crude oil from hydrocarbon rich countries which puts a lot of burden on government exchequer. To meet the increasing energy demand and to reduce this import bill Indian government decided to give a push to ramp-up India's crude oil production by increasing Oil & gas exploration activities in officially recognised sedimentary basins in last few years. Even though the exploration campaign in India predates Independence but no basins is fully explored yet due to various reasons.

The already appraised areas have significant seismic data available to support the exploration activities however, unappraised areas either have no seismic data or very scanty old seismic data which was insignificant for exploration activities. NSP was envisaged to fill in this gap of seismic data with high quality regional 2D seismic data.

NSP or National Seismic Programme was launched by Union Petroleum and Natural Gas minister on October 13th, 2016 from Odisha for acquisition, processing & interpretation of 48243 LKM 2D wide grid regional seismic data of all unappraised areas in India. OIL has hydrocarbon exploration history in North-East India more than a century and has the honour to record first seismic survey in North-East. Government of India entrusted OIL for conducting 7,408 LKM 2D seismic data acquisition, processing and Interpretation (API) under NSP in the unappraised area of Assam-Arakan basin which is spread Assam, Arunachal Pradesh, Manipur, Mizoram, Tripura and Nagaland.

Area of Study

The Assam-Arakan Basin covers the North-Eastern part of India and spanned around 1,16,000 Sq. Km area. It is a very prolific sedimentary basin, producing decent amount of hydrocarbon since more than a century and is a Category-I basin. Sedimentary Basins of India are categorised into four categories based on their degree of hydrocarbon prospectivity as presently known.

Though hydrocarbon exploration is continuing in this area since more than a century but still a big part of the basin is unappraised. The unappraised area spread in parts of Assam Shelf as well as in parts of fold belt, falling in state of Assam, Arunachal Pradesh, Mizoram, Manipur, Nagaland. Visualising the similarities and accessibilities of the areas, total unappraised area to be cover under NSP was divided into 2 areas viz. Area-1 (Assam Shelf) & Area-2 (fold belt) to minimize the operational difficulties & effective management. These areas were further subdivided into various sector as shown below:

Area-1 / Sector-I: Assam - Arunanchal Pradesh
Area-1 / Sector-II: Arunanchal Pradesh – Assam
Area-2 / Sector-I: Nagaland
Area-2 / Sector-II: Manipur
Area-2 /Sector-III: Karbi-Anglong & North Cachar Hills
Area-2 / Sector-IV: Mizoram & Tripura

This paper discusses in length the seismic study (API) of Area-1/Sector-1: Assam-Arunachal Pradesh sector. Topographically this area covers foothills and flood plains of river Brahmaputra & its tributaries. The major part of the area of seismic study falls on the North bank of the Brahmaputra river & a minor part falls on south bank of the river. To cover this vast unappraised area, a total of 69 2D lines were planned amounting to ~2416 GLKM. Seismic 2D lines covers almost entire North bank of the Brahmaputra river from North Lakhimpur in the north-eastern side upto Bongaigaon in the southern-western side and also cover some area near Nagaon & Nagarbera on southern bank (Figure 1).

In the northern side, 2D profiles goes upto the edge of the Shelf which is also the basin boundary on the northern side. Many tributaries of Brahmaputra river pass through this area. Most of the area is plain, thinly populated and under cultivation where paddy, sugar cane etc. are grown. Road network is good in the northern bank as well southern bank and easily accessible by road.

Figure 1: Area-1/Sector-1 (Assam-Arunachal) on satellite map

Seismic data API in the North Bank of Brahmaputra River (Assam) under NSP

Plate Tectonics, Geology and topography

The Assam-Arakan basin is a poly history basin which evolved due to the plate tectonic movement of Indian plate in relation to the Eurasian & Burmese plates. It is a shelf–slope–basinal system and tectonically it can be divided into two major basins viz. Assam-Shelf & Assam-Arakan fold belt. The Assam shelf part of the basin spreads over the Brahmaputra valley and the Dhansiri valley, the latter lying between the Mikir hills and the Naga foothills. From the Digboi, the shelf runs westward to the southern slope of the Shillong plateau. The shelf-to-basinal slope, i.e., the hinge zone lies below the Naga Schuppen belt. The basinal (geosynclinal) part is occupied by the Cachar, Tripura, Mizoram and Manipur fold belts (Figure 2). Basin developed as a composite Shelf-slope basinal system under a passive margin setup during the early stage of the basin from Early cretaceous to the Oligocene, however afterwards different part of the basin witnessed different evolutionary trends under compressive tectonic forces.

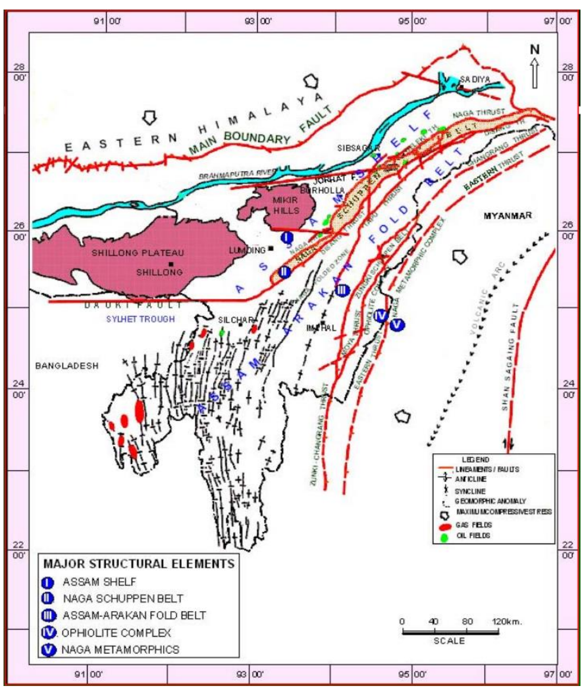

Figure 2: Map of Assam-Arakan basin with major structural and tectonic elements (after DGH)

Early Cretaceous to middle Eocene, the Assam-Shelf was situated on a passive continental margin having a predominantly near-shore to shallow marine depositional environment. The shelf zone experienced a change in the depositional setting to a deltaic-estuarine condition during the latter part of the Eocene and Oligocene, followed by a fluviatile phase in the Miocene and younger times. Geologically, major formations of the Assam Shelf are Langpar (Paleocene to Eocene) deposited in nearshore to shallow marine environment, Jaintia Group (Eocene) & Barail Group (Eocene- Oligocene) deposited in deltaic-estuarine conditions and Tipam (Miocene), Girujan (Miocene), Namsang (Miocene-Pliocene) & Siwalik/Dhekiajuli (Recent) deposited in fluviatile phase.

Seismic Data Acquisition

The survey geometry is kept simple symmetric split spread to capture the regional image of the unappraised area and is more or less same for all the sectors or segment. The acquisition parameters are designed on the basis of the geological information of the area and nearby areas. The parameters are given below in Table 1.

Table 1: Acquisition parameters

Acquisition Parameters	Details
Recording System	Sercel 428 XL
GeoPhone	6x2, SM-24, Bunched
Geometry	Symmetric split spread
Active channels /shot	600 channels
Group interval	20 meters
Min offset	10 meters
Max offset	6,000 meters (6 km)
Shot interval	60 meters
Shot hole depth	20m - Single hole, 10m X 2 Pattern hole 8 m X 3 Pattern hole
Charge Size	Single hole -5 kg 2 Pattern holes -3 Kg each 3 Pattern holes -2 Kg each
Nominal foldage	100
Recording length	8 seconds
Sample interval (Reco.)	2 milliseconds.

LVL were planned at every one-kilometer interval. The LVL Geophone spread length was 105 meters, the interval between geophones varies from 1 meter to 11 meter on both side of the center point (instrument location). The shot was taken using Hammer (iron plate) as energy source at a distance of one meter from the first / last geophone on both end of the spread. Uphole data was recorded at every two-kilometer interval, keeping 500m distance from nearest LVL point. Recommended hole depth was 40-meter depth for uphole data recording. Detonators are placed successively in the hole at 1m intervals from the bottom to the top level of the hole and three geophones were planted in a straight line with an interval of 1m, 3m and 5m from the center of the hole on the surface for recording of data. Data was recorded at a sampling interval of 0.125 millisecond and record length of 1 second.

Data recorded from Uphole survey and LVL survey were interpreted separately and later combined to develop a combined NSM model (Figure 3). This combined model was used to derive weathering and sub-weathering layer velocities, thicknesses and to optimise the shot hole depth for good energy penetration. In this case optimum depth of the shot hole was 20m.

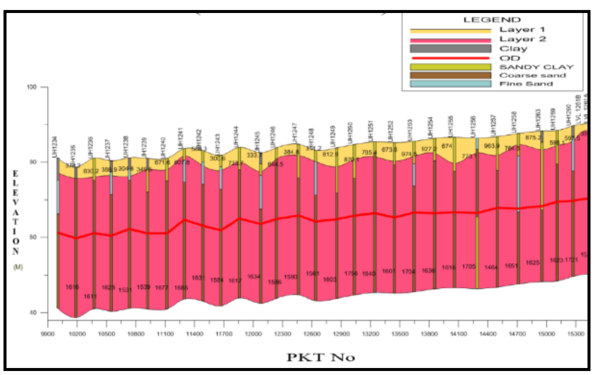

Figure 3: Combined Near Surface Model (NSM) from Uphole and LVL survey

Seismic data recording was done with utmost care so the data quality achieved is very good to good. Reflected event can be seen clearly on the shot gathers with the fairly good frequency content (Figure 4 & 5).

Initial processing of the data was done in the field camp location and brute stack were developed to get the feel of data quality & subsurface imaging.

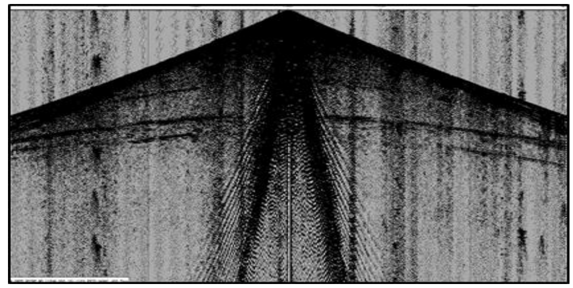

Figure 4: Shot gather from a single hole 20m, 5 kg

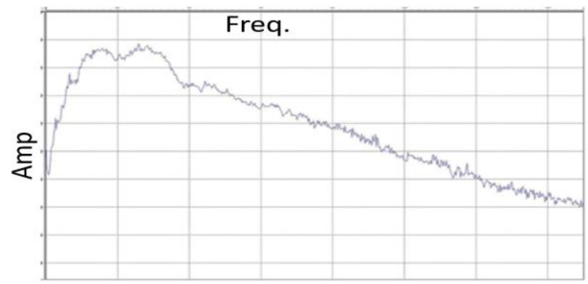

Figure 5: Amplitude spectrum for a single hole 20m, 5kg

In brute stack data quality looks fairly good and number of reflectors with good amplitude can easily be observed up to the basement (Figure 6).

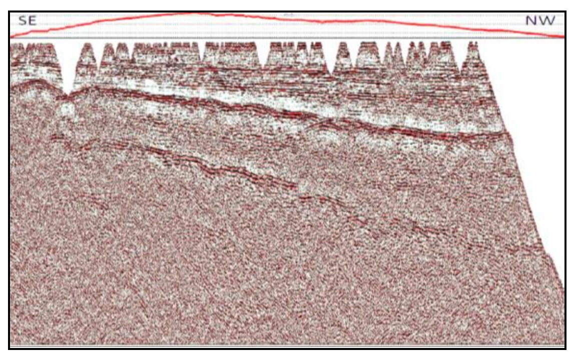

Figure 6: Brute stack of SE-NW profile data set.

Seismic Data Processing

After acquiring the seismic data, seismic imaging of data was an important step to enhance the signal and reduce the noise in the data. Data processing of the acquired seismic data was done with extreme care in the processing center by a competent team of Geophysicist to generate structurally mappable & geologically meaningful subsurface image. Each geological setting presents its own specific challenges, hence there is no cookbook routine to follow for data processing. To resolve the geological complexity of the study area, data processing is done up to PreStack Time Migration using routine processing workflow. The elevation varies from 34m to 300m, First Break pick of refracted wave methodology was applied for static corrections. The results of static & velocity corrections are quite good (Figure 7).

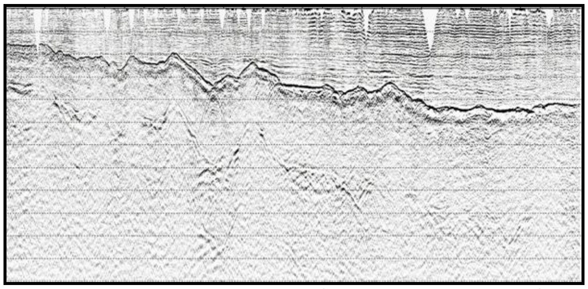

Figure 7: Static correction using first break pick time of the refracted wave.

Velocity is picked at every 50 km using semblance (Figure 8). Rigorous testing of each parameters was done on each step for designing meaningful filters to remove the random noise & coherent noise from the data and to achieve the best possible subsurface image.

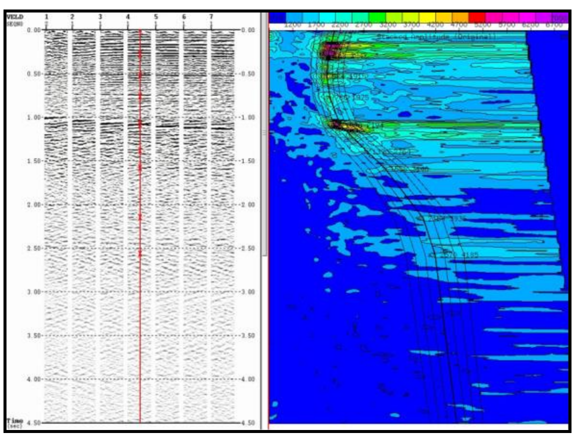

Figure 8: NMO corrected gathers with velocity picks on semblance.

Overall post data processing seismic image look good and shows good continuous reflecting events from recent deposition till basement in the study area (Figure 9). The processed image clearly depicting the meaningful subsurface geological depositional information.

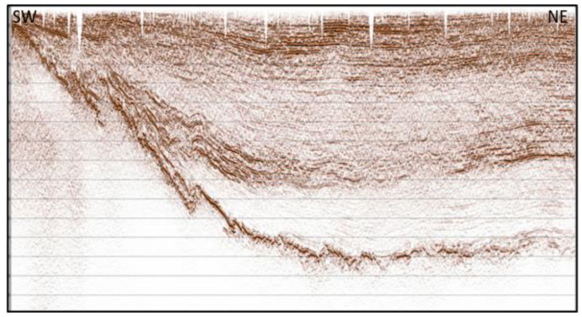

Figure 9: PreSTM stack of SW-NE profile in the southern part of the study area

Seismic Data Interpretation

The 2D Seismic data was acquired in a wide grid (20 X 20 km approx.), covering a wide span of area from North Lakhimpur in North-North-East to Bongaigaon in South-South-West. The acquisition was done to extract the regional subsurface image. A total of six (6) reflectors were considered for regional mapping. Out of these six reflectors, three major reflectors were present throughout the study area and there were other three reflectors which have geological significance were also considered to map in the seismic data. Given the wide extent of survey area and different depositional settings, the formation names change frequently. Accordingly, (except basement), the reflectors have been named after their geological age. i.e.

1. Basement
2.Near_Lower_Eocene top (Prang top)
3.Near_Upper_Eocene_top (Barail top)
4.Near_Lower_Miocene_top (Tipam top)
5.Within_Pliocene (Namsang top)
6.Near_Pliocene_top (Dhekiajuli top).

A solitary well (Madhupur) data was used to perform well to seismic tie and identify the reflectors in the seismic image. The depth maps of the above said horizons, reveals the following:

Known basement highs Mikir hills & Shillong plateau are visible on the seismic data (Figure 10 & 11). The reflectors are dipping from South to North and as a result, sediment thickness decreases from North to South towards the basement high and increases toward the main boundary fault (Figure 10). Sedimentary thickness on south bank of Brahmaputra river in the study area varies from 200m to 1200m while on northern bank it varies from 200m to 5700m, the maximum sedimentary thickness found in North-East corner of the area.

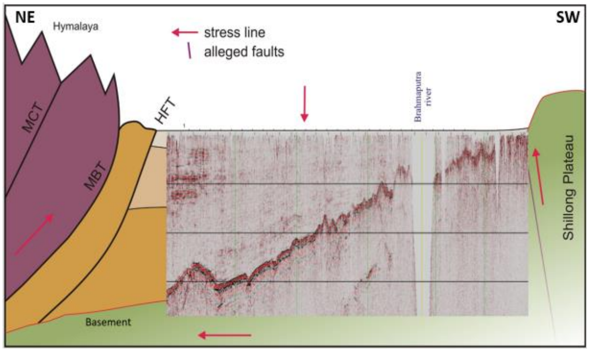

Figure 10: Schematic seismic-geological section from NE-SW direction

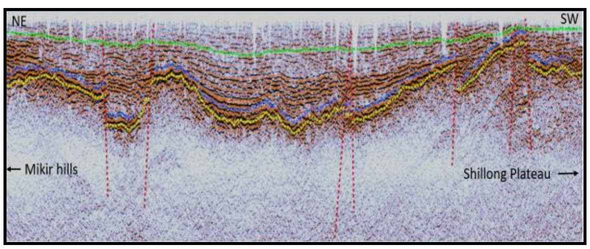

Figure 11: Seismic image of NE-SW profile in the central part of the study area

Lower Eocene package is present with similar thickness throughout the area whereas the Upper Eocene is only limited to North-Eastern side of the area. Geological formations from Miocene to Lower Pliocene are also limited only to North-Eastern part of the area, dipping towards North-East with increasing thickness. There is a possibility of these formations being deposited on the South-West part of the study area as well where basement depth is more than ~ 1500 m but due to absence of any well control in this area, these were not mapped there. By the end of Pliocene, slope become much gentler and sediments are deposited all over the area, this trend continued till recent time.

Conclusions

Acquiring the seismic data of the unappraised areas is a much-appreciated decision of Government of India. It will unlock the path for Oil industry to discover new plays & new hydrocarbon discoveries in the coming years. The data acquired in the study area also suggest the same, initial study of the data indicate some fault controlled 2-way, 3-way structures & some potential basement play. North-Eastern part of the study area, where Eocene to Miocene sands are present, looks more promising compare to South-western part where presence of Oligocene-Miocene sands is doubtful. Basement can be a good candidate to explore in the central part of study area (Figure 11).

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