Integrated approach for frontier basin exploration using seismic and non-seismic methods

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Summary

Presently the consumption of oil and gas in India is 4,159,000 Bbl/day whereas the production rate is 735,000 Bbl/day. With economy and population growth in India, the main drivers for increasing oil and gas demand i.e., 7 to 8 percent every year, we need not merely to increase exploration activities but promising exploration techniques as well. An estimated sedimentary area in India is around 3.14 million square kilometers, which consists of 26 sedimentary basins, out of which Deep water area is approximately 1.35 million square kilometers and 1.79 million square kilometers area is onland and shallow offshore. Among 26 sedimentary basins only 7 are producing and remaining 70 percent of Indian basins are largely unexplored.

To meet the demands of dynamic market and discover new ventures more assertively, an integrated study approach was performed encompassing both seismic and non-seismic methods. Gravity inversion and forward modeling methods were used to delineate the subsurface structures in sparse data conditions in the unexplored frontier basins. These methods were used to define both the intrasedimentary and basement structures, when combined with basin modeling and seismic.

Introduction

Due to enormous development in Geophysical field over the recent years, seismic method has emerged as an indispensable tool for oil and gas exploration for defining and locating geological structures for the accumulation of hydrocarbon. With increasing complexity of the exploration targets and some limitations of seismic method especially in sub-basalt, irregular and unreachable areas etc., integration of non-seismic methods become crucial for sub surface modeling of structures. With this multidisciplinary approach exploration and appraisal wells can be proposed more accurately and with greater chance of success.

The paper presents the results obtained from gravity data where issues like basement delineation and sediment thickness estimation were undertook. Additionally basin architecture, well planning and seismic survey development can be done by combining the seismic and basin modeling prospects with gravity magnetic studies.

Theory and/or Method

Gravity methods are not new in oil and gas exploration. The gravity method was used firstly in oil exploration for locating salt domes in Gulf coast of United States and Mexico. Oil captured by the block faulting in shallow indurated formations have been found with drilling guided by suitable anomalies on gravity map. The gravity method can be supplemented with magnetic method which is used for locating oil & gas on the basis of detection of diagenetic magnetite, triggered by hydrocarbon seepage. The presence of magnetic bodies over oil and gas accumulations is well-known for many producing areas.

Employing 2D seismic data to delineate sub surface information can be deceitful especially in fields having complex geology. Therefore, to contemplate requirement of 3D seismic acquisition in the area or ascertain prospectivity of the area, gravity inversion can be used.

Subsurface layers are predominantly an interface between materials having different acoustic impedance. Ideally all such layers should be visible in seismic section but presence of layers having basalt or clay leads to imaging problems and deprive interpreter of true subsurface image.

Possible solution could be to map density contrast from other methods such as gravity and identify prominent reflectors. Classically, gravity inversion has been carried out for this purpose and has been extensively carried out throughout the world.

The gravity inversion theory (Priezzhev I, 2005) is based on the forward modeling equations in the frequency wave number domain, derived by Parker R.L. (1973), and optimization technique derived by A.I. Kobrunov (1981).

Study Area

For the scope of this paper, we have identified an area from Rockall Basin having gravity data and 2D seismic sections. Challenges in the area is due to presence of basalts of Eocene age that cover much of the Faroes-Shetlands Basins and Rockall Trough, and seismic data quality is generally very poor below the basalt. There are very promising oil and gas field discoveries in the shallower eastern portions of both Rockall and Faroes-Shetlands, but no wells have drilled below the thick basalts down to target depths in the Cretaceous and Jurassic. Here, we have tried gravity inversion to image deeper Mesozoic portion by scrutinizing density contrast.

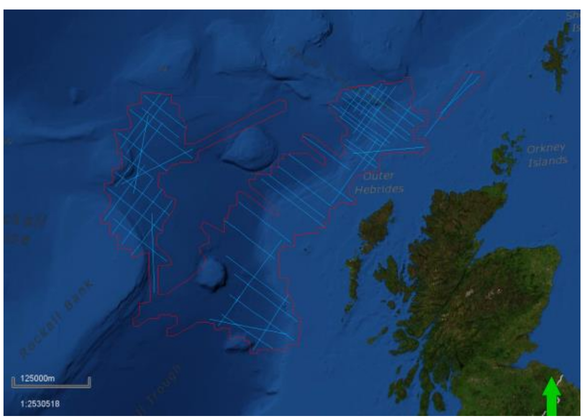


Figure 1: Study area and 2D seismic survey geometry.

We have worked with 88 lines covering around 8896 LKM and 11 wells. Gravity data of around 10237 LKM is also present. Seismic data present in the area fails to reveal deeper horizons due to presence of basalt as shown in Figure 2.

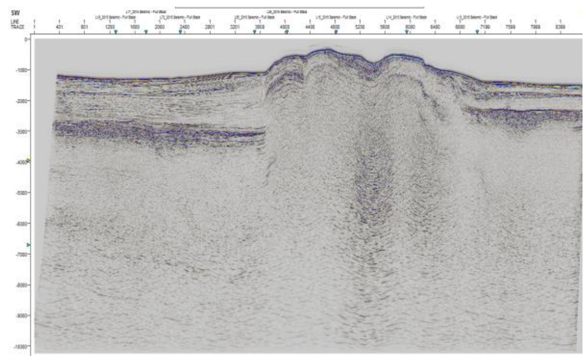


Figure 2: Seismic section fails to reveal reflectors.

Seismic interpretation would be a futile exercise for deeper horizons since imaging quality is abysmal. To aid interpretation we tried gravity inversion that will essentially provide density cube. Since, basement is supposed to be dense as per geology of the area, density cube can unravel deeper geometry.

Gravity inversion module used for this purpose needs a gravity surface and initial density model. We used density logs from 11 wells and populated them using kriging to obtain initial density model. Standard deviation property was also assigned with initial density model that increase as distance increased from the well data. Idea is that obtained result will be very close to the initial density model for the cells with low standard deviation, and during iteration the cells with high standard deviation will be corrected. After running multiple iterations we arrived at density model as shown in Figure 3.

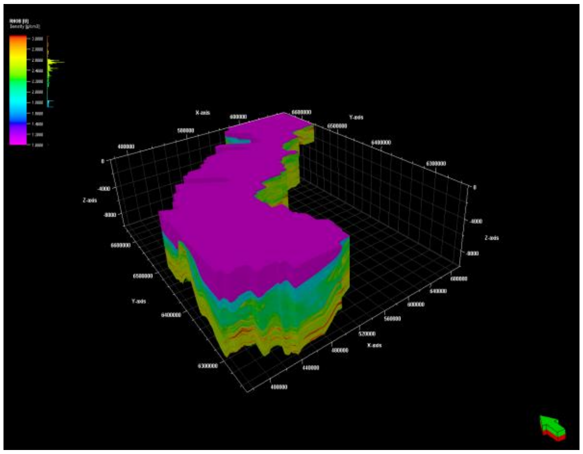
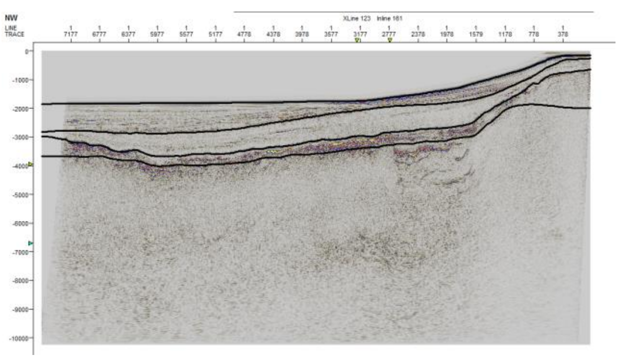


Figure 3: Density model obtained from gravity inversion.

This model comprises of around 2046 sq km area with grid increment of 1 km, and to capture heterogeneity, cell thickness was kept at around 30 m. Since the area is too big, number of cells for this model reached around 23 million cells. In each of the cells initial property was iterated and refined to obtain final result.

On further scrutiny of density model that was obtained, it was observed that density contrast was evident along the seismic section and reflector depth can be easily ascertained as shown in Figure 4.



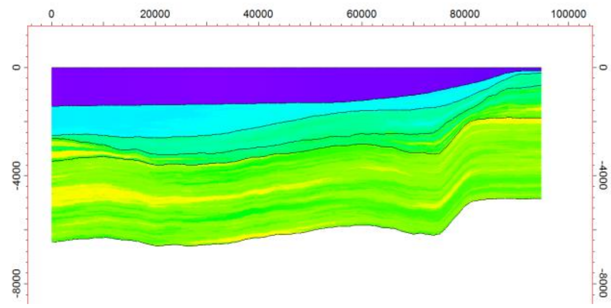


Figure 4: Density model along seismic section.

As evident from the above figure at around 4300 ms density contrast points to a stratigraphic layer that fails to get imaged in seismic section. Geology of the area indicates presence of basement around 4500~4600 m. Hence, it appears that the density model obtained is good enough. To further check quality of output, blind well testing was carried out and difference obtained was around 5% and less implying quality is good enough.

This area lacks 3D seismic so we carried out velocity modeling using VSP logs and TDR associated with these wells. Combining 2D seismic velocity and log data lead us to velocity model and an average velocity cube.

Presence of velocity cube and inverted density cube was further used to compute Acoustic impedance as shown in Figure 5.

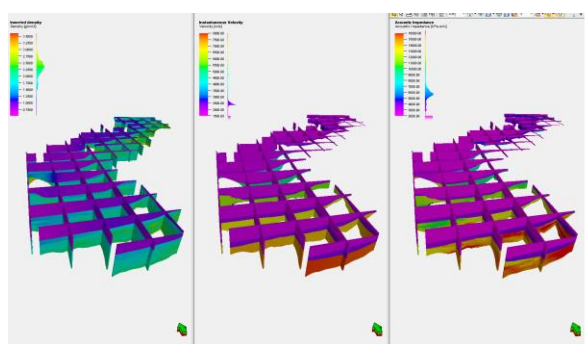


Figure 5: Inverted density, velocity and acoustic impedance cube

Basin modeling simulation tool was used to generate Gravity anomaly maps of Bouger and Free-Air, using the Forward modeling principles.

Different background densities were used with provided range as shown below in Figure 6 for simulation to derive stochastic results and then a comparison of the calculated results with measured gravity anomalies was performed.

	Density [g/cm^3]
Water	1
Sediments	1.8 – 2.6
Crust	2.6 – 2.8
Upper Mantel	2.8 – 3.2

Figure 6: Density ranges used in simulation

After comparing the results the calibration was done and simulation was run again which helped in ascertaining the chance of success (COS).

Conclusions

Gravity inversion techniques can not only be used to solve complex geological issues in Frontier basin but it also reduces the uncertainty of exploration targets in very cost operative way. Exploration and appraisal wells can be sited more accurately and with greater chance of success when gravity, magnetic and seismic methods are combined with basin modeling.

Gravity methods are used to delineate structural highs and lows which represent sedimentary thickness and facies change. Additionally gravity results can be used in geographically unreachable and difficult terrains to define both the intra-sedimentary and basement structure aided in planning new 2D seismic and integrated geological interpretation. Magnetic anomaly information can be integrated with other geophysical and geochemical methods.

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