Geothermal Energy Resources

*Exploration*

*using*

*Gravity and magnetics*

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What is Geothermal Energy?

Geothermal Energy = heat from the Earth

Transmitted by

fluids

via fractures and pores within the rock
Information needed

- Volume, geometry, boundary conditions of resource
- Permeability, density, heat capacity and conductivity
Sizing of Resource

- Surface exploration to determine existence of resource
- Determine areal extent and potential power
- Exploration drilling to prove resource, determine physical and geochemical parameters
- Determine total heat available
Geophysical investigations

• Geophysics  =  X-Raying the Earth

IN VOLVES

• Sending signal into the earth
• Monitoring natural signals from the earth
Geophysical methods available

- Schlumberger Array
- Dipole
- Electromagnetics
- Head on Resistivity
- Transient Electromagnetics (TEM)
- Magnetotellurics (MT)
- Gravity
- Magnetic
- Seismic
Geophysics methods...

Note:

• All geophysical techniques are expensive, although some more than others
• BUT still much, much cheaper than drilling
Common Geophysical Methods used in Geothermal Energy investigations

- Resistivity
- Seismic
- Gravity
- Magnetics
GRAVITY
Gravity as a force

Gravity is a potential field

i.e.,

a force that acts at a distance

Measures differences in the earth’s gravitational field at specific locations
Gravity field

The strength of the gravitational field is directly proportional to:

- the mass (the density)
- the depth
- the depth of subsurface materials
Gravity field.....
GRAVITY SURVEY

Results in

- Density indications in subsurface

HEAVIER Rocks may imply possibility of HEAT Source
INSTRUMENTATION

Common gravimeters

> Worden

> Scintrex and

> La Coste Romberg
INSTRUMENTATION.....

Worden  and  La Coste Romberg

gravity meters
Gravimeter

- Important for mapping
  - Dense bodies
    - Heat sources
    - Dikes
  - Buried faults zones
  - Ground subsidence
    - Mass withdrawal

Equipment cost upwards of US$ 150,000
Data Acquisition

Gravity data acquisition can be performed by one person.

But Two people are better

Readings at each site:

Gravity – Coordinates - Elevation
Data Acquisition…..

Speed and amount of data collected depends on:

- Station separation
- Operator experience
- Terrain conditions
Data Processing
The most tedious and time consuming!!!

REDUCTION
Must remove all known gravitational effects not related to the subsurface density changes
Data Processing.....

Each reading has to be corrected for Elevation, Tides, Latitude and if significant local topography exists, a topographic correction.
Data Processing.....

Tides and Drift removal

[Diagram showing gravimeter readings, instrument drift, and tidal variations over time (hr)]
Data Processing…..
Correction for topography
Corrections to Gravimeter Reading

1.) Correct for drift in terms of dial units

2.) Calculate difference between stations and base (Rdg)

3.) Convert difference to units of gravity (g) by multiplying Rdg values by the gravimeter scale constant

4.) Calculate \( g_{\text{obs}} \) at the station by adding \( g \) to observed gravity at base

5.) Calculate the Free Air (\( C_{FA} \)) correction (below reference surface \( h \) is negative, above \( h \) is positive) and add to \( g_{\text{obs}} \) of the station

6.) Calculate Bouguer slab (\( C_{BS} \)) correction and subtract from \( g_{\text{obs}} + C_{FA} \) of the station.

7.) Calculate terrain (\( C_{TC} \)) correction if necessary and add to \( g_{\text{obs}} + C_{FA} - C_{BS} \)

8.) Calculate \( g_{th} \) for the station and subtract from \( g_{\text{obs}} + C_{FA} - C_{BS} + C_{TC} \). This is the complete Bouguer anomaly.

9.) The simple Bouguer anomaly is \( g_{\text{obs}} + C_{FA} - C_{BS} - g_{th} \).

10.) The Free Air anomaly is \( g_{\text{obs}} + C_{FA} - g_{th} \).
Data Analysis and interpretation…..

From the reduced data:

- Plot contour maps
- Locate interesting features
- Construct profiles across
- Model
Data Analysis and interpretation…..

Contour maps
Data Analysis and interpretation.....

Profile Construction

![Graph showing observed Bouguer Gravity Anomalies and estimated regional anomaly.](image-url)
Data Analysis and interpretation.....

Modelling

Observed

Model
Costs for a Gravity Survey

Typical costs for a gravity survey depends on

> contract out the survey to a consulting company

➢ the clients wants to perform the survey themselves,

➢ the amount of interpretation and data processing

➢ the number of stations

➢ and the object of interest
### Costs for a Gravity Survey

<table>
<thead>
<tr>
<th>Service</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Gravity meter rental</em></td>
<td></td>
</tr>
<tr>
<td>Lacoste and Romberg model G</td>
<td>$50-60/day plus $240-270 mobilization</td>
</tr>
<tr>
<td>Lacoste and Romberg model D</td>
<td>$70-100/day plus $240-270 mobilization</td>
</tr>
<tr>
<td>Scintrex CG3-M autograv</td>
<td>$100-130/day plus $240-270 mobilization</td>
</tr>
<tr>
<td>Portable GPS receivers</td>
<td>$45-55/day plus $90-110 mobilization</td>
</tr>
<tr>
<td><em>Consulting services</em></td>
<td></td>
</tr>
<tr>
<td>Gravity survey (data collection only)</td>
<td>$900-1100/day</td>
</tr>
<tr>
<td>Station surveying</td>
<td>$300-350/day</td>
</tr>
<tr>
<td>Data processing (Bouguer gravity anomalies)</td>
<td>$200-300/day</td>
</tr>
<tr>
<td>Data processing and interpretation</td>
<td>$300-400/day</td>
</tr>
</tbody>
</table>
Data Analysis and interpretation.....

Example from Menengai, Kenya
Gravity model across Menengai volcano

[Diagram showing gravity model with depth and distance measurements]
MAGNETICS
Magnetometer

• Important for mapping
  – Demagnetized bodies
    • Heat sources
    • Dikes
  – Buried faults zones
  – Alteration zones
## Magnetic Susceptibility of Representative Rock Types

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Susceptibility ($k$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altered ultra basics</td>
<td>$10^{-4}$ to $10^{-2}$</td>
</tr>
<tr>
<td>Basalt</td>
<td>$10^{-4}$ to $10^{-3}$</td>
</tr>
<tr>
<td>Gabbro</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Granite</td>
<td>$10^{-5}$ to $10^{-3}$</td>
</tr>
<tr>
<td>Andesite</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Rhyolite</td>
<td>$10^{-5}$ to $10^{-4}$</td>
</tr>
<tr>
<td>Metamorphic rocks</td>
<td>$10^{-4}$ to $10^{-6}$</td>
</tr>
<tr>
<td>Most sedimentary rocks</td>
<td>$10^{-6}$ to $10^{-5}$</td>
</tr>
<tr>
<td>Limestone and chert</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>Shale</td>
<td>$10^{-5}$ to $10^{-4}$</td>
</tr>
</tbody>
</table>
Magnetic signatures

PRINCIPLE OF MAGNETIC METHOD OF EXPLORATION

THE EARTH'S MAGNETIC FIELD PULLS HARDER ON A MAGNET AT POSITION A THAN IT DOES AT POSITION B

SOIL
SHALE
LIMESTONE
SHALE
SANDSTONE
BASALT DIKE WITH MAGNETIC
GRANITE
Instrumentation

Proton Precession magnetometers. (a) Geometrics G-856 (b) Geometrics G-858
Data Acquisition

> Ground

> Aero-magnetics

To obtain a representative reading

- the sensor should be operated well above the ground
- the operator is “magnetically clean.” No Zippers, watches, eyeglass frames, boot Grommets, room keys, and mechanical pencils, can all contain steel or iron
- No cultural noise, e.g., power-lines, waterlines
Data Processing

- Correct for diurnal drift
- Cultural noise

Done by use of two instruments and Filtering
Data Interpretation

After all corrections have been made, magnetic survey data are displayed as contour maps from which individual profiles are constructed.
Data Interpretation…..

Profile across interesting feature
Total magnetic intensity over Olkaria

- Olkaria East
- Olkaria N-E
- Olkaria West
- Olkaria Domes
Advantages of Magnetic Surveys

- It is expedient and cost effective
- ideal for both reconnaissance and focused surveys
- covers more ground in less time and
- requires a minimum of field support
Cost of Magnetic Surveys.....

DEPENDS on whether

Ground

or

Aero-magnetics
Cost of Magnetic Surveys…..

Economic factors governing ground survey

- Mobilization and demobilization will require 1/2 day each
- Area/nature to be covered, total number of stations
- Number of field crew (minimum 3)
- Total person-hours required for processing, interpretation and report preparation
- Cost of renting two instruments
- Subsistence and travel expenses
- Transport costs
- Consulting fee
- Overhead = 100% of total direct cost
What then ???

And hopefully be happy, thereafter
Thank you!