Role of Passive Seismic Tomography in Hydrocarbon Exploration: A Case Study from Upper Assam Basin

Manish Kumar Singh, Oil India Limited, Duliajan, Assam*

manish_singh@oilindia.in

Keywords

Tomography, fore-land, thrust, hypocenter.

Abstract

Active seismic imaging in complex and in-accessible areas is major challenge to E&P industry. In these scenarios, Passive Seismic Tomography (PST) can provide value addition as a complementary tool in order to improve the sub-surface understanding. PST can contribute immensely both in early as well as later stage of hydrocarbon exploration. This paper showcases a case study from Upper Assam basin for two areas, first which is entirely at early stage of exploration and second which includes both developed as well as less explored (thrust belt) parts. Both the study areas were having their own sets of challenges such as tough logistics, limited data availability, near surface & sub surface challenges. It has been discussed how PST results correlate with other geoscientific datasets and when integrated can provide better insight of subsurface.

Introduction

Upper Assam basin can be tectonically sub-divided in two parts: Assam shelf foreland and the Thrust fold/ Schuppen belt. The geological formations inside the basin primarily comprise of sand and shale alternations of the sediments from Paleocene/Eocene to Recent age. The study areas: Area-1 & 2 falls in Upper Assam basin (Figure-1).

Area-1 is located in the fore-land part of the Upper Assam basin with respect to the Tipi Thrust of the Himalayas towards north. The basement depth is varying from 5 to 6 Km approximately. This area is at early stage of exploration with tough logistics and poor accessibility as it is predominantly a river catchment area. Hence, it becomes less favorable for conducting a full fledge active seismic campaign.

Area-2 is elongated along Naga thrust having producing fields towards the foreland part. However, the thrust part is relatively less explored due to sub-surface complexities, tough logistics and limited accessibility (thick forest area, hilly terrain etc.). The target formation in the study area is of Oligocene-Miocene age with varying depth from 2 to 5 km approximately.

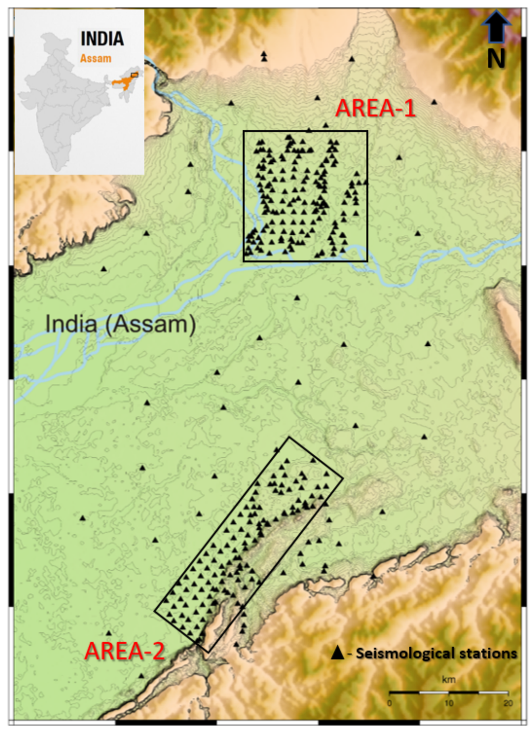

Figure-1: Basemap of study area

Passive Seismic Tomography

Passive Seismic Tomography (PST) is an environment friendly exploration tool that exploits naturally occurring low-magnitude earthquakes (micro-earthquakes) as sources and portable seismological stations as receivers. The objective is to acquire one-way travel-times both for P-waves and for S-waves in order to perform travel-time tomography and create velocity models of the sub-surface (Figure-2 a & b). Detailed analysis and interpretation of velocity models helps to create a 3D subsurface image of the area. Major advantages of PST are its low cost, environment friendly nature and operational convenience as compared to active seismic especially in areas with tough logistics and limited accessibility.

Despite of relatively low resolution of PST as compared to active seismic, it can provide reliable information of overall structural configuration in areas where active seismic data is sparse/low quality.

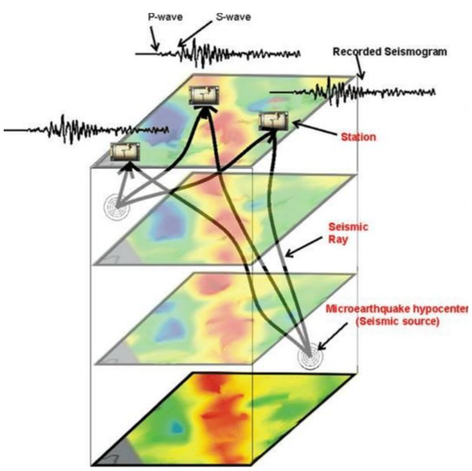

Figure-2 (a): Passive Seismic Tomography (Blom et al., 2019)

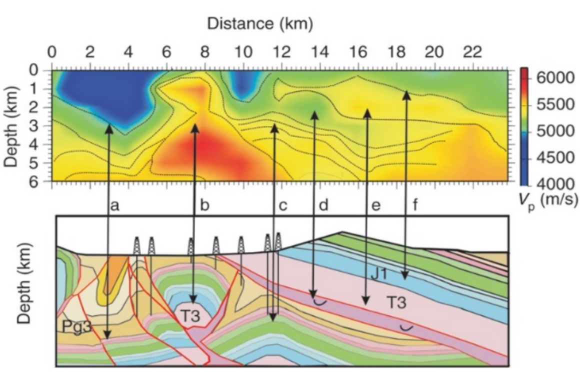

Figure-2 (b): Comparison of geological section with PST derived Vp-velocity (Tselentis et al., 2011)

Acquisition, Processing & Tomography:

During acquisition phase of the PST campaign, a total of 272 numbers of seismological stations were installed covering a total area of around 7000 Km^2 which included both Area-1 & 2. The network geometry is designed for a dense grid of stations with an average interval of 2 Km in both Area-1 (129 stations) & Area-2 (114 stations) covering ~ 500 Km^2 of area. These dense networks were complemented by sparse network of 29 peripheral stations covering the surrounding for better control over earthquakes. Seismicity of the area is very crucial for a successful PST campaign. In order to assess the seismicity, initial feasibility survey was conducted which indicated adequate seismicity in the area. Continuous data is recorded for a period of twelve (12) months. During processing, data conditioning, event picking & data analysis was performed for locating the micro-seismic events (hypocenter location). A total of 231 earthquake events recorded in seismological network from depth upto 60 Km (Figure-3). The location of the events along with the recorded P and S-wave first arrival times have been taken for input for the modeling. Further, travel-time tomography was performed with a grid of 1x1x1 Km^3 in order to derive P-wave velocity (Vp) & Vp/Vs volumes over the study areas.

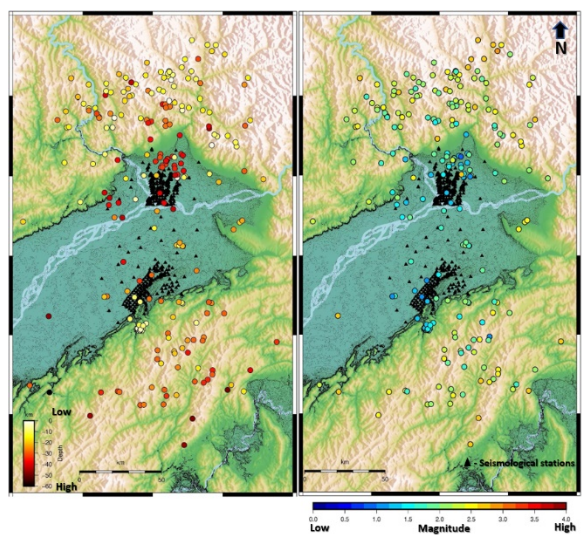

Figure-3: Distribution of 231 earthquake events with Hypocenter depth (left) and Magnitude (right).

Analysis of PST results:

Analysis of PST results was very crucial in order to assess its effectiveness in the area. PST derived Vp distribution at Mean Sea Level (MSL) was superimposed on the regional structural map of Upper

Assam basin in order to correlate the PST results with the major structural features. It was observed that major structural features are well captured by a clear velocity contrast (Figure-4).

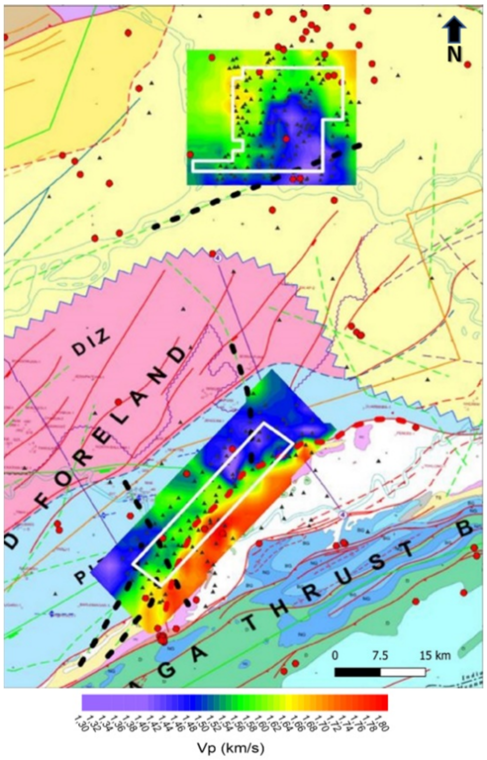

Figure-4: Vp distribution at MSL superimposed on regional structural map

The outputs of PST were analyzed in detail for both the areas in order to assess the value addition in terms of sub-surface understanding. During the process, other available geoscientific datasets were also used for validation/integration in the respective areas.

a) Early Exploratory Stage (Area-1):

Since the area is at initial stage of exploration with no well data, analysis/comparison of the PST results carried-out with available Airborne Gravity Gradiometry & Gravity-Magnetic (AGG & GM) results. AGG-GM survey carried-out as a regional survey over larger area for broader understanding of Basement at basinal scale. However, PST survey was carried-out specifically within the block with relatively finer scale to obtain more detailed features. A comparison of Basement configuration was done between both AGG-GM and PST surveys in order to assess the reliability/effectiveness of PST results. It has been observed that the impression of Basement high in AGG-GM which is broad in nature, has been captured more precisely in PST results (Figure-5). Further, more detailed image of Basement (major & minor highs and lows) could be mapped using PST results in comparison to AGG-GM. A spatial shift was observed in Basement high trend in AGG-GM results in comparison to PST which may be due to difference in survey scale of both the surveys.

This indicates the reliability and effectiveness of PST results in the area. Subsequently, PST results were utilized for better understanding of Basement configuration along with major structural features in Oligocene & other formations in order to narrow down the prospective areas (Figure-6).

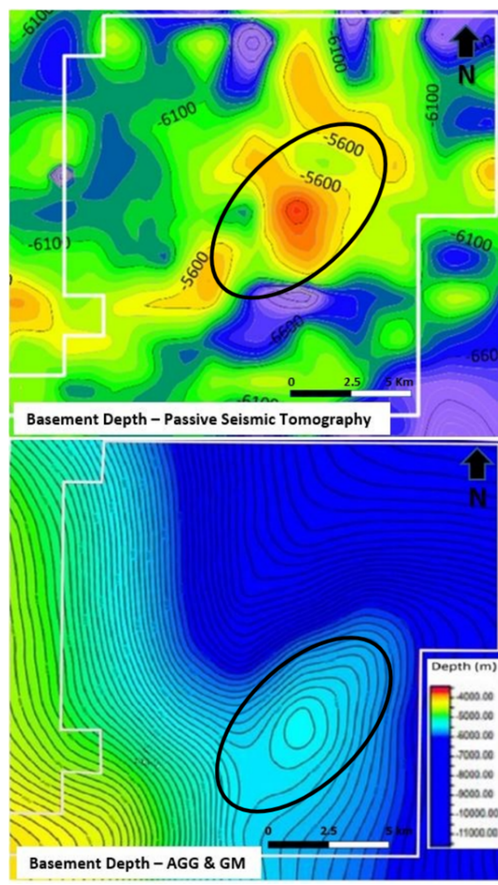

Figure-5: Basement configuration: PST vs AGG-GM

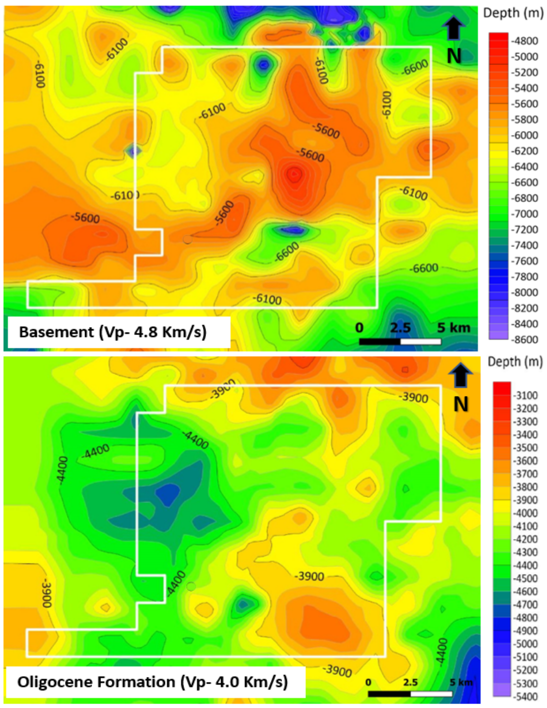

Figure-6: Structural configuration of Basement & Oligocene formation based on PST-Vp-volume

So, in this area PST provided higher confidence on prominent structures more prone to hydrocarbon accumulations which eventually can help in more focused exploration strategy.

b) Partially at Development Stage (Area-2):

This area partially falls on foreland part with remaining part on thrust part of the basin. The foreland part of the area is at development stage having producing fields from Oligocene & Miocene formations with adequate geo-scientific datasets and sub-surface understanding. However, towards the thrust part of the area, sub-surface understanding is limited due to limitation of active seismic imaging in thrust belt. Since, fore-land part of the area is having adequate seismic & well datasets, the PST derived volumes were first validated in known (fore-land) part and then utilized towards unknown (thrust) part of area for better insight of sub-surface.

Initially, P-wave velocity (Vp) and Vp/Vs ratio obtained from the full wave sonic log recorded at well-A & then compared with PST derived Vp & Vp/Vs values at well-A which indicated overall good trend match. Further, an arbitrary line selected passing through wells A, B, C, D, E & F for validation of PST derived Vp volume, which indicated overall good correlation at wells for different formations in the area (Figure-7). So, in foreland (known) part PST-Vp volume found to be effective in order to delineate reasonable structural information which proved that it could reliably provide broader structural information towards thrust (unknown) part.

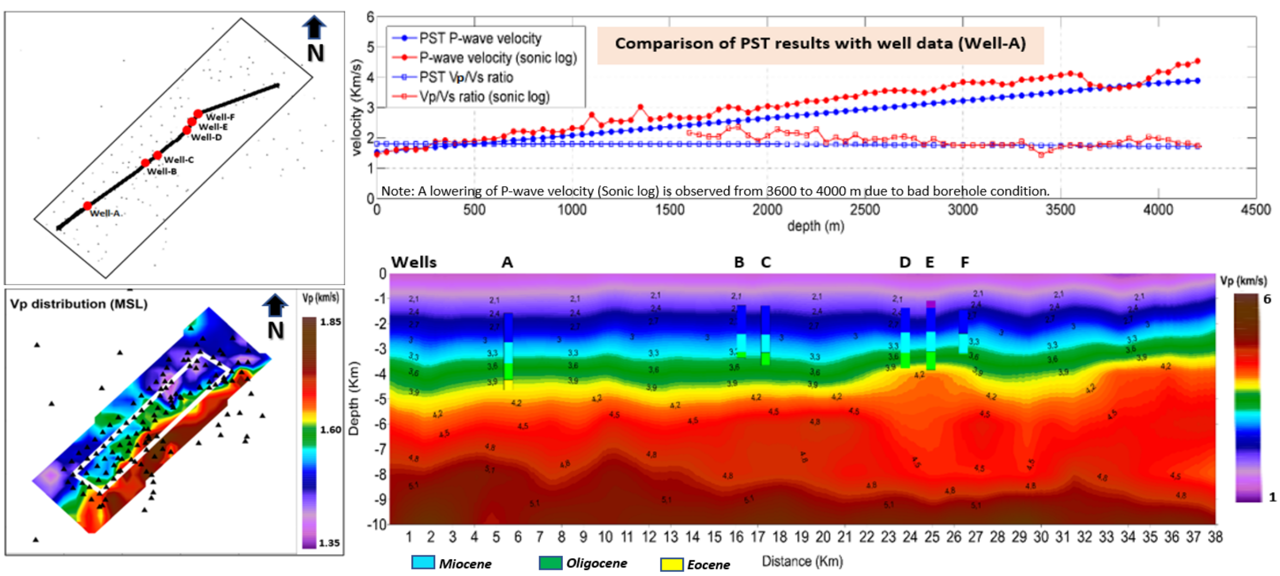

Figure-7: Correlation of PST results at wells

Role of Passive Seismic Tomography in Hydrocarbon Exploration: A Case Study from Upper Assam Basin

For further analysis, a seismic line passing across the thrust was selected for comparison of PST-Vp-velocity with active seismic imaging which indicated good correlation for both fore-land as well as thrust part (Figure-8).

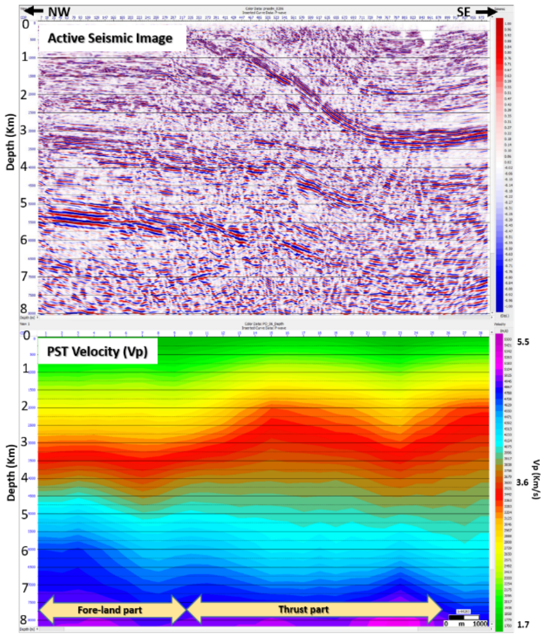

Figure-8: Seismic image vs PST Velocity (Vp)

In order to derive a broader structural understanding towards thrust part, PST derived Vp volume was analyzed and subsequently, Vp-velocities were assigned to different formations. PST based 3D model provided better understanding of structural configuration of formations especially towards thrust part (Figure-9).

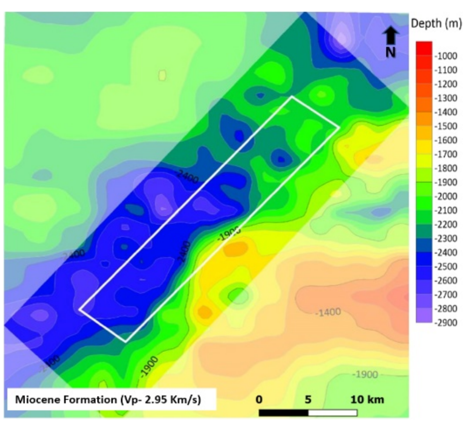

Figure-9: Structural configuration of Miocene formation based on PST-Vp-volume

Conclusions

In an early exploratory stage (Area-1) where limited dataset is available with tough logistics, PST-Vp volume could provide better insight of major structural features. Despite of the low resolution of PST volumes, it is found to be highly reliable at deeper levels. Comparison with AGG-GM results also suggests that even without validation with well or seismic data, we can rely on PST results to narrow down the potential areas for more focused exploration approach.

Whereas, in Area-2, where adequate well & seismic dataset is available, the PST results can be validated/interpreted in known part in order to assess the effectiveness & then can be applied towards unknown (thrust) part for better insight where active seismic have imaging limitations due to tough logistics and sub-surface complexities.

As an environment-friendly tool with relatively easier operations, PST survey provided an edge over active seismic in terms of data coverage in logistically difficult/in-accessible areas.

References

Nienke Blom, Alexey Gokhberg and Andreas Fitchner, 2019, Solid Earth: An Interactive Open Access Journal of the Europian Geoscience Union.

Akis Tselentis, Nikos Martakis, Paraskevas Paraskevopoulos, and Athanasios Lois, 2011, High-resolution passive seismic tomography (PST) for 3D velocity, Poisson's ratio v, and P-wave quality Q_P in the Delvina hydrocarbon field, southern Albania; Geophysics, vol 76.

Acknowledgement

Author is thankful to the management of Oil India Limited for granting permission to publish this paper. The author would also like to acknowledge Geophysics Department, Oil India Limited for providing all the necessary resources and data to carry out the study. Views expressed in this paper are that of author only and may not be necessarily be of OIL.