GEOTHERMAL MAPPING USING TEMPERATURE MEASUREMENTS

By

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THE EARTH'S TEMPERATURES

- Earth's temperatures remain relatively constant over time except in the very near surface

- The temperature difference between the cool crust and hot molten magma causes a temperature gradient

- Normal temp gradient in deep boreholes around the world shows an increase of 15 to 30°C per km.

- In geothermally active region temperature increases more rapidly with depth, hence, higher heatflow.

The Earth's Temperatures, cont'd

- For high temp resources development, there's need to target areas with elevated temp gradient.

    •How? (heat-flow measurements)

- For low temp resources development, the relatively stable earth's temp is sufficient (e.g. geothermal heat pumps).

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THEORY OF HEATLOSS SURVEY

- Heat loss analysis involves evaluation of heat transfer in a geothermal system.

- Heat transfer mechanism is divided into three major processes
  - conduction
  - convection.
  - Radiation

CONDUCTION

Occurs when;

- When adjacent atoms vibrate against one another, or as electrons move from atom to atom.
- No flow of the material medium.
- Occurs mainly in solids.

Conduction, cont'd

Conduction heat flow is calculated by using one dimension heat conduction equation

$$Q = Ak\frac{dT}{dy}$$

Where

- Q Conductive heat flow (watts),
- A Surface area of hot ground (m2),
- k = 2 Thermal conductivity of rock (w/m°C),
- T Temperature (°C)
- y Depth (m).

Sample calculations for Conductive heat transfer

Name	East (Km)	North (Km)	T_s (°C)	T_{50} (°C)	T_{100} (°C)	$Grad_{50}$ (°C/m)	$Grad_{100}$ (°C/m)	Average (°C/m)	Mean (°C/m)	Area (m2)	Heat flow (MW_t)
KH-1	190.9	91.0	24.3	28.4	28.4	4.1	4.1	4.1	14.6	5000	73
KH-2	188.4	93.5	95	95	95	0	0	0			
KH-3	188.3	93.5	28	34	36.2	6	8.2	7.1			
KH-4	187.9	93.4	61.3	97	97	35.7	35.7	35.7			
KH-5	187.6	93.2	35.4	57	68	21.6	32.6	27.1			
KH-6	186.8	83.2	23.1	28.8	29.7	5.7	6.6	6.15			
KH-7	189.3	86.7	24	30.7	32.4	6.7	8.4	7.55			

CONVECTIVE HEAT TRANSFER

Convective heat transfer occurs in hot springs and fumaroles

involve transfer of heat energy due to movement of fluid particles.

This process is faster than conduction.

Convection, cont'd…(2)

- Calculation of convective heat transfer is calculated using the fluid flow equation

$$V = C_d A_t \sqrt{\frac{2g\Delta H\left(\frac{\rho_w}{\rho_s} - 1\right)}{\left(1 - \frac{d_t^{\,2}}{d^2}\right)}}$$

Where

V	Volumetric flow rate (m3/s),
Cd	Coefficient of discharge (assumed to be 0.96),
g	Acceleration due to gravity (9.81 m/s2),
dt	Venturimeter throat diameter,
d	Venturimeter diameter at the high pressure tapping (m),
ΔH	Differential height at the manometer (m),
ρ	Density of the fluid (kgm-3),
A_t	Throat area (m2)

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Convection, cont'd…

- Equation below is used to calculate the convective heat flow.

$$Q_c = V\rho_s h$$

- Where
  - Qc Convective heat flow (watts)
  - h Enthalpy of steam at the corresponding measurement temperature (Jkg-1).

Sample calculations for convective heat transfer

PROPERTIES	SYMBOL	VALUE
Venturi diameter	d	0.0254 m
Water density	ρ_w	1000 kg/m^3
Diameter (throat)	d_t	0.00635 m
Steam density	ρ_s	0.4753 kg/m^3
Throat area	A_t	$3.16532E^{-05}$ m^2
Steam enthalpy	h_s	2670 kJ/kg
Coef. of discharge	Cd	0.96
Water enthalpy at ambient conditions	h_o	117 kJ/kg
Gravity	g	9.81 m/s^2

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Sample calculations, cont'd

Name	North (km)	East (km)	Man. height (mm)	Volumetric flow (m^3/s)	Heat flow (kW_t)
KFMRL-1	177.0	89.2	9	0.000604765	0.767
			17	0.000831169	1.055
			9	0.000604765	0.767

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Temperature and Pressure in Boreholes

- Temperature measurement
  - Boreholes serve as gradient holes for temp gradient computation.
  - Results used to estimate geothermal reservoir temperatures

- Pressure measurements
  - Assist in modelling the hydrological picture of the area
  - Give an indication of possible recharge and outflow zones.

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Tools Used during heat-flow survey

- GPS
- Digital Thermometer
- Fabricated spikes
- Hammer
- Field note book
- Metal rod
- Field Map
- Winch
- Kuster temperature and pressure tools
- Jembe, Spade, Plastic basins, Panga
- Reliable means of communication e.g radio calls, Satellite phones, mobile phones etc

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PLANNING FOR HEAT-LOSS SURVEY

- Spacing of gradient holes
  - 100 m – 1 km in an area of high thermal activity
  - 1 - 4 km in an area of low activity.
- Area, time and resources available
  - –This determines how fast the work is to be accomplished
- Geological formation of the area
  - –Some important features
- Social constraints
  - –Areas prohibited or controlled (religious, tourist attraction, cultural)

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Heat-loss survey and other Geo-scientific studies

- Assists in quantifying amount of heat being lost on the surface
- Complements other disciplines in:
  - determining the reservoir temperature
  - identification of active structures
- Gives extent of leakage through the capping.
- suggests possible orientation of the fracture zones

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Challenges Encountered

- Hostile climate
- Poor communication (no roads)
- No proper tools and equipments
- Some areas are covered with hard material which are difficult to penetrate
- No surface manifestation so convective heat transfer becomes difficult to measure
- Heavy and cumbersome equipments

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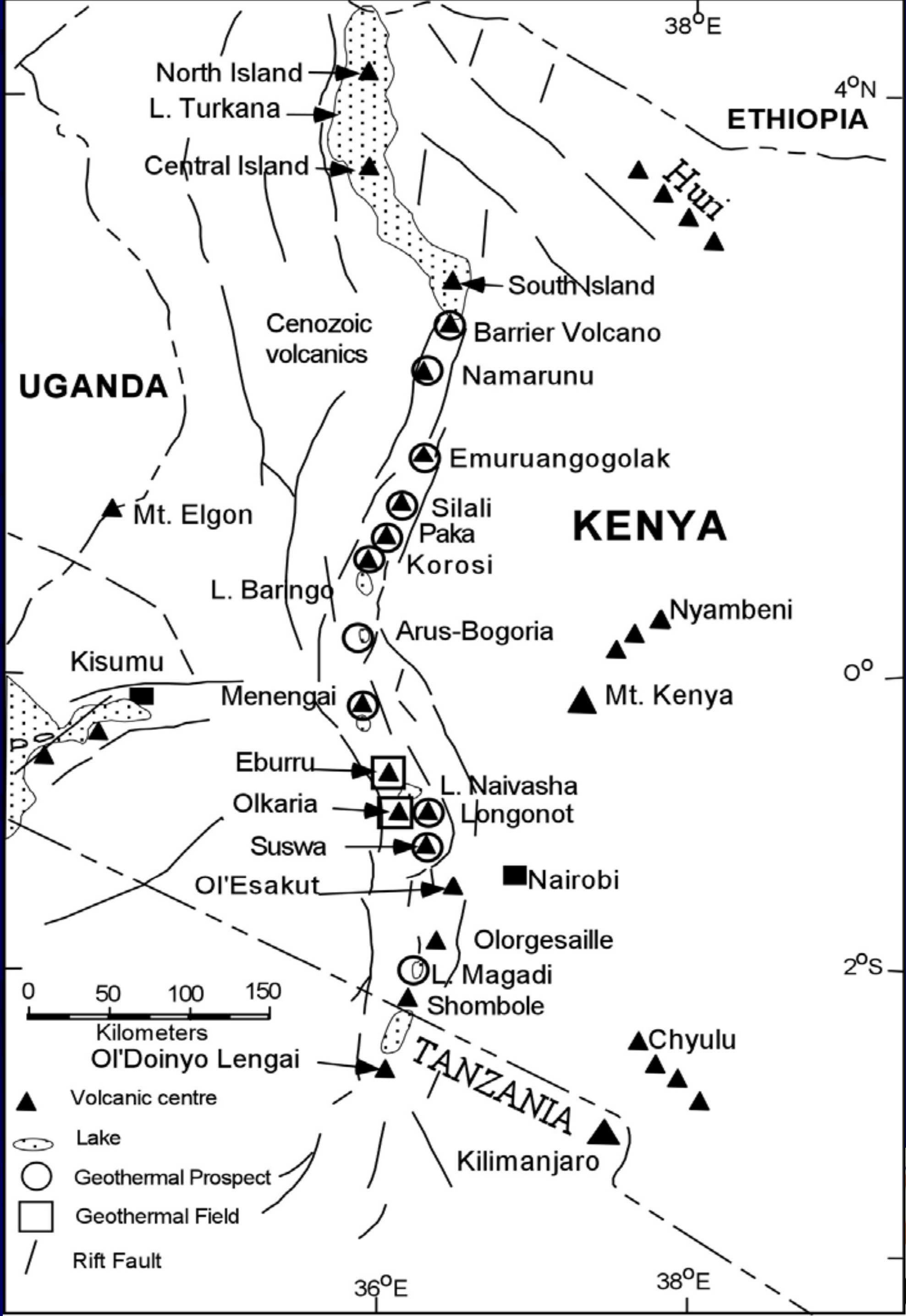
CASE STUDIES (EXAMPLES IN KENYA)

Heatflow measurement has been carried out in five of geothermal prospects

- Menengai-Olbanita Prospect (2004)
- Baringo Prospect (2004)
- Arus-Bogoria Prospect (2005)
- Korosi and Chepchuk Prospect (2006)
- Paka Prospect (on-going) (2006 on-going)

There are 14 geothermal prospects in Kenya

Total estimated geothermal potential >3000 MWe



Menengai-Olbanita Prospect (2004)

- The prospect is associated with the 90 km^2 Menengai Caldera
- Collection of heat flow data was done in an area of about 900 km^2.
- No hot springs were encountered.
- Convective heat flow was obtained from the steaming grounds within the caldera
- Boreholes drilled to 300 m depths in this area discharge water at temperatures of 40 °C to 60 °C

Menengai Caldera

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Menengai-Olbanita Prospect , cont’d

- orientation of the high temperature features are
  - NNW-SSE, and NE-SW
    - major fault/fracture are also in this direction
- Over 3536 MWt heat lost naturally.
  - 2690 MWt is lost in the Menengai Caldera
- This large heat loss could be an indicator of a huge heat source underneath this prospect

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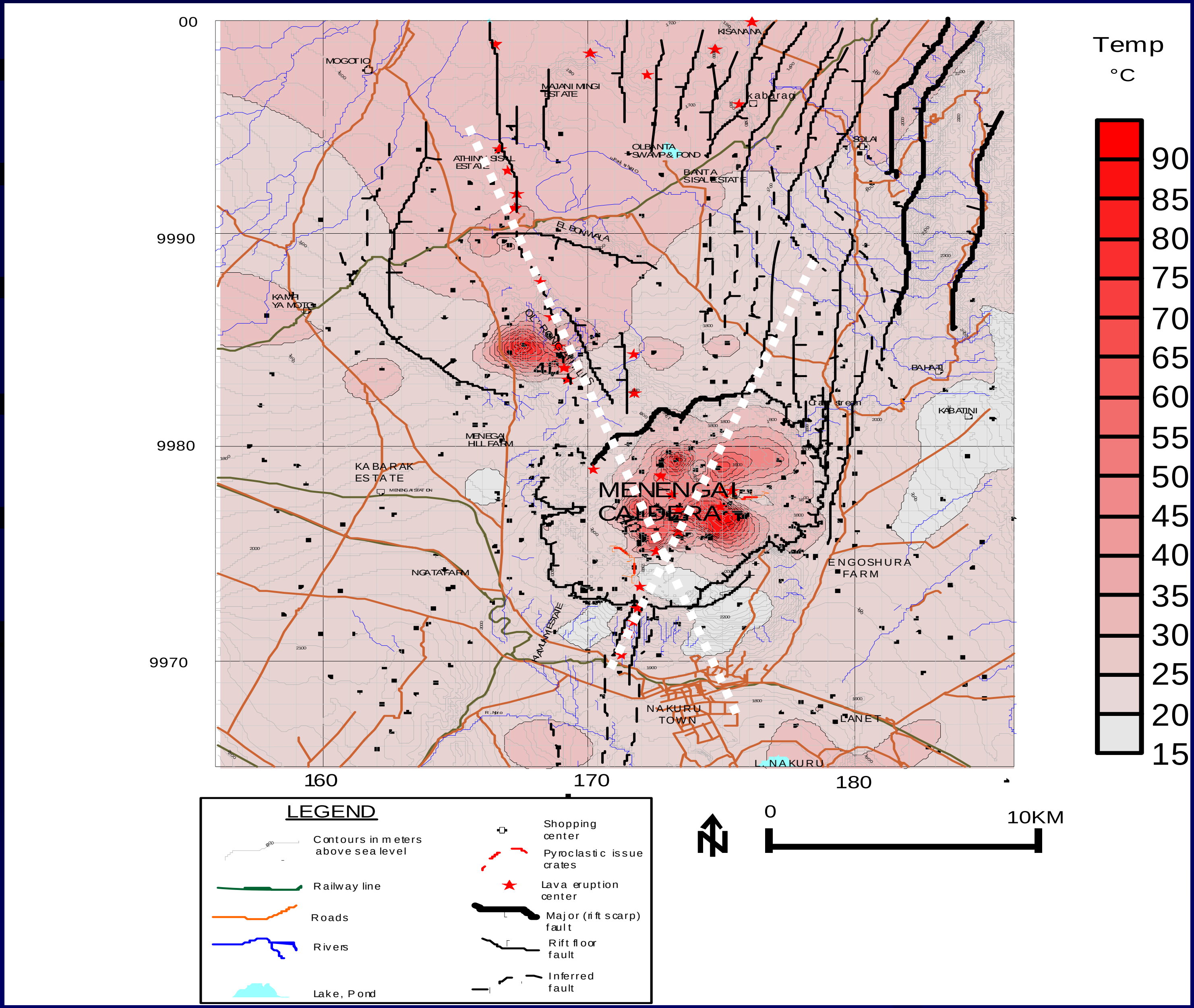
Menengai-Distribution of Gradient holes



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BARINGO PROSPECT (2004)

- Heat source is due to dyke swamps along fault lines
- orientation of the high temperature areas is NE-SW
- Coincides with those of major fault/fracture zones.
- Total heat loss from the prospect is > 1049 MWt
- Conduction
  - 941 MWt
  - 90% of the conductive heat loss occurs along the fault zones
- convection
  - 108 MWt by (105 MWt is lost in Kokwa Island)

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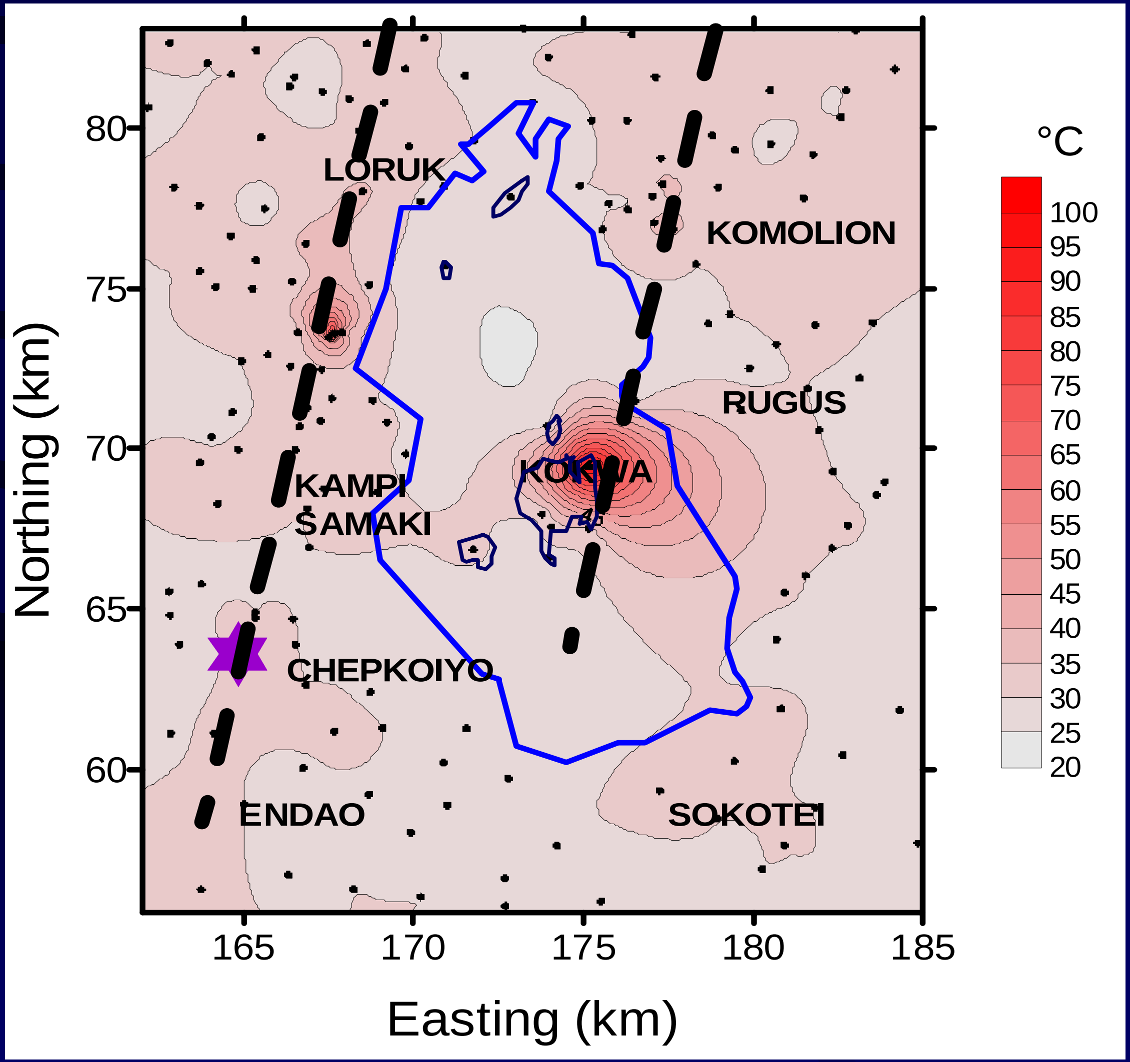
Baringo-Distribution of Gradient holes



Arus-Bogoria Prospect , cont'd

- Total heat loss from the two prospects is in excess of 1666 MWt

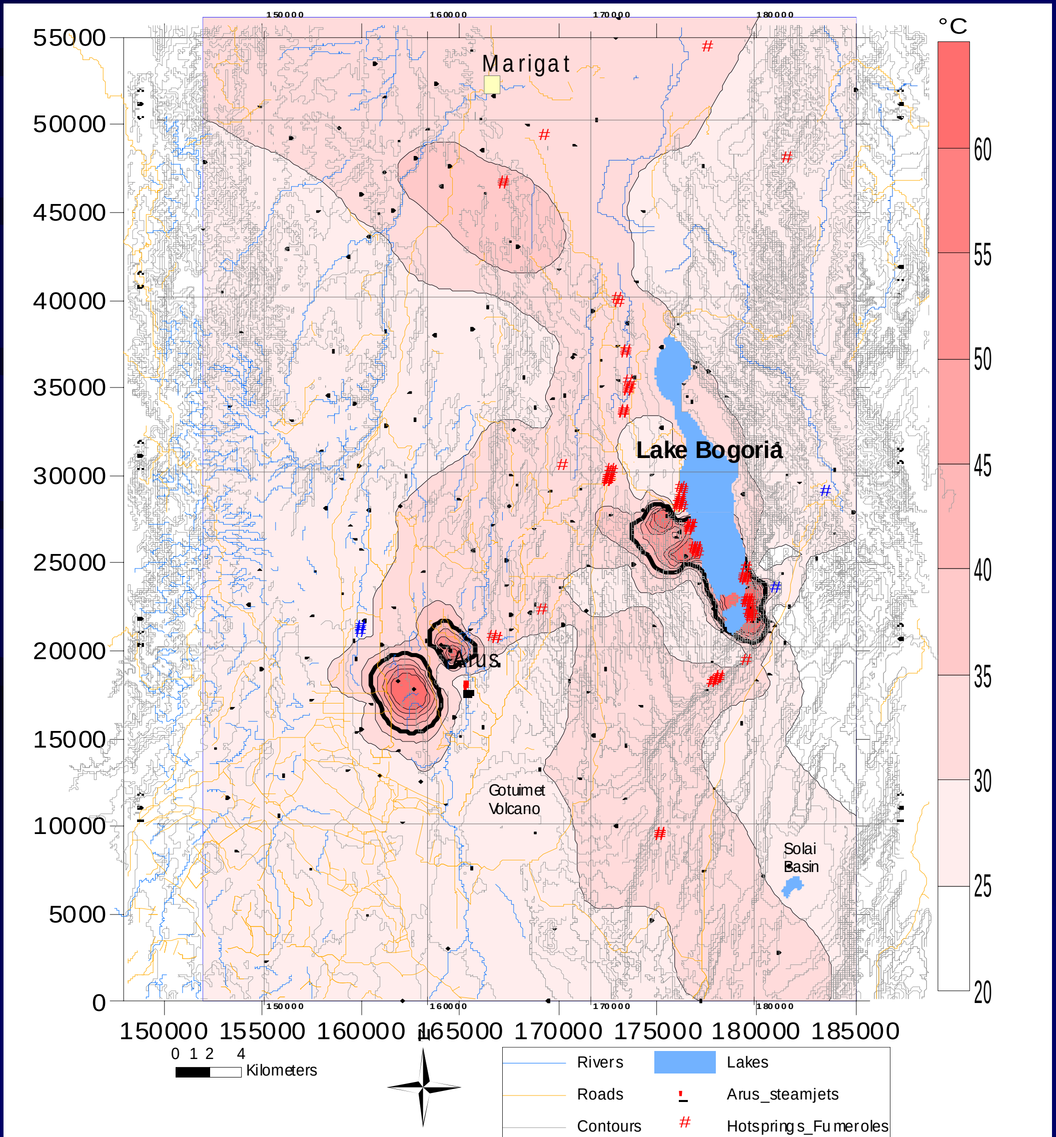
- Conductive 1229 MWt
  - Lake Bogoria 762 MWt
  - Arus 467 MWt

- Convective 437 MWt
  - Lake Bogoria 437 MWt
  - Arus 0.03 MWt

Geyser at Lake Baringo

Arus Steam jets at Arus

Arus Bogoria-Distribution of Gradient holes



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KOROSI AND CHEPCHUK PROSPECT

- Heat source at Korosi is therefore controlled by NE-SW and NW-SE trending faults.

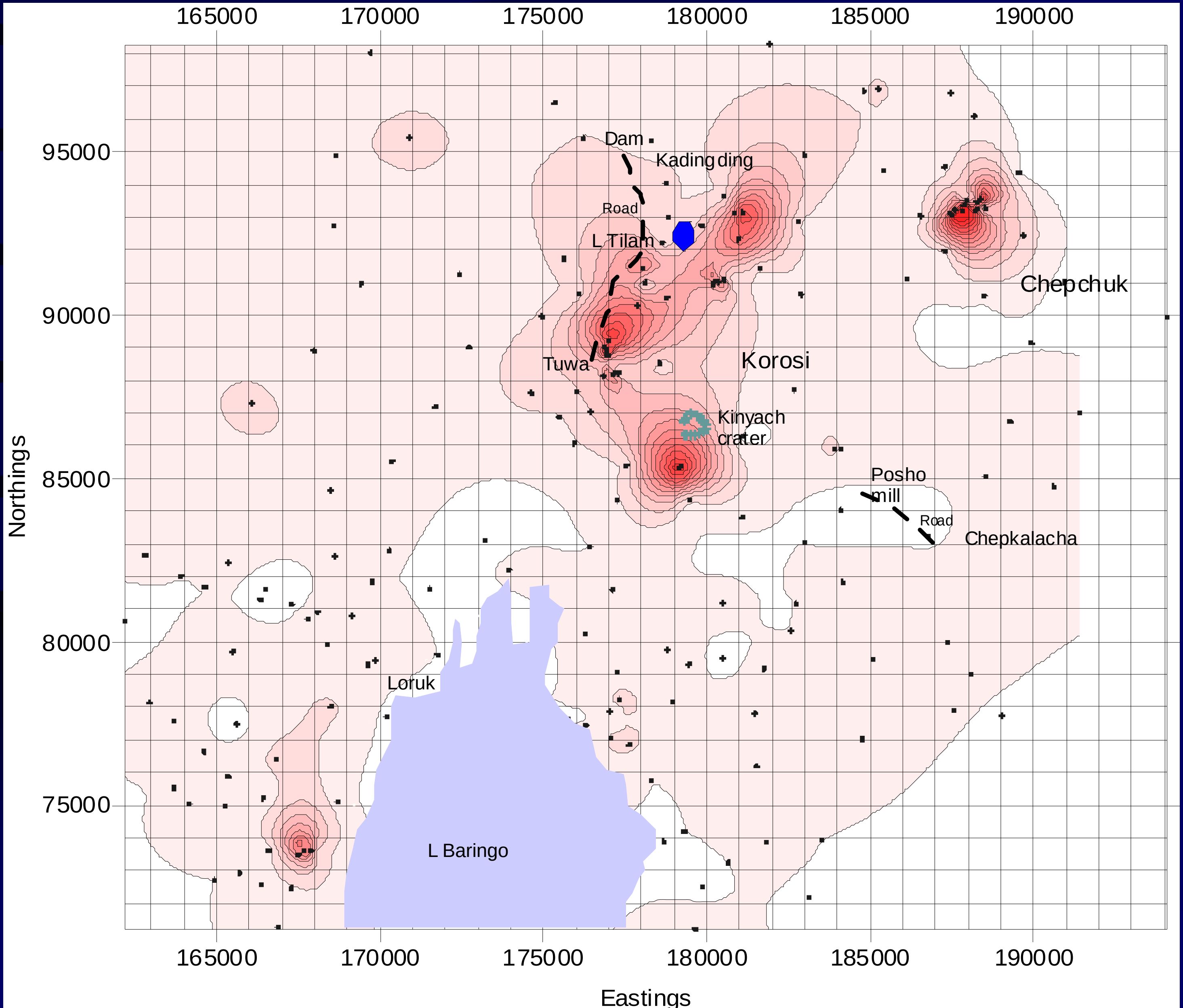
Conduction

- About 2,135 MW_t Korosi
- About 546 MW at Chepchuk.

Convection

- 0.4 kW_t
- Almost all the heat lost is by conduction

Korosi Prospect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Northings
Eastings
Dam
Kadingding
Road
L Tilam
Chepchuk
Tuwa
Korosi
Kinyach crater
Posho mill
Road
Chepkalacha
Loruk
L Baringo

PAKA PROSPECT

- Paka is a caldera north of Korosi
- Surface manifestations cover about 45 km^2 (hot grounds and fumaroles)
- Surface studies are in progress and expected to end in January, 2007

Paka Prospect

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Comparison between prospects

Prospect	Conduction (MWe)	Convective (MWe)	Total (MWe)
Menengai-Olbanita	1060	2476	3536
L. Baringo	941	108	1040
Arus-Bogoria	1229	437	1666
Korosi-Chepchuk	2681	0.4	2681
Paka	On-going		

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CONCLUSION

Heatloss survey is an important tool in;

- Analysis of the distribution of the heat loss features
- Results obtained are used as an indicator of the heat source size
- Give an indication of the magnitude of recharge
- extent of leakage through the capping.
- determining the reservoir temperature
- Serve as a guide in locating hidden fracture zones.
- Ranking the prospect for development

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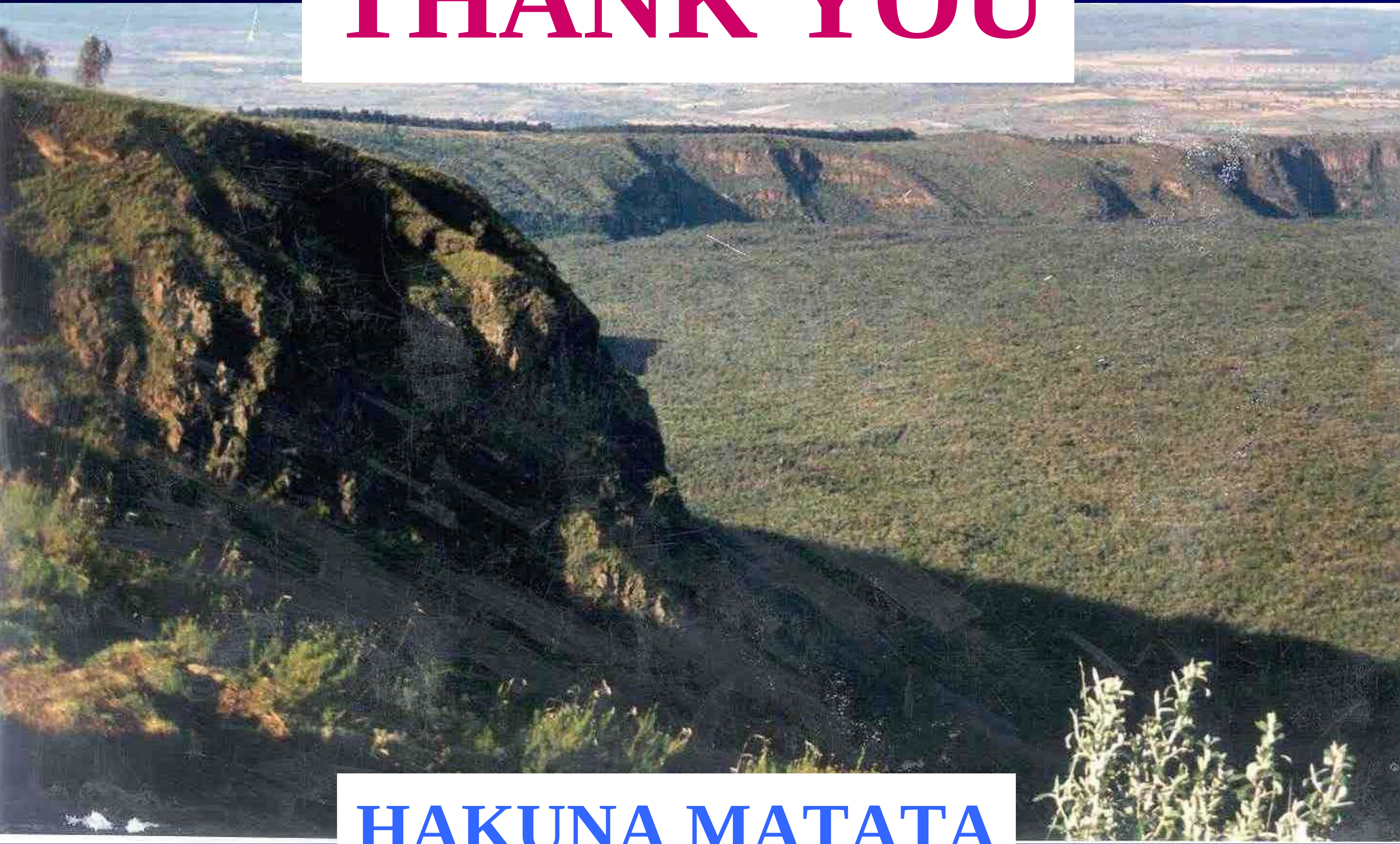
THANK YOU



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