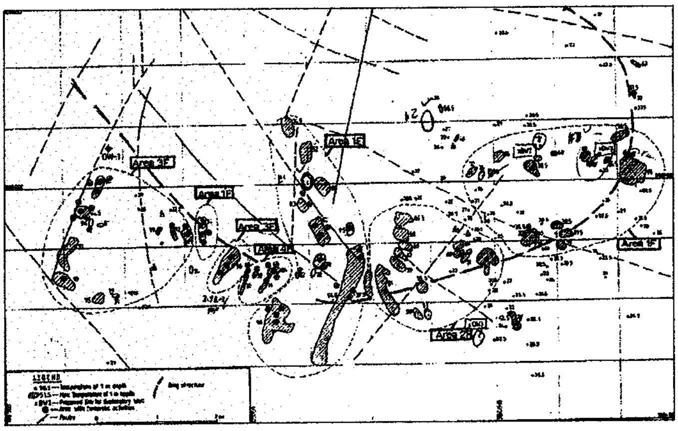

Fig. 5: Domes area showing distribution of surface temperatures.

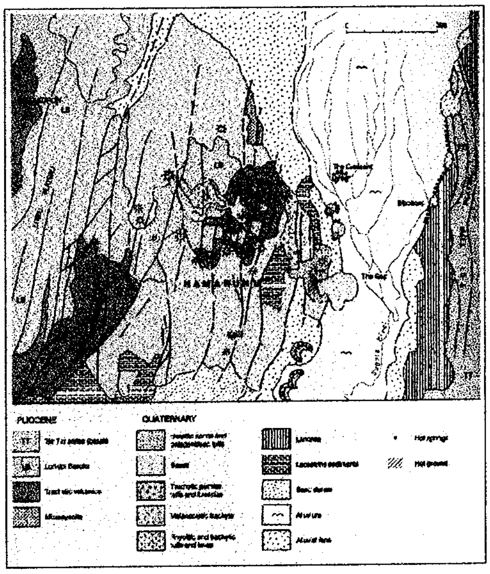

Fig. 6: Namarunu and Elboitong hot springs.

Table 2: Olkaria Domes Prospects (Steaming ground re-evaluation)

AREA 1F:

Temp. Range (°C)	Data Points	Inferred subarea (E 3 m²)	Approx. $\Delta T/\Delta z$ (°C/m)	Q (MWt)
10 – 30	8	250	20	5
30 – 50	18	560	50	28
50 – 70	8	250	100	25
70 – 90	7	220	200	44
> 90	1	30	300	9
	Total area	1310	Total heat losses	111
The 31 fumaroles in this area produce a steam discharge of about 9.1 MWt				

AREA 2F:

20 – 30	16	335	28	9.4
30 – 40	6	125	65?	8.1
40 – 50	1	20	110	2.2
	Total area	480	Total heat losses	19.7
The 6 fumaroles in this area produce a steam discharge of about 1.8 MWt				

AREA 3F:

30 – 50	8	100	25	2.5
50 – 70	14	175	100	17.5
70 – 90	5(2)	5(25)	250(300)	16.2(7.5)
> 90	2	25	300	8.7
	Total area	390	Total heat losses	45± (7.5)
(Two points in 70 - 90°C range are treated as convective with $\Delta T/\Delta z$ = 300°C/m.				
The 18 fumaroles in this area produce a steam discharge of about 5.5 MWt				

AREA 4F:

35 – 45	3	20	< 110?	< 2.2
45 – 55	3	20	170	3.4
55 – 65	1	6.5	220	1.4
65 – 75	1	6.5	260	1.7
	Total area	53	Total heat losses	8.7 MWt

The values obtained above are in reasonable agreement with those in the two reports as shown in Table 3 below.

Table 3: Total heat losses (in MWt) of Olkaria Domes Prospects.

Total quasi-conductive losses	184.5 (176)
Direct steam losses (Fumaroles)	16.5 (10)
Liquid losses (Kagiri, 1994)	1.0 (1)
Total	202 (187)

First value are those of the author, while those in brackets were obtained by Kagiri (1994). Both sets are in reasonable agreement.

Table 4: Subdivision of hot ground at Olkaria Domes Prospect.

Classification	Assessment 1. Area(E m²)	Assessment2. Area(E m²)	Assessment 3. Area(E m²)
High Temp. (>92°C)	200	280	268
Intermediate (70 - 92°C)	600	525	485
Low Temp. (40 - 70°C)	1430	1370	1493
Totals	**2230**	**2175**	**2246**

Assessment 1: obtained from detailed T-data shown in report by Kagiri (1994)
Assessment 2: obtained using only T-max for a given sub-area (M.P.H)
Assessment 3: obtained using only T-max for a given sub-area (author)

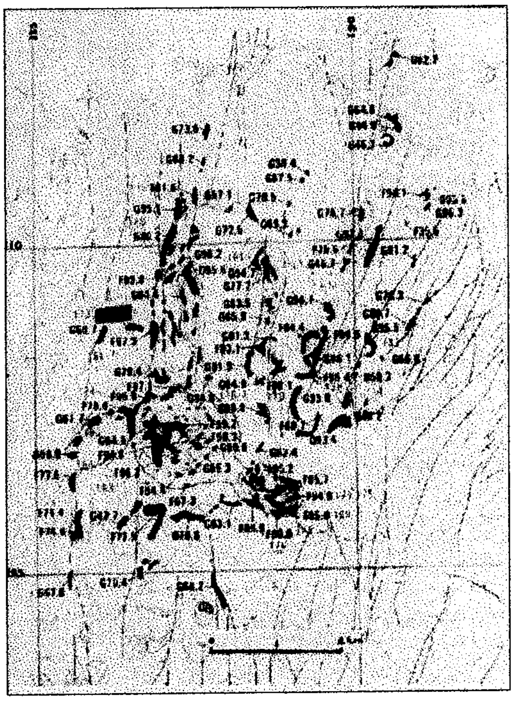

Fig. 7: Location map of Paka geothermal activity.

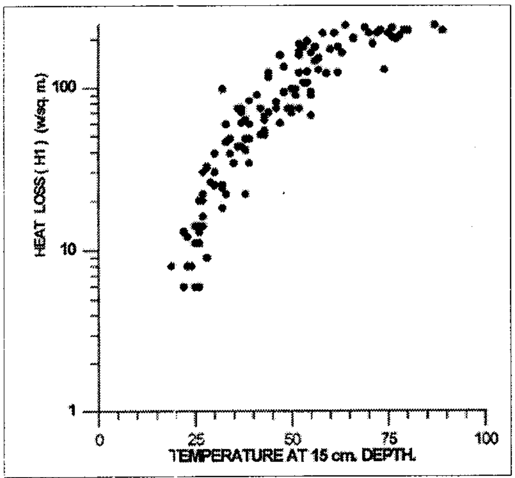

Fig. 8: Temp. at 15cm vs Heat loss (w/sq.m) at Olkaria South Domes Prospect.

Table 5: Range of computed heat loss (W/m²) for each category.

	High	Intermediate	Low
Maximum:	340	210	61
Mean:	300± (40)	160± (50)	33± (10)
Minimum:	260	110	16

Table 6: The Northern Kenya rift Volcanic complexes thermal activity data

Classification

> 90°C. - High Temperature (H)
70 - 90°C. - Intermediate Temperature (I)
40 - 70°C. - Low Temperature (L)

Locality	Classification categories	Inferred area (E 3 m²)	Inferred heat loss (W /m²)	Discharge (Q) MWt
Olkokwe and Chepchuk	H	71	300	21.3
	I	102	160	16.4
	L	187	33	6.1
Total	=	360	=	43.8
Korosi	H	66	300	19.8
	I	622	160	99.5
	L	1303	33	43.0
Total	=	1991	=	162.3
Paka	H	396	300	118.8
	I	886	160	141.8
	L	1078	33	35..6
Total	=	2260	=	296.1
Silali	H	130	300	39.0
	I	354	160	56.6
	L	373	33	12.3
Total	=	857	=	107.9
Emuruan go-golak	H	35	300	10.5
	I	166	160	26.6
	L	425	33	14.0
Total	=	626	=	51.1
Barrier	H	86	300	25.8
	I	247	160	39.5
	L	382	33	12.6
Total	=	715	=	77.9

Gross Total = 6809 E 3 m². = 739.2 MWt.