Chap II : Gravity method used in Hydrogeology

Gravity Method: as already mentioned in table 1 Gravity is a secondary geophysical method used in hydrogeology while it is a primary method for hydrocarbon (Oil & Gas). It consist of the measurement in gravitational acceleration changes from location to another and it give information about subsurface density variations that can be related to variations in lithology or moisture (liquid) content. The successful application of the gravity method in groundwater geophysics is documented in many papers, in the last five decades.

The development of tools/instruments and data processing allow detection of **small magnitudes of gravity anomalies** by a high accuracy in measurement which lead to a new discipline "Microgravity" that is able to quantify changes in water storage associated with hydrological processes and to characterize cavities in karstic terrains.

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Gravity

Gravity physical principle: Newton's law of gravitation defines the gravitational force F between two point masses m1 and m2 as follow:

The attraction force $$\boldsymbol{F = G.m1.\frac{m2}{r^2}}$$ -------(1)

Where G is gravitational constant $G = 6.67\ X\ 10^{-11}\ \frac{m^3}{Kg\ S^2}$.

r: the distance between m1 and m2.

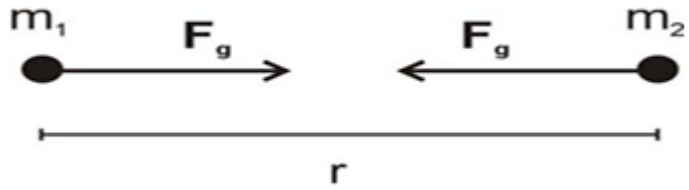

Figure 4: Universal gravitation

The gravitational acceleration acting on a unit mass is not only caused by gravitation, but it is superimposed by the centrifugal acceleration a_c because of earth rotation .

- This centrifugal acceleration is given by the following formula:

$$a_c = \boldsymbol{\omega^2.d} \quad \text{------(2)}$$

- Where: $\boldsymbol{\omega}$ the angular velocity of the earth.
  d perpendicular distance of the unit mass from the rotation axis of earth
- As a result: the centrifugal acceleration becomes maximal at the equator and zero at the poles.

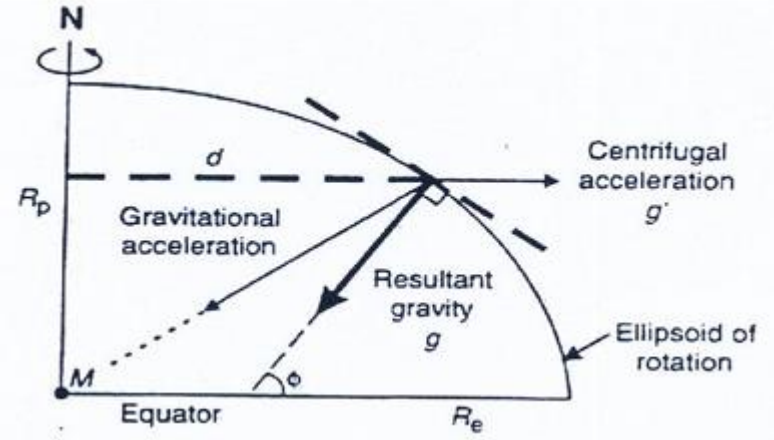

Figure 5: Centrifugal acceleration effect on gravity

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Consequently the resulting gravitational acceleration on the earth surface increases from the equator to the poles. Another factor that strengthens this increase is the earth's flattening.

- In the "SI-units" gravity is given in $\frac{m}{s^2}$ but in geophysics it is given in Gal in honour of Galileo Galilei.

$$1\,mGal = 1.10^{-5}\frac{m}{s2}$$

Gravity is affceted in space and time by the following:

A) Temporel variation: Changes caused by the gravitational attraction of the sun and moon (Tidal affects) and instrument drift (gravimeter use over time).

B) Spatial variation due to latitude and elevation variations in addition to topographic and density of the underlying rocks.

Gravity Survey: Gravity surveys can be can be either land-based or aerial, ship-based (hydrocarbon exploration). On land, the survey is conducted using a very delicate instrument **the gravi-meter**. The collected data is recorded by the gravi-meter then processed by a geophysicist to be presented as gravity anomalies map.

Figure 6: Gravi-meter

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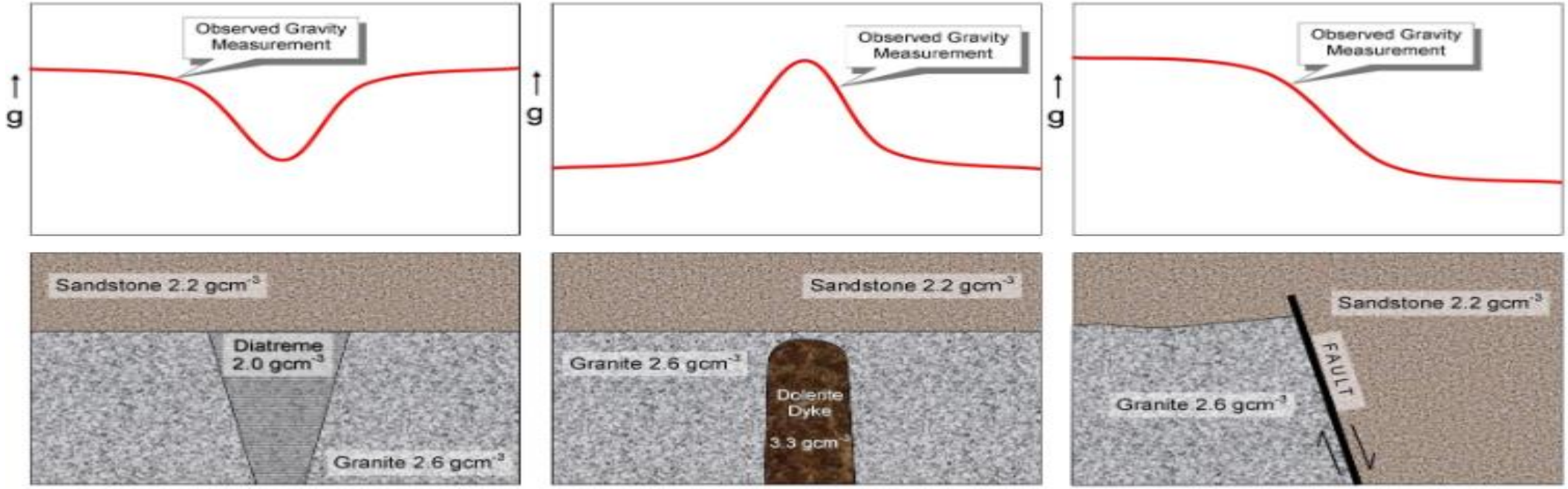
- **Gravity reading:** gravity anomalies have different shapes and sizes. Positive gravity anomalies are produced by regions of higher than average density and vice versa.
- A broad long wavelength anomaly points to the presence of a deeply buried massive body.
- A sharp, short wavelength anomaly indicates a shallow, dense object.



Source: https://www.geologyforinvestors.com/gravity-surveys/ **(7/10/2025)**

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- **Gravity Anomaly #1 – Diatreme (**plug formed when gas filled magma forced its way up through overlying strata). the negative gravity anomaly indicate a reduction in density has occurred due to an increase in porosity of diatreme. Although a sandstone layer covers the diatreme it is detectable by the gravity survey method because a mass deficit exists.
- **Gravity Anomaly #2 – Dyke** a positive gravity anomaly is recorded in this survey that give a much denser rock than the granite which is a dolerite dyke intruding the granit rock.
- **Gravity Anomaly #3 – Hidden Fault** A positive response occurs over the granite while a negative response occurs over the sandstone. This sharp change in gravity anomaly reading show up a fault action.

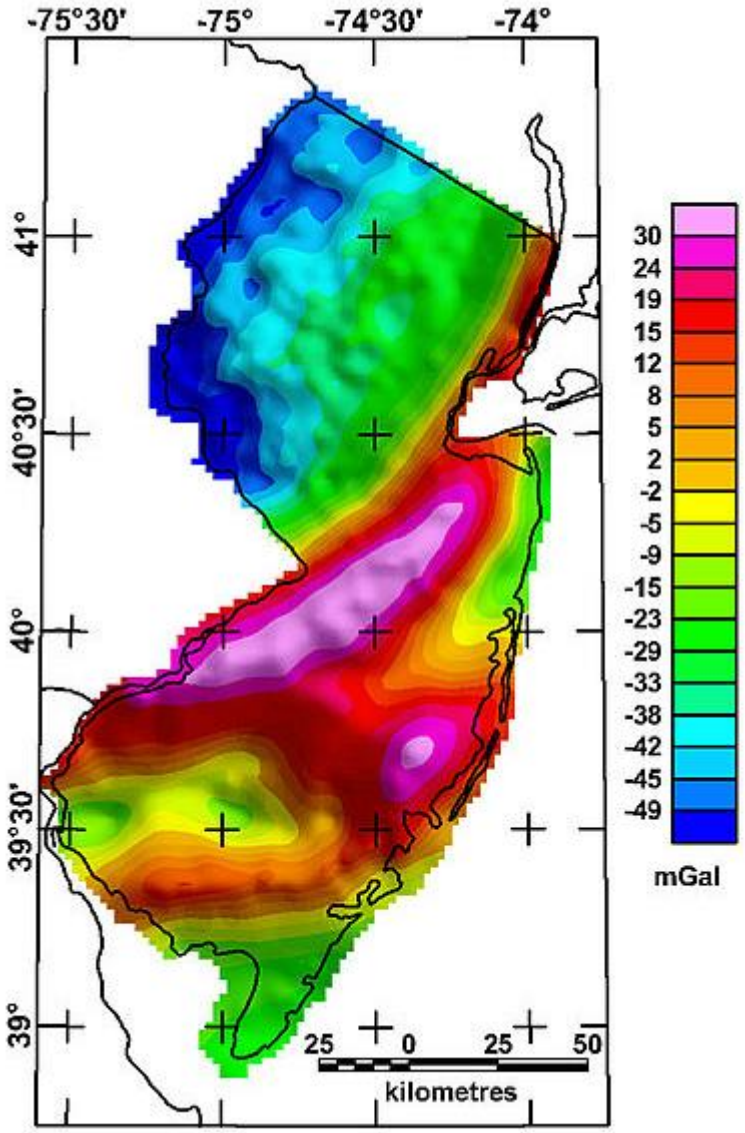

Figure 8: 2D gravity anomaly map

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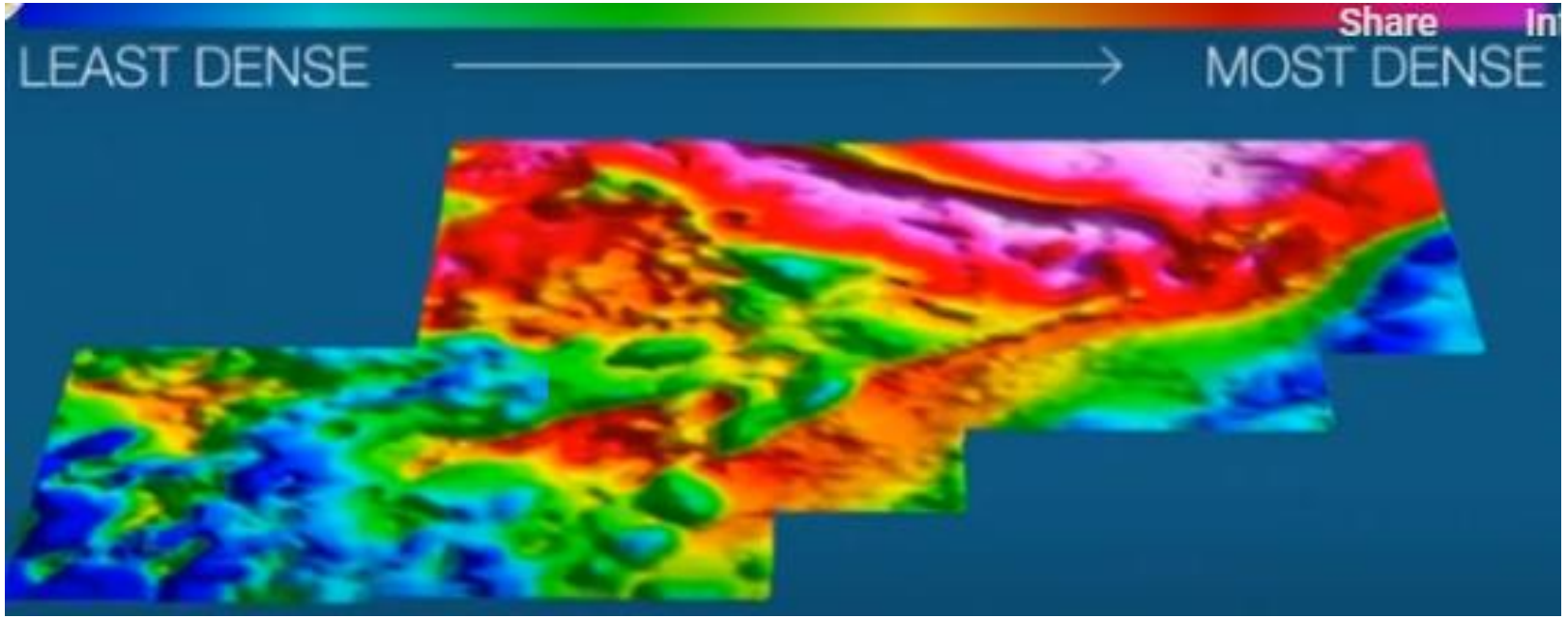

Figure 8: 3D Gravity with scale from low to most dense soil formation

[Gravity Survey video.mp4]

Chap II: Geophysical methods used in Hydrogeology
Gravity

Table 2: Advantages and limitations of gravity methods in hydrogeolog

Advantages	Limitations
Suitable for large scale geological basin	Extremly sensitive to environmental noise such as tides and topography changes
Effective for deep target, directly senses mass/water content	Can not provide information on permeability or the nature of the fluid (Water vs Oil)
Completly passive method no need to inject anything (Electric, chemical, waves)	Slow data acquisition and labor intensive (to much working hours)
When combined with other data (porosity from boreholes), time-lapse microgravity surveys can be used to calculate aquifer recharge and pumping effects	Poor resolution (V or Hz); poor for imaging detailed stratigraphy within an aquifer.

Conclusion: as already explained before Gravity is a secondary method in hydrogeology but when it is integrated within other methods (borehole, seismic, time laps microgravity) it became more powerful.