9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-385

# Gravity Gradiometry: Potent Potential Field Method

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***Keywords**: Gravity, Gravimeter, Density, Gradiometer*

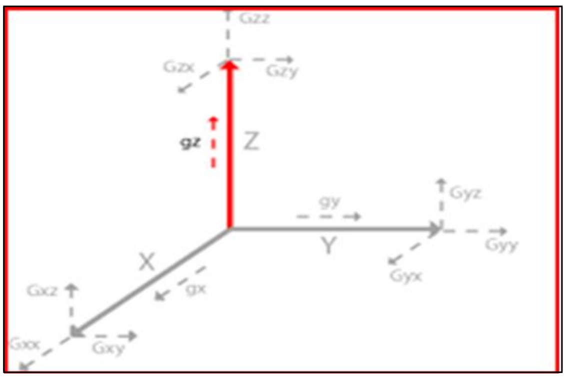
## Introduction

Density is the most diagnostic physical property of an economic mineral deposit, and is also fundamental to oil and gas exploration. To date, density has been the most difficult property to measure and infer. In view of this, gravity survey was essentially a reconnaissance tool in E&P industry. During the last decade, there has been significant development in this field, particularly, w ith the advent of GPS and gravity gradiometer survey. In conventional gravity survey, earth's gravity acceleration is measured using gravimeter whereas in gravity gradiometry survey, the gravity gradient or how the gravitational acceleration changes over distance (or in some cases time) is measured. In essence, both techniques measure the variations in the Earth's gravity field. The gravity field varies precisely from one location to another depending on the surrounding mass (and density) distribution. Hence if the gravity field is measured accurately enough it can yield information on the density of local rocks which can be valuable information in hydrocarbon exploration.

The Eotvos Torsion Balance (1920) has been ignored for Geophysical prospecting in oil industry due to its clumsy and lengthy observation sessions. It is also very sensitive to small pebbles near the point of observation which made necessary to scrape up the area for several meters before measurements. The desire to perform gravity surveys over large area full of terrain which is logistically very difficult and not accessible by veh icles such as thick forest, swamps, mountains, highly undulating terrains, thickly populated areas etc., and need to accomplish these surveys with a minimum expenditure of time and money led to the several schemes of Airborne Gravimetry. Further, gravity measurements obtained by a "moving base" gravimeter are subject to spurious results due to uncertainties in the position and velocity of the vehicle. The Gradiometers are being developed which can be incorporated into moving base system capable of gravity surveys over large areas with minimum expenditure of time.

## Gravity Gradiometry

Gravity gradiometry is the study and measurement of variations in the acceleration caused by gravity. The gravity gradient is the spatial rate of change of gravitational acceleration. It is also adopted in oil, gas and mining companies to measure the density of the subsurface, effectively the rate of change of rock properties. The conventional gravity survey records a single component of the gravitational force, usually in a vertical plane, whereas gradiometry measures the derivative of all three components in all three directions.

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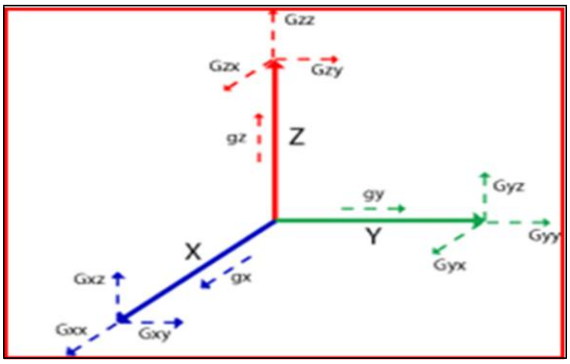
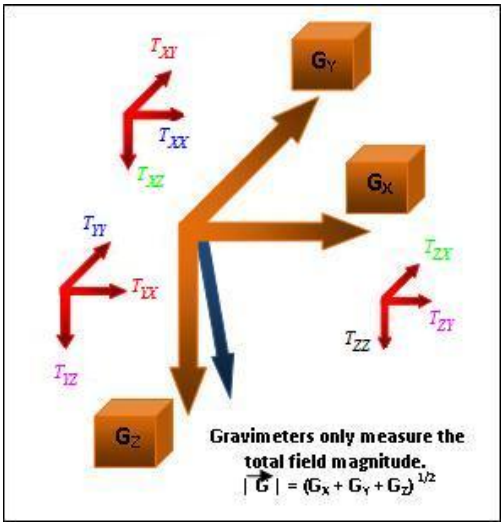



Fig-1 : Component measured by Gravimeter & Gradiometer

### Principle of Gravity Gradiometry

The conventional gravity survey records a single component of the three-component gravitational force, usually in the vertical plane; Full Tensor Gravity Gradiometry measures the derivative of all three components in all three directions (Fig.1). The method measures the variation of the vertical component of the gravitational force in the vertical direction and in two horizontal directions and, similarly, it measures the variation of the horizontal components of gravity in all three directions while Gravimeters only measure the total field magnitude. Gravity is a vector quantity which has both magnitude and a direction. Conventional gravimeters only measure the magnitude at one location whereas the Full Tensor Gravity gradiometry measures the variation of three vector components in each of the three primary directions, thus producing a nine component tensor $T_{I,J}$ . The Tensor is Laplacian and hence the sum of the diagonal components is equal to zero. Opposite sides of the diagonal are equivalent, as it is indicated by like colours (Fig.2) whereas only five of the nine tensor components $\left(T_{XX}, T_{XY}, T_{XZ}, T_{YY}, T_{YZ}\right)$ are independent




$$T_{I,J} = \begin{pmatrix} T_{XX} & T_{XY} & T_{XZ} \\ T_{YX} & T_{YY} & T_{YZ} \\ T_{ZX} & T_{ZY} & T_{ZZ} \end{pmatrix}$$

$$T_{XX} + T_{YY} = -T_{ZZ} \; (Laplacian)$$

$$T_{XZ} = T_{ZX}$$

$$T_{XY} = T_{YX}$$

$$T_{YZ} = T_{ZY}$$

Fig-2 : Representation of components of Gradiometers

Additionally, the $T_{ZZ}$ component is also displayed because it most closely relates to the subsurface geology. Gradients are measured in a unit of Eotvos (E) which is equivalent to 0.1 milligal per km.

### Why Gravity Gradiometry

The ability of Gravity Gradiometry to measure spatially independent gravity components has significant advantages over conventional gravity measurements, which records only the vertical component. The components capture unique signature patterns related to specific attributes of target geology that when collectively interpreted enable detailed imagery of the target itself in terms of geometry, composition and depth of burial. The multicomponent measurement also helps to constrain the non-uniqueness of conventional potential fields. An inevitable consequence of the gravity gradient being the derivative of gravity is that there is much more signal power in the shorter wavelength (high frequency) of the gravity gradient signal. This allows for much better resolution of the subsurface geology. Gravity gradiometry is also better suited in moving platforms. The inertial acceleration (motion from a ship / airplane) seen by two (or more) accelerometers required to perform the gradient measurement is not present in gravity gradiometry output, because inertial accelerations are common to both accelerometers and intrinsically rejected. The Gravity measurements assumes that over a sufficiently long period of time the average vertical acceleration of the survey vessels is negligibly small but when the sea-state degrades the only option left is to increase average time which leads to poor resolution and increased noise in the data. This effect reduces the ability of conventional Gravity method to recover high frequencies and hence, for conventional gravity measurement the inertial acceleration is a dominant signal in the output. This is generally corrected knowing the direction and speed of the aircraft using a GPS which is good for long wavelengths, therefore reducing the geological resolution. In turn Gravity gradiometry outputs a high resolution data. Also, the gradiometric data can be acquired much faster with more certainty as compared to conventional Gravity surveys. The gradiometric facilitates the near real time review and interpretation of the data which may be employed to make decisions where more or less survey details are required. Finally, the gradiometric surveys are far less expensive than stand alone gravity surveys.

***Gradient Data Measurement and Processing***

Each of the tensor components responds uniquely to size, shape and thickness of density anomalies and each are employed in the overall interpretation process. However, Tzz, the vertical downward edge tensor component, is the most easily related directly to subsurface geology. Typically, Tzz gradient highs relate to structural highs and the lows to areas of thickening basin sediment.

The technique is applied to the 3D Gradiometric Tzz data to quickly assess the geological complexity of the region i.e. to identify and map the key geological features resolved in the data. A Fast Fourier Transform (FFT) approach is applied to extract frequency slices which are then used to qualitatively assess particular characteristics attributed/related to subsurface geology. Typically, high-frequency anomalies tend to be shallow-sourced while low frequency anomalies arise from depth Estimated depth to source mass is approximately a third to a quarter of the spatial wavelength.

***Gradient Data Interpretation***

The horizontal tensor components Txx, T yy, Txy, Txz & Tyz are commonly used to identify and map lineaments associated with structural and / or stratigraphic changes or target geometry in a survey area. The vertical tensor component, Tzz, is used to estimate depth and predict compositional information related to target geology of the area. However, these components have traditionally been interpreted separately from one another and often run the risk of missing out on key information.

## Advantages of Gravity Gradiometry

***1. Reducing Exploration Risk***

Gradient data can reduce risk by enhancing seismic imaging when the two are integrated within a forward model utilizing depth structure and density data. The 3D model balances mass and thereby provides a quantitative solution for structural configuration and thickness, as well as lateral density variability. Gradient data is also utilized qualitatively to gain valuable insight into key geological features using the full tensor to define multidirectional mass information such as structural and stratigraphic edges and lineaments. A good example of this is frequency filtering, which allows separation of signal from causative geology. This enables discrimination of the igneous high-density features at various depths and so enables interpretation of sub-basalt geology without seismic control.

***2. Better resolution and increased S/N ratio***

Resolution is always significantly better at shallow depths and better or equal at all depths because of calculated

Tzz (an enhanced form of gravity data which effectively integrates the measured gradients). This is achieved via a better-stabilized Gravity Measuring Assembly, or GMA which allows for better compensation of horizontal ship accelerations. The multi-component gradient measurement provides for further noise reduction as compared to gravity alone.

***3. Very Low Noise Interference due to accelerations of Vehicle***

The acceleration of Vehicle carrying Gravimeters cannot be separated from gravity measurements due to which it is assumed that over a sufficiently long period of time the average vertical acceleration of the survey ship will be negligible. These effects reduce the ability to recover higher frequencies of conventional Gravimeters whereas Gravity gradiometer equipment consists of two horizontally positioned gravimeters that are rigidly connected. The two gravimeters experience the same accelerations, earth tides, and latitude effects, etc. The gradient is the difference in the two gravimeter readings divided by the baseline distance between them. More advanced gradiometers consist of four non-coplanar gravimeters; these systems measure the full gravity gradient tensor.

***4. Faster and Cheaper Data Acquisition***

Gradiometric data can be acquired at greater line spacing for equivalent resolution as compared to gravity surveys. Because gradiometric data is less affected by the vertical accelerations, the time required to accomplish the survey is more definite. Gravity surveys are acquired at slower ship speeds due to ship acceleration effects. Due to the potential for increased speed, greater line spacing gradiometric surveys are less expensive than conventional gravity surveys.

***5. Near real-time Data Review and Interpretation***

Rapid data review, interpretation and near real-time processing of the gradient data is possible and this capability can be exercise to make decisions regarding where more or less detailed survey is required, as well as decision can be taken for repetition of noisy or unreliable data. Quick-look capability provides additional certainty in the data and reduces the potential for increased cost.

***6. Reliable Integration with Seismic for Modeling***

The Gravity Gradient data allows 3D mapping of the prospective level with 2D seismic control. For PSDM it can provide an initial accurate model and hence reducing the number of iterations time as well as cost involve in it.

## Gravity Gradiometry in perspective of Oil India Limited (OIL):

Upper Assam falls in one of the most prolific hydrocarbon bearing basins of India. The Upper Assam Basin is a part of Assam-Arakan Basin which encompass foreland, hinterland to thrust in it. First drop of oil is spilled from the mother subsurface and spotted by Geoscientist is sometimes ten decades ago. This is a matured field and most of the production is maintained by IOR/EOR techniques. Some of the areas are highly inaccessible due to large undulations, thick forest, thickly populated areas, swamps etc. due to which proper layout and recovery of data while seismic data Acquisition is quite difficult which leads to challenge for better subsurface imaging. This basin is geologically very complex and hence mapping of subsurface in some areas especially in thrust belt, boulder bed areas is very difficult. Hence, there is an urgent need to discover new hydrocarbon reservoir to sustain in the global cut throat competition.

In context of OIL`s operational area in Upper Assam Basin and considering the fact that thrust belt areas yield poor resolution seismic data, a gravity gradiometry with optimum traverse lines will ensure better understanding of complex geology of the area. Moreover, latest instruments offer low noise, a stable platform, longer endurance and very favorable in quiet / sensitive areas. The earlier Bouguer gravity map of the survey area covering logistically difficult areas of Assam and Arunachal Pradesh shows the defined distinct high and lows in the areas which are related mainly to the basement configuration. The gradiometric survey will help in gathering more information simultaneously, thereby reducing time and will enhance possibility for a better inference of the basin, delineating structures in thrust belts, unexplored areas, **BRB, Mizoram, North**

**Cachar hills** and areas where sudden increase in sedimentary thickness is observed in seismic. The method may be engaged to determine basement fault throws and strike direction or to establish intrasedimentary faults, defining delicate lithologic contacts and improved target delineation through simultaneous inversion and modeling. The potential methods (gravity and magnetic methods) may be implicated to map the sub- surface at a variety of scale. Moreover, gradiometry enables in understanding basement configuration, which will be beneficial in acquiring acreages over PEL areas, open area acreages, and also can immensely support for shale gas studies. Through innovative integration of gravity gradiometry and magnetic data with that of seismic, each measuring different, but related rock parameters, may indoctrinate more robust geological interpretation that may lead to higher rates in discovery. As a result of this we maximize the accuracy of final interpretation and minimize the number of potential targets for seismic survey particularly for such difficult areas. In view of this, it is necessary to cover OIL`s exploration and production areas by gravity gradiometry.

## Conclusion

The days of easy oil are over and we are poignant from big structural traps to very small stratigraphic traps in which the conventional way of exploration may not work efficiently. In the field of Oil & Gas Exploration no science is able to answer all tribulations independently and hence a multidimensional and multidisciplinary approach is requisite in hydrocarbon exploration. In recent year's different techniques such as Gravity Gradiometry, high resolution Magnetic surveys, improved endurance of systems, improved electronics, increased sensitivity and multidisciplinary studies has attributed to add new reserves from the depleting and matured fields. In recent years there is a significant advancement in gravity gradiometer instrumentation and deployment. The gradiometer is fast becoming a widely accepted tool for the resource exploration and hydrocarbon production monitoring. There are number of issues need to be addressed from sensor performance to data resolution. While these challenges might seem daunting, the value offered by Gradiometry looks very strong and future looks bright as new innovation going to yield more results.

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## Acknowledgement

Authors thank to Oil India Ltd . (OIL) for permitting to submit this paper. We acknowledge the support and advice extended by ED (E&D), Oil India Limited.