TRAINING ON SURFACE EXPLORATION STUDIES FOR GEOTHERMAL RESOURCES AND
DEVELOPMENT OF CONCEPTUAL MODELS
UNDER THE AUSPICES OF INTERIM PROJECT COORDINATION UNIT OF THE AFRICA
GEOTHERMAL CENTER OF EXCELLENCE

GRAVITY SURVEYING – DATA ACQUISITION,
PROCESSING AND INTERPRETATION
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OUTLINE

✓ Introduction of the Method
✓ Theory
✓ Field design
✓ Data collection
✓ Data preprocessing
✓ Advanced processing and modelling
✓ Interpretation
Gravity is a potential field: a force that acts at a distance (Indirect Method)

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

Gravitational field varies due to heterogeneity of rock densities,
Introduction

In gravity surveying subsurface geology is investigated on the basis of variations in Earth’s gravitational field generated by differences of density between subsurface rocks.

A buried body represents a subsurface zone of anomalous mass and causes a localized perturbation in the gravitational field known as a gravity anomaly.

The basis of the gravity survey method is Newton’s Law of Gravitation, which states that the force of attraction $F$ between two masses $m_1$ and $m_2$, whose dimensions are small with respect to the distance $r$ between them,
Gravity Method is guided by the Newton's Law of attraction between two bodies. The law is described by the equation:

$$F = \frac{GM_1M_2}{r^2}$$

where $G$ (universal gravitational constant) $= 6.673 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$, $M_1$ and $M_2$ are the two masses in kg, and $r$ is the distance between the point masses, in metres.
Force is related to mass by acceleration and the term \( g = \frac{GM}{R^2} \) is known as the gravitational acceleration or – gravity.

The weight of the mass is given by \( mg \). On such an Earth gravity would be constant. However the ellipsoidal shape, rotation, irregular surface and internal mass distribution cause gravity to vary over its surface.
Introduction

The mean value of gravity at the Earth’s surface is about 9.80 \( m/s^2 \).

The variation caused by density variations at the surface are in the order 100 \( \mu m/s^2 \).

The unit micrometer per sec squared is referred as the gravity unit (gu). The cgs unit of gravity is the milligal (1 mgal = 10\(^{-3}\) Gal =10\(^{-3}\) cm/s), equivalent to 10 gu.
# Density of Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g cm⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>~0</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
</tr>
<tr>
<td>Sediments</td>
<td>1.7-2.3</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2.0-2.6</td>
</tr>
<tr>
<td>Shale</td>
<td>2.0-2.7</td>
</tr>
<tr>
<td>Limestone</td>
<td>2.5-2.8</td>
</tr>
<tr>
<td>Granite</td>
<td>2.5-2.8</td>
</tr>
<tr>
<td>Basalts</td>
<td>2.7-3.1</td>
</tr>
<tr>
<td>Metamorphic Rocks</td>
<td>2.6-3.0</td>
</tr>
</tbody>
</table>
Gravity Data Acquisition

Field Equipment

✔ Gravity Meter
✔ Global Positioning System

Important targets:

• Dense bodies
  Magmatic chambers
  Dikes

• Buried faults zones

Micro-gravity monitoring
Ground subsidence
Mass withdrawal
Gravity meters
Field Preparation

1. Identification of the survey area
2. Drift calibration
3. Absolute gravity station identification
4. Base station set up
5. Field data collection
Field Preparation

Readings at each site:
- Gravity
- Coordinates & Elevation
Use GPS equipment

Survey Crew: 2

Speed and amount of data acquired depends on:

- Station separation
- Operator experience
- Terrain conditions
The objective of gravity survey is to detect subsurface density variations.

Observed/Measured gravity value at the station includes all kinds of attraction.

Remove the effect of attraction except that of subsurface density anomaly.
Gravity Method

1st step

Observed Value

Absolute Gravity value

2nd step

Bouguer Values
Gravity Data Reduction

- Gravimeter reading data
- Tidal correction
- Height correction
- Drift correction
- Relative gravity value
- Conversion to absolute gravity value

- Free air correction: \( FA = \gamma - g - \beta h - Ca \)
- Bouguer correction: \( SBA = FA - 2\pi G \rho h \)
- Terrain correction: \( BA = SBA + \rho T \)

- \( FA \): Free air anomaly (mgal)
- \( G \): Measured gravity (mgal)
- \( \gamma \): Regular gravity (mgal)
- \( \beta \): Free air gradient (mgal/m)
- \( Ca \): Atmospheric pressure correction
- \( h \): Elevation (m)

- \( SBA \): Simple Bouguer anomaly (mgal)
- \( FA \): Free air anomaly (mgal)
- \( G \): Gravitational constant (m³/kg·s⁻²)
- \( \rho \): Subsurface average density (g/cm³)
- \( h \): Elevation (m)

- \( BA \): Bouguer anomaly (mgal)
- \( SBA \): Simple Bouguer anomaly (mgal)
- \( \rho \): Subsurface average density (g/cm³)
- \( T \): Terrain correction value (mgal)
Gravity Data Analysis

- **Bouguer anomaly**
  - Trend analysis or Upward filtering
    - **Regional anomaly**
    - **Residual anomaly**
      - Trend analysis or Upward filtering
        - **Long wave component**
          - 3D analysis
            - Basement structure
              - Estimate the depth of basement rock
        - **Short wave component**
          - Filtering analysis
            - Gravity lineament
              - Detect fault or fracture
Limiting depth refers to the maximum depth at which the top of a body could lie and still produce an observed gravity anomaly. Gravity anomalies decay with the inverse square of the distance from their source so that anomalies caused by deep structures are of lower amplitude and greater extent than those caused by shallow sources.
Bouger anomaly fields are often characterized by a broad, gently varying, regional anomaly on which superimposed higher wave number local anomaly occurs.

In gravity surveying for geothermal, it is the local anomalies that are the prime interest and the first step is to remove the regional field.
Gravity Data Analysis

Gravity Anomaly enhancement

- Vertical second derivation
- Horizontal first derivation
- Gravity distribution

Sedimentary layers
Basement
Sedimentary layers
Basement
Gravity Lineament and geological structures. {Black dots} are gravity stations, {blue circles} are existing structures and {red dashed lines} are gravity lineaments.
This process is aimed in modelling the source of the gravity signal measured at the surface.

This can be done thru processing of

- 2D Density Models
- 3D Density Models
2D Density Modelling Gravity Data

2D Density Modelling
Gravity Data Modeling

The gravity anomaly from the map can be modeled with at least two bodies.

Gravity modeling does not give a unique interpretation. With knowledge of the geological setting, the densities the number of possible models do decrease.
In indirect interpretation, a model whose theoretical anomaly can be computed simulates the causative body of a gravity anomaly. The shape of the body can be altered until the computer anomaly closely matches the observed anomaly.
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The shape of the body can be altered until the computer anomaly closely matches the observed anomaly.
3D Density Modeling of Gravity Data
Gravity methods are good in structural mapping in geothermal exploration:

- Heat Sources (dense material in shallow crust)
- Fractures/Faults (gravity gradients/slopes)

• Help to identify potential drilling sites
• Help to identify potential recharge areas

Advantages of gravity Method

- Faster and Relatively Cheaper
- Requires minimum field support
Thank You