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Application of Gravity Method in Fault Path Detection

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Abstract: A fault is a crack in the Earth's crust. Typically, faults are associated with, or form, the boundaries between Earth's tectonic plates. *Faults are important in mineral and petroleum exploration and hydro geological studies.* In this paper, We use gravity method in fault path detection. Considering two-dimensional view of the faults, three models considered .with mat lab programming we generate gravity, horizontal and vertical gradient charts due to these models. Some results of this discussion: 1) around a vertical fault, there is a minimum and maximum. The position of the fault is the middle between minimum and maximum.2) Used to find edges of anomalies for shallow bodies with vertical edges the max horizontal gradient will occur over the edge.3) Due to a Inclined Faulted and Displaced Horizontal Sheet a)When φ> 90°, which corresponds to a high-angle reverse fault. The excess mass in the overlap zone generates a pronounced maximum b) When φ< 90°, which corresponds to a high-angle normal fault. The mass deficiency in the sheet gap zone creases a distinct minimum.4) Both Gravity and Vertical Gravity Gradient Are Zero Over, And Ant symmetric About, The Fault Trace.5) It Is Also Difficult To Say Simply That A Gravity Gradiometer Is Better Than A Gravimeter Up To A Certain Depth Without A Knowledge Or Assumption Of The Target Geometry.6) It is shown that a Gradiometer Is better than a Gravimeter In Detecting Short- Wavelength Anomalies. In Other Words, A Gradiometer Can Provide A Better Lateral Resolution Than a Gravimeter.

Key words: Fault, mat lab programming, horizontal and vertical gradient, vertical fault, Inclined Faulted

INTRODUCTION

The gravity method involves measuring the earth's gravitational field at specific locations on the earth's surface to determine the location of subsurface density variations. The gravity method works when buried objects have different masses, which are caused by the object having a greater or lesser density than the surrounding material. However, the earth's gravitational field measured at the earth's surface is affected also by topographic changes, the earth's shape and rotation, and earth tides. These factors must be removed before interpreting gravity data for subsurface features. The final form of the processed gravity data can be used in many types of engineering and environmental problems, including determining the thickness of the surface or near-surface soil layer, changes in water table levels, and the detection of buried tunnels, caves, sinkholes and near-surface faults. Relatively new applications include four-dimensional (4-D) gravity, where temporal variations of the gravitational field can used to determine variations in the water table (Mokkapati 1995;Hare *et al*., 1999) and changing of subsidence levels in sinkholes (Rybakov *et al*., 2001).

The gravity method can be a relatively easy geophysical technique to perform and interpret. The technique has good depth penetration when compared to ground penetrating radar, high frequency electromagnetic and DC-resistivity techniques and is not affected by the high conductivity values of near-surface clay rich soils. Additionally, lateral boundaries of subsurface features can be easily obtained especially through the measurement of the derivatives of the gravitational field.

The main drawback is the ambiguity of the interpretation of the anomalies. This means that a given gravity anomaly can be caused by numerous source bodies. An accurate determination of the source usually requires outside geophysical or geological information.

The use of the gravity data is relatively straightforward as can be seen in the following summary of the fundamentals of the gravity method as applied to engineering and environmental studies including overviews of the theory, data collection, processing, and interpretation.

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Lists the main uses of the gravity method in engineering and environmental studies are shown in table 1.

Table 1. Environmental and engineering applications of the gravity method

- Detection of subsurface voids including caves, adits, mine shafts
- Determining the amount of subsidence in surface collapse features over time
- Determination of soil and glacier sediment thickness ,bedrock topography) Location of buried sediment valleys)
- Determination of groundwater volume and changes in water table levels over time in alluvial basins
- Mapping the volume, lateral and vertical extent of landfills Mapping steeply dipping contacts including faults
- Determining the location of unexploded ordinances.

In this paper, We use gravity method in fault path detection. Considering two-dimensional view of the faults, three models considered .with mat lab programming we generate gravity, horizontal and vertical gradient charts due to these models.

1. Gradient of a Scalar:

Gradient Of A Scalar Is Defined As The Maximum Rate Of Change Of Any Scalar Function Along A Particular Direction In A Space Domain. The Gradient Is A Mathematical Operation. It Operates On A Scalar Function Arid Makes It A Vector. So The Gradient Has A Direction. This Direction Coincides With The Direction Of The Maximum Slope Or The Maximum Rate Of Change Of Any Scalar Function.

Let ϕ (X, Y, Z) Be A Scalar Function Of Position In Space Of Coordinate X, Y, Z. If The Coordinates

Are Increased By dx, dy And dz, (Fig. 1) Then

$$\mathbf{d}\phi = \frac{\partial \phi}{\partial x}\mathbf{d}x + \frac{\partial \phi}{\partial y}\mathbf{y}x + \frac{\partial \phi}{\partial z}\mathbf{d}z \qquad (1)$$

*1.*Gradient Of A Scalar

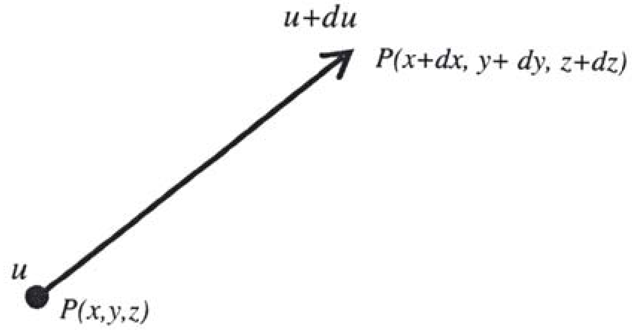


Fig. 1: Change of Position of a Scalar Function in a Field

If We Assume the Displacement to Be dr, Then

$$\vec{\mathbf{dr}} = \vec{\mathbf{i}}\,\mathbf{d}x + \vec{\mathbf{j}}\mathbf{d}y + \vec{\mathbf{k}}\,\mathbf{d}z \qquad (2)$$

In Vector Algebra, the Differential Operator ∇ Is Defined As

$$\vec{\nabla} = \vec{\mathbf{i}}\frac{\partial}{\partial x} + \vec{\mathbf{j}}\frac{\partial}{\partial y} + \vec{\mathbf{k}}\frac{\partial}{\partial z} \qquad (3)$$

In addition, The Gradient of a Scalar Function Is Defined As

$$\mathbf{Grad}\phi = \vec{\mathbf{i}}\frac{\partial\phi}{\partial X} + \vec{j}\frac{\partial\phi}{\partial y} + \vec{k}\frac{\partial\phi}{\partial z} \quad (4)$$

The Operator ∇ Also When Operates On A Scalar Function Y, Z) ,We Get

$$\vec{\nabla}\phi = \vec{\mathbf{i}}\frac{\partial\phi}{\partial X} + \vec{j}\frac{\partial\phi}{\partial y} + \vec{k}\frac{\partial\phi}{\partial z} \quad (5)$$

Where $\frac{\partial\phi}{\partial X}, \frac{\partial\phi}{\partial y}$ and $\frac{\partial\phi}{\partial z}$ are The Rates Of Change Of A Scalar Function Along Three Mutually Perpendicular Directions. We Can Now Write

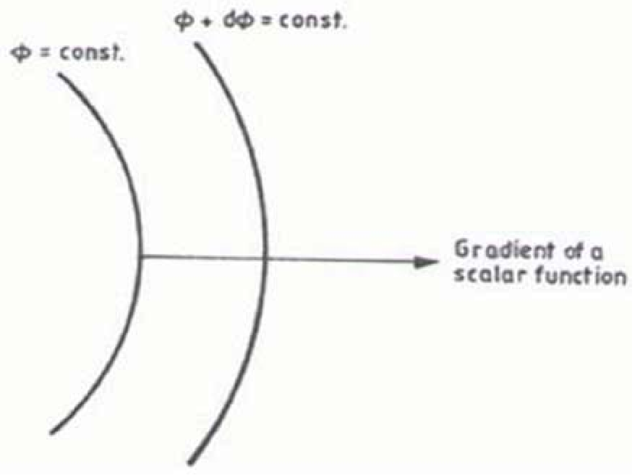


Fig. 2: Gradient Of scalar Function,

$$\mathbf{d}\phi = \left(\vec{i}\frac{\partial\phi}{\partial y} + \vec{j}\frac{\partial\phi}{\partial y} + \vec{k}\frac{\partial\phi}{\partial z}\right)(\vec{i}\ dx + \vec{j}dy + \vec{k}dz) = (\nabla\phi).\mathbf{dr} \quad (6)$$

Where dr Is Along The Normal of The Scalar Function ϕ (X, Y, Z) = Constant. We Get The Gradient of A Scalar Function As $\mathbf{d}\phi = (\nabla\phi).\mathbf{d}r = 0$, When The Vector $\nabla\phi$ Is Normal To The Surface ϕ =Constant. It Is Also Termed As Grad ϕ or The Gradient of ϕ (Fig. 2).

2.1. Fault:

A fault is a crack in the Earth's crust. Typically, faults are associated with, or form, the boundaries between Earth's tectonic plates. In an active fault, the pieces of the Earth's crust along a fault move over time. The moving rocks can cause earthquakes. Inactive faults had movement along them at one time, but no longer move. The type of motion along a fault depends on the type of fault. The main types of faults are described below.

Normal dip-slip fault

- Normal faults happen in areas where the rocks are pulling apart (tensile forces) so that the rocky crust of an area is able to take up more space.
- The rock on one side of the fault is moved down relative to the rock on the other side of the fault.
- Normal faults will not make an overhanging rock ledge.

- In a normal fault it is likely that you could walk on an exposed area of the fault.

Reverse dip-slip fault

- Reverse faults happen in areas where the rocks are pushed together (compression forces) so that the rocky crust of an area must take up less space.
- The rock on one side of the fault is pushed up relative to rock on the other side.
- In a reverse fault the exposed area of the fault is often an overhang. Thus you could not walk on it.
- Thrust faults are a special type of reverse fault. They happen when the fault angle is very low.

Transform (strike-slip) faults

- The movement along a strike slip fault is horizontal with the block of rock on one side of the fault moving in one direction and the block of rock along the other side of the fault moving in the other direction.
- Strike slip faults do not make cliffs or fault scarps because the blocks of rock are not moving up or down relative to each other.

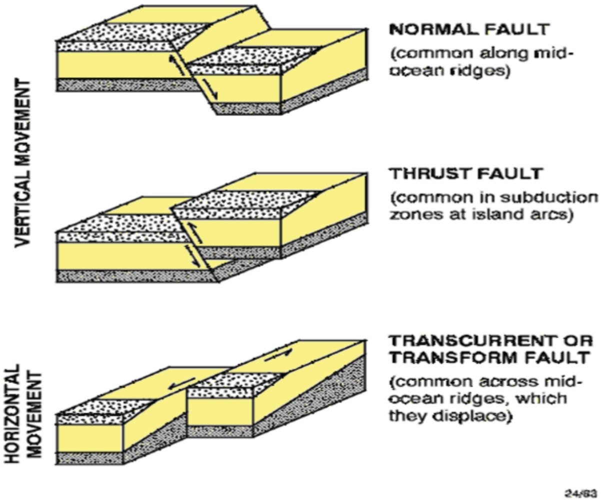


Fig. 3: Main types of faults.

However, faults are usually more complex than these diagrams suggest. Often movement along a fault is not entirely of one variety. A fault may be some combination of strike slip and normal or reverse faulting. To further complicate these conditions, faults are often not just one orderly break in the rock, but are instead a number of fractures caused by similar motions of the Earth's crust. These clusters of faults are called fault zones.

2.2. Importance of Fault Location:

Faults are important in mineral and petroleum exploration as they may either seal or act as a barrier to fluid flow (e.g., due to smearing of mud or shale along them), or may be important conduits for the migration of petroleum or mineralizing fluids. Many mineral deposits are fault and fracture controlled. Recognition of faults is also important in hydro geological studies as fracturing along faults may produce hard-rock aquifers.

2.3.Horizontal Slab: Model for a Vertical Fault:

The Gravity Anomaly across a Vertical Fault Increases Progressively To a Maximum Value over the Uplifted Side (Fig. 4a). This Is Interpreted As Due To The Upward Displacement Of Denser Material, Which Causes A Horizontal Density Contrast Across A Vertical Step Of Height (Fig. 4b). The Faulted Block Can Be Modeled As A Semi-Infinite Horizontal Slab Of Height H And Density Contrast Δp With Its Mid-Point At Depth Z_0.

Let The Slab Be Divided Into Thin, Semi-Infinite Horizontal Sheets Of Thickness dz At Depth Z. The Gravity Anomaly Of A Given Sheet Is Given By Eq. (7) With dz For The Thickness T. The Anomaly Of The Semi-Infinite Slab Is Found

$$\Delta g_z = 2\pi G\Delta pt\left[\frac{\pi}{2} + \tan^{-1}(\frac{x}{z_0})\right] \tag{7}$$

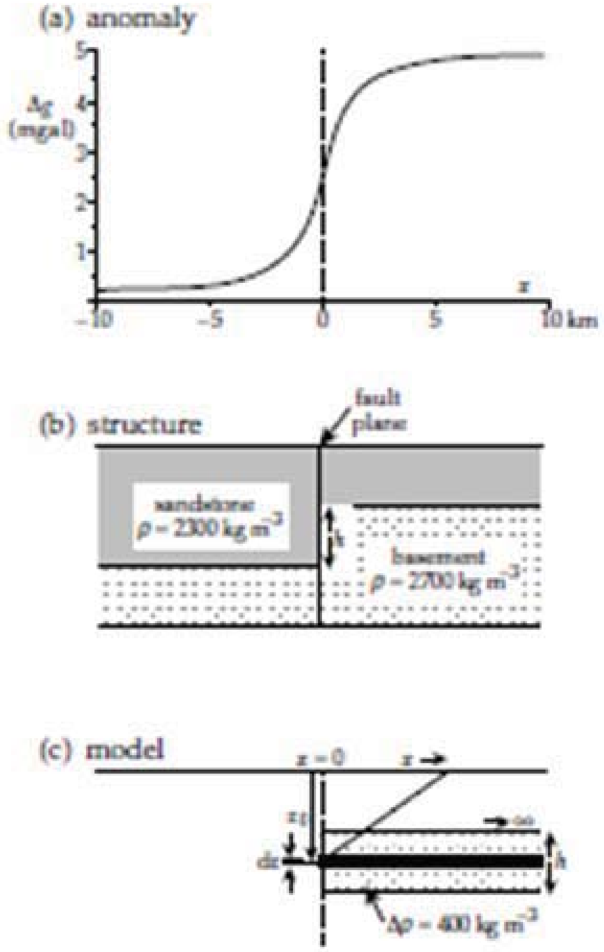


Fig. 4:

Fig. 5 (a) The Gravity Anomaly Across A Vertical Fault; (b) Structure Of A Fault With Vertical Displacement h, And (c) Model Of The Anomalous Body As A Semi-Infinite Horizontal Slab Of Height h.

By Integrating With Respect To Z Over The Thickness Of The Slab; The Limits Of Integration Are Z-(H/2) And Z+(H/2). After Slightly Rearranging Terms This Gives

$$\Delta g_z = 2\pi G\Delta pt\left[\frac{\pi}{2} + \frac{1^{z_0+h/2}}{h_{z_0-h/2}}\tan^{-1}(\frac{x}{z})\mathbf{dz}\right] \tag{8}$$

The Second Expression In The Brackets Is The Mean Value Of The Angle $\tan^{-1}$ (X/Z) Averaged Over The Height Of The Fault Step. This Can Be Replaced To A Good Approximation By The Value At The Mid-Point Of The Step, At Depth Z_0. This Gives

$$\Delta g_z = 2\pi G\Delta pt\left[\frac{\pi}{2} + \tan^{-1}(\frac{x}{z_0})\right] \tag{9}$$

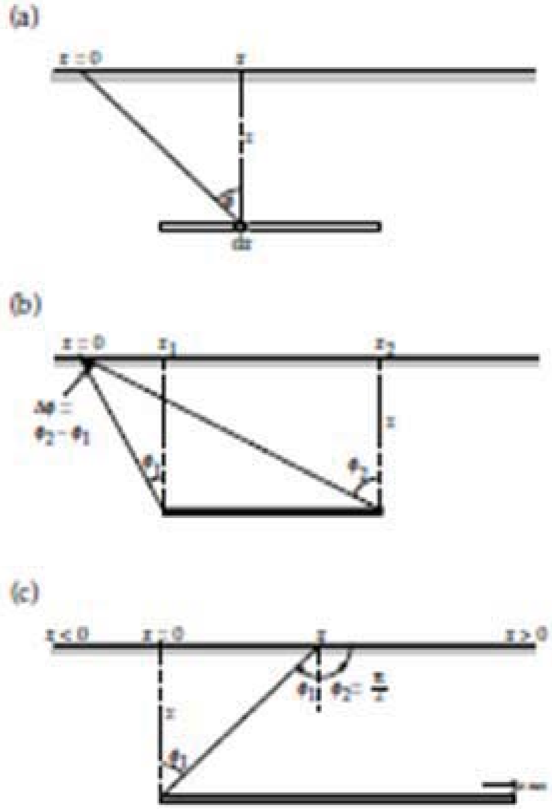
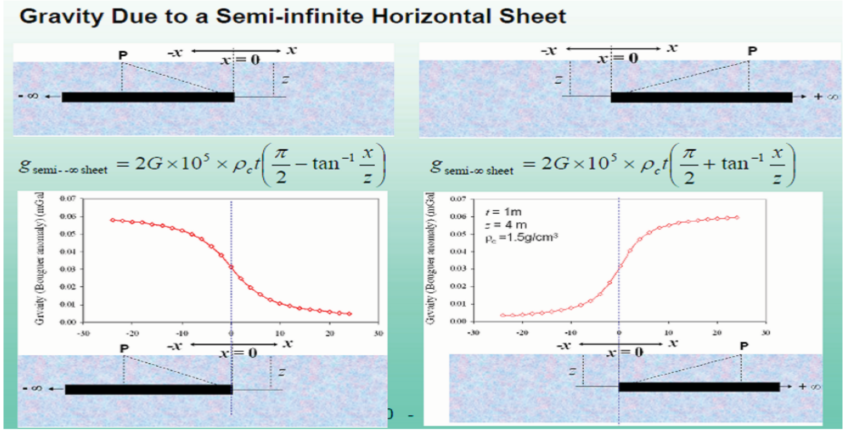


Fig. 5:

Comparison Of This Expression With Eq. (9) Shows That The Anomaly Of The Vertical Fault (Or A Semi-Infinite Thick Horizontal Slab) Is The Same As If The Anomalous Slab Were Replaced By A Thin Sheet Of Thickness h At The Midpoint Of The Vertical Step. Equation (9) Is Called The "Thin-Sheet Approximation." It Is Accurate To About 2% Provided That $Z_0 > 2h$. In summary the following models can be considered:

1.Gravity Due to a Semi-infinite Horizontal Sheet

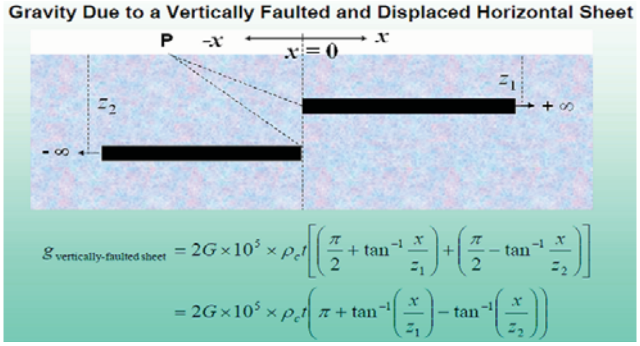

Gravity Due to a Semi-infinite Horizontal Sheet

$$g_{\text{semi-}-\infty\text{ sheet}} = 2G\times10^5\times\rho_c t\left(\frac{\pi}{2}-\tan^{-1}\frac{x}{z}\right)$$

$$g_{\text{semi-}\infty\text{ sheet}} = 2G\times10^5\times\rho_c t\left(\frac{\pi}{2}+\tan^{-1}\frac{x}{z}\right)$$

Fig. 6:

2. Gravity Due to a Vertically Faulted and Displaced Horizontal Sheet



Gravity Due to a Vertically Faulted and Displaced Horizontal Sheet

$$g_{\text{vertically-faulted sheet}} = 2G\times10^5 \times \rho_c t\left[\left(\frac{\pi}{2}+\tan^{-1}\frac{x}{z_1}\right)+\left(\frac{\pi}{2}-\tan^{-1}\frac{x}{z_2}\right)\right]$$

$$= 2G\times10^5 \times \rho_c t\left(\pi+\tan^{-1}\left(\frac{x}{z_1}\right)-\tan^{-1}\left(\frac{x}{z_2}\right)\right)$$

Fig. 7:

3. Gravity Due to a Inclined Faulted and Displaced Horizontal Sheet

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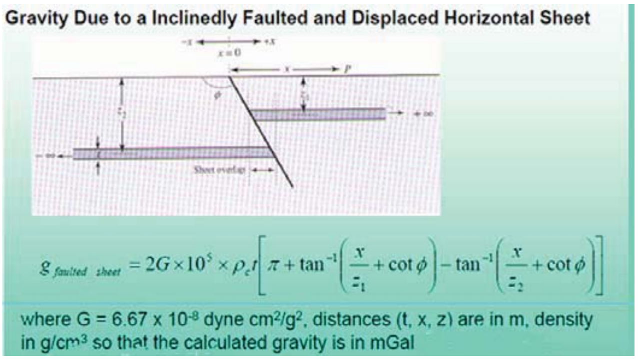

Gravity Due to a Inclinedly Faulted and Displaced Horizontal Sheet

$$g_{\textit{faulted sheet}} = 2G\times10^5 \times \rho_c t\left[\pi+\tan^{-1}\left(\frac{x}{z_1}+\cot\phi\right)-\tan^{-1}\left(\frac{x}{z_2}+\cot\phi\right)\right]$$

where G = 6.67 x 10^{-8} dyne cm^2/g^2, distances (t, x, z) are in m, density in g/cm^3 so that the calculated gravity is in mGal

Fig. 8:

Discussion:

1) Results from above example indicate that around a vertical fault, there is a minimum and maximum•The position of the fault is the middle between minimum and maximum, i.e., xfault= (xmin+ xmax)/2

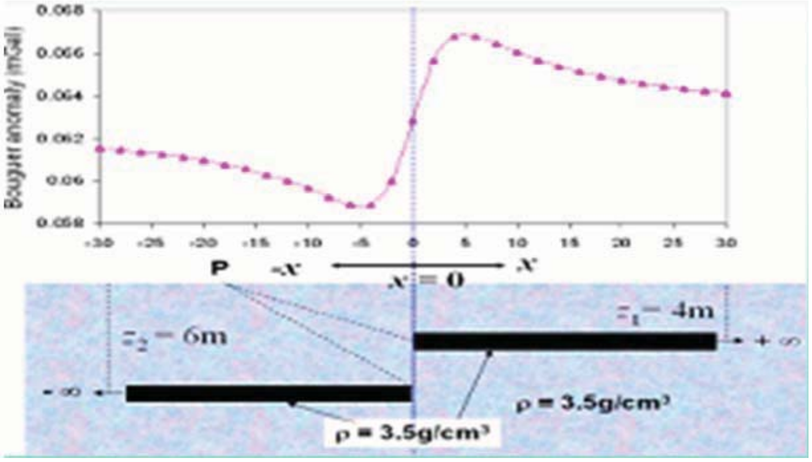

Fig. 9:

2) Used to find edges of anomalies for shallow bodies with vertical edges the max horizontal gradient will occur over the edge.

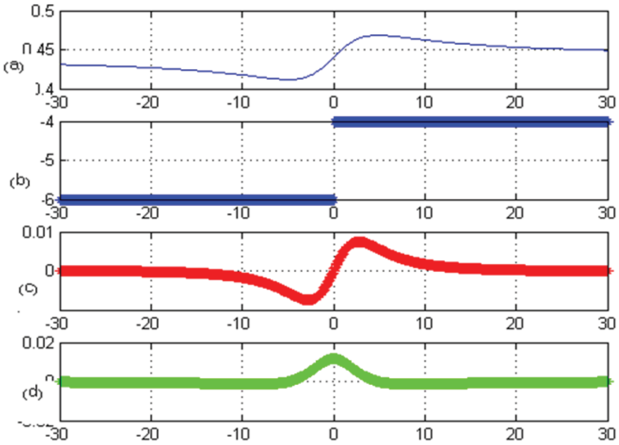

Fig. 10: a)gravity anomaly)fault model c)vertical gradient d)horizontal gradient

3) When φ> 90°, which corresponds to a high-angle reverse fault. The excess mass in the overlap zone generates a pronounced maximum

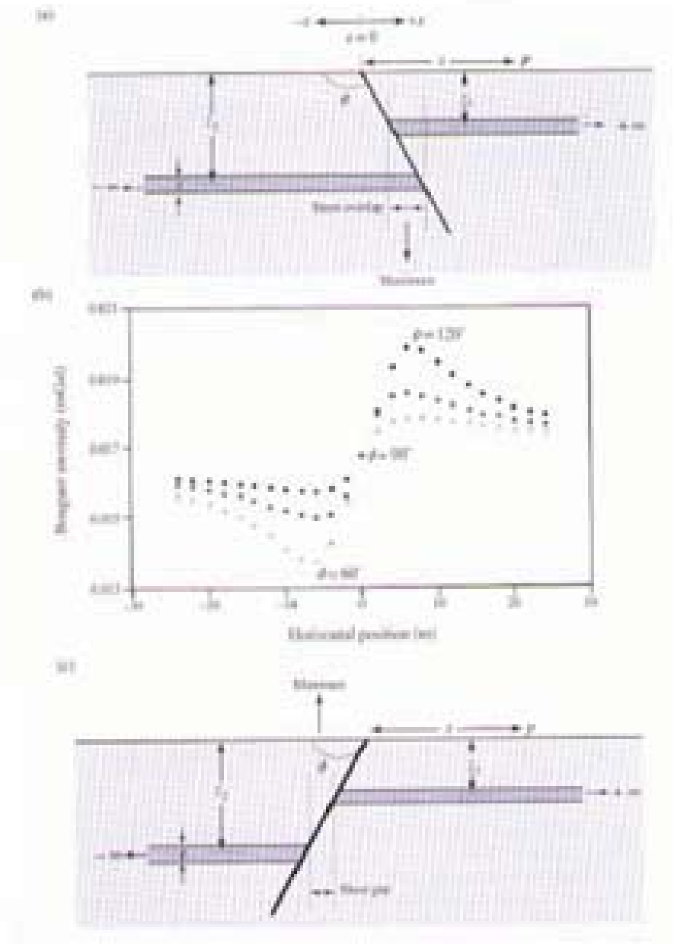

Fig. 11:

4) When φ< 90°, which corresponds to a high-angle normal fault. The mass deficiency in the sheet gap zone creases a distinct minimum

4) Typical Gravity And Vertical Gravity Gradient Responses Over Such A Fault Are Displayed In Figure 12. Both Gravity and Vertical Gravity Gradient Are Zero Over, And Ant symmetric About, The Fault Trace.

5) For a Positive Density Contrast, the Elongated Maximum is on the Up thrown Side and the Elongated Minimum on the Down- Thrown Side. Figure 6 Shows Results For Relative Magnitudes of Gravity and Vertical Gravity Gradient Data Equal To Various Accuracies of A Gravimeter and A Gradiometer. The Density Contrast between the Faulted Bed and Its Over- and under laid Sediments Is Assumed to Be a Constant 0.1-gram/cm3.

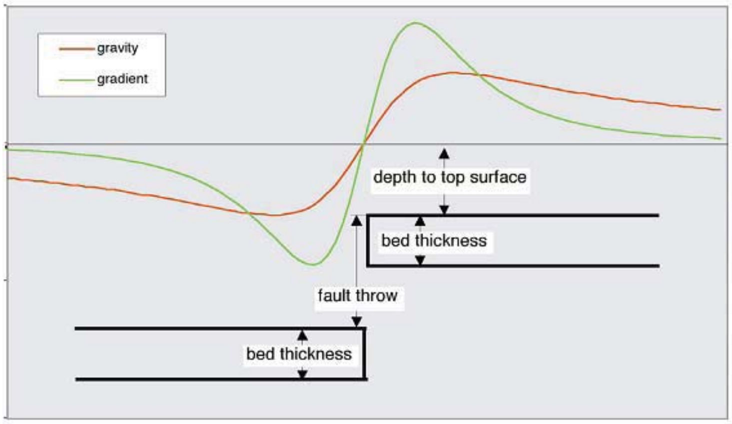

Fig. 12:

6) Figure 13 Demonstrates That For A Faulted Bed Thickness Of 500 M, 0.1 And 0.2 Mgal Accuracy Gravity Data And 0.5 And 1 E Accuracy Vertical Gravity Data Can Resolve a Fault Throw Of 340, 750, 330, And 780 M, Respectively, At a Depth Of 2000 M, And A Throw Of 500,1200, 750, 2000M, Respectively, At A Depth Of 3000 M. At 0.5 E Accuracy,

Vertical Gravity Gradient Data Are Better Than 0.1 Mgal Accuracy Gravity Data When The Fault Is Shallower Than 2100 M , 1 Eötvös And 2 Eötvös Better Than 0.2 Mgal up To A Depth Of 1900 M And 1000 M Or So, Respectively.

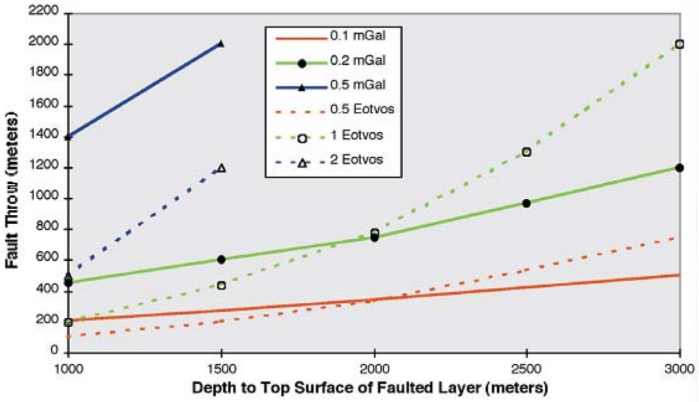

Fig. 13:

7) Figure 14 Indicates That 0.5-Mgal Accuracy Gravity Data Are Approaching 2 Eötvös Accuracy Vertical Gravity Gradient Data, 0.2 Mgal Compare To 1 Eötvös, And 0.1 Mgai To 0.5 Eötvös Extremely Well, When The Faulted Bed Is 2000 M Deep And 500-1500 Rn Thick. The Thicker The Faulted Bed, The Smaller Fault Throw A Given Accuracy Gravity Or Vertical Gravity Data Set Can Resolve. When The Faulted Bed Thickness Is 1000 M, 0.1 And 0.2 Mgal Accuracy Gravity Data And 0.5 And 1 Eötvös Accuracy Vertical Gravity Data Can Detect A Fault Throw Of 180, 390, 190, And 410 M, Respectively.

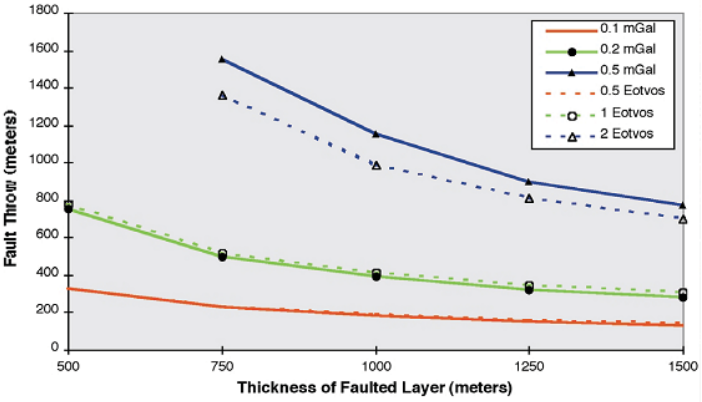

Fig. 14:

8) Can Gravity Really Detect A 200-Rn Fault Throw At 3000 M Depth? Yes, If The Minimum Resolvable Gravity Anomaly Of A Gravity Survey Is 0.1 Mgal, The Faulted Sedimentary Layer Is 500 M Or Larger In Thickness, And The Density Contrast Is 0.2 G/Cm3 Or Greater.
9) It Is Also Difficult To Say Simply That A Gravity Gradiometer Is Better Than A Gravimeter Up To A Certain Depth Without A Knowledge Or Assumption Of The Target Geometry. For Example, For Detecting A Sphere like Body , 2 Eötvös Accuracy Vertical Gravity Gradient Data Are Better Than 0.5-Mgal Accuracy Gravity Data Up To 5000 Rn Deep.
10) In Terms Of Currently Available Techniques, Gravity Gradiometry Is Definitely Superior To Gravimetry In Detecting A Target Of Hundreds Of Meters Deep But Hardly Deeper Than, Say, 3000 M.

Conclusions:

Some results of this paper: 1) around a vertical fault, there is a minimum and maximum. The position of the fault is the middle between minimum and maximum.2) Used to find edges of anomalies for shallow bodies with vertical edges the max horizontal gradient will occur over the edge.3) Due to a Inclined Faulted and Displaced Horizontal Sheet a)When φ> 90°, which corresponds to a high-angle reverse fault. The excess mass in the overlap zone generates a pronounced maximum b) When φ< 90°, which corresponds to a high-angle normal fault. The mass deficiency in the sheet gap zone creases a distinct minimum.4) Both Gravity and Vertical Gravity Gradient Are Zero Over, And Ant symmetric About, The Fault Trace.5) It Is Also Difficult To Say Simply That A Gravity Gradiometer Is Better Than A Gravimeter Up To A Certain Depth Without A Knowledge Or Assumption Of The Target Geometry.6) It is shown that a Gradiometer Is better than a Gravimeter In Detecting Short- Wavelength Anomalies. In Other Words, A Gradiometer Can Provide A Better Lateral Resolution Than a Gravimeter.

7) In Other Words, A Gradiometer Can Provide A Better Lateral Resolution Than a Gravimeter. Similar to the Vertical Resolution Comparison, The Lateral Resolution Comparison between a Gradiometer and a Gravimeter Might be Quantitatively Made. For Example, It Can Be Demonstrated That Vertical Gravity Gradient Data May Exhibit Two Separate Extreme Over Two Bodies When Gravity Does Not. 8) It Is Also Widely Known That The Magnitude Maxima Of The Horizontal Gravity Gradient Are Directly Over Vertical Or Near-Vertical Boundaries Of Structures, While Gravity Interprets These Boundaries Roughly And Qualitatively.9)in summery Gravity is very sensitive to vertical geologic contact , The vertical gradient is particularly sensitive to edges and Faults generate strong gradients.

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