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Acquiring 2D Seismic Data in a Logistically Difficult and Highly Complex Area: A Case Study in Mizoram

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Summary

The proven hydrocarbon discoveries in the periphery of Mizoram state in the north eastern part of India impelled Oil India Limited (OIL), Duliajan to start the hydrocarbon exploration in the area. The area is extremely difficult with hilly terrain, drastic elevation variations having geological setting with thrust and folded beds. The seismic data acquisition is a great challenge in such kind of highly undulating terrain with complex subsurface. OIL has acquired more than 1300 Ground Line Kilometers (GLKM) 2D quality seismic data. The paper explains about the details of challenges faced, mythology & strategies adopted by OIL for acquisition of the quality seismic data and its correlation and integration with all other geoscientific data like geological, geochemical, gravity and magnetic for understanding the subsurface model for successful hydrocarbon exploration.

Keywords: Gravity, Magnetic, Seismic, Basement, Tibetan Plate, Burman Plates

Introduction

OIL has been awarded a block with more than 3000 SQKM area in Mizoram state for carrying out the hydrocarbon exploration. The area is totally unexplored, however, the hydrocarbon discoveries in and around the periphery of this area in the recent past has made the area promising for the hydrocarbon discoveries. During the span of last four years OIL has acquired more than 1300 GLKM of 2D seismic data. Initially, straight line 2D seismic data acquisition has been taken up, however, later on after analyzing the seismic response Crooked lines acquisition geometry was opted due to terrain constraints and relatively better seismic response with respect to straight lines 2D Seismic.

The more difficult part of the survey area is movement of equipments and drilling rigs due to poor communication of road and navigation system. The surface elevation in the study area varies from 100 m to 1800 m with rugged hilly terrain and undulating topography. Shot hole drilling is a great problem due to scarcity of water, transportation of drilling crew, material & technical accessories. Shifting material for camp construction, managing necessary living facilities as potable drinking/ usable water, frequent presence of insects like snakes, mosquito and poor medical services, understanding of local language etc are another

few difficulties faced by the crew due to remoteness of the area. Another most important constraint is non availability of skilled and unskilled labor for carrying out initial field survey, shifting & laying cable/ geophones for data acquisition and for tough drilling work in the area etc.

In the presence of all these surface complexities and extreme hilly terrain conditions, seismic data acquisition work has been done successfully within prescribed time period. The location of area of study and surface topography are shown in **Figure-1** and **Figure-2** respectively.

Petroleum Provinces

The area of study is located in the Mizoram fold and thrust belt between Bangladesh and Myanmar and located to the south and east of established petroleum provinces, 70 km from the nearest producing hydrocarbon field. The closest well is Rengte-2 situated 54 km to the north therefore the petroleum potential of this block relies heavily on regional data (Ganguly 1983). The development of the fold belt began in the Late Cretaceous on the north-eastern margin of the Indian craton. It was here, in a passive margin setting, that the first sediments were deposited. Open marine conditions prevailed across the shelf as the Indian continent

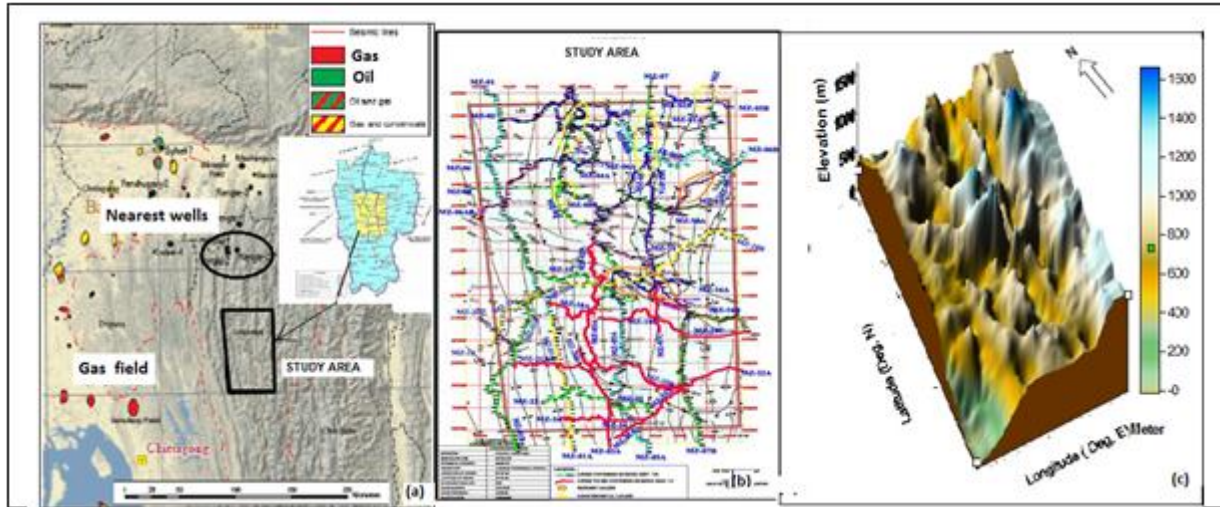


Figure 1: (a) Location map of the study area, (b) Crooked line survey Base Map of the study area (c) Elevation profile.

drifted northward. In the north, oceanic crust of the Neo-Tethys was subducting beneath the Tibetan Plate. Some of these early sediments were metamorphosed in the collision of the two continents which began in the Late Cretaceous to Early Tertiary times. Collision of the Indian, Tibetan and West Burman Plates led to a hiatus in sedimentation and the development of an unconformity in the study area. Sedimentation resumed in the Eocene with the arrival of sediment from the north. A large fluvio-deltaic system developed across the whole Bengal-Assam area fed from the developing orogens to the north and east. In the Late Eocene to Oligocene the Burmese Plate closed over the Assam Shelf, giving its approximate modern day shape.

Deltaic facies continued in the study area well into the Miocene, where the stratigraphic record stops. Upper Miocene and younger sediments are missing from this area, eroded during the final and most recent phase of continental collision. Continued crustal shortening occurred as the Burmese Plate tightened against northeast India. A fold and thrust belt developed in the Mizoram and Tripura areas, detaching at depth, possibly on Upper Cretaceous shales. It is in this late phase of tectonic development that structures suitable for trapping hydrocarbons developed (Murty 1983).

The Mizoram fold belt consists of a series of tight elongate folds that trend roughly in north south direction. They are arcuate, concave to the east and doubly plunging arranged in an en echelon fashion moving west into the Tripura fold belt, away from the epicenter of deformation; the folds (particularly the synclines) become more open and gentle. The uplift and erosion in this area are also less severe as younger strata are preserved and outcrop at surface. Miocene sediments are the youngest to outcrop within the block.

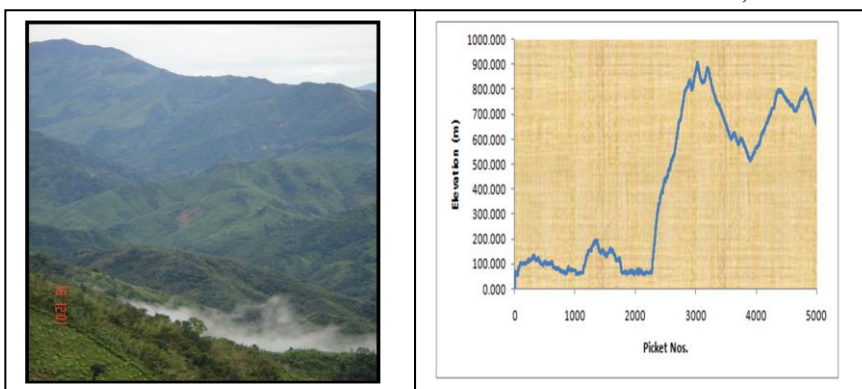


Figure 2: Elevation profiles of one seismic 2D Crooked lines in study area where the elevation varies from 100-900 m.



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Stratigraphy of the Area

The oldest fossiliferous sediments in the study area belong to the Upper Cretaceous Disang Group which exceeds 300m in thickness, but has not been differentiated in this area. Exposures can be found in central Manipur and northern Mizoram. The Disang Group was deposited in relatively deep marine waters on the northeast margin of the Indian Plate, which was passive at the time. The formation is dominated by shales but does contain some arenaceous intervals. The Upper Eocene to Oligocene Barail Group lies unconformably above the Disang. It represents a thick deltaic sequence of approximately 3500m.

Exposures are known from south and east Manipur, where the group has been further subdivided into 3 intervals, the Laisong (1500m), Jenam (1200m) and Renji (800m) Formations. The sequence as a whole coarsens upwards and is dominated by sand, but also contains mudstone and coal horizons. At this time, the Indian Plate was docking against the West Burma and Asian Plates and sediment was sourced from the northeast. The Miocene Surma Group is the next stratigraphic interval in the study area, though much of the top of this interval has been eroded. It is split into the Bhuban and Bokabil Formations (Dasgupta and Biswas 2000). The Bhuban Formation is further split into Lower, Middle and Upper intervals. As a whole, the group comprises alternations of sandstone and shale that were deposited in a deltaic environment. Outcrops of the Bhuban and Bokabil Formations can be found across the block, though the Upper Bhuban and Bokabil intervals are only present as thin intervals in the cores of synclines. The Middle Bhuban is the oldest drilled interval in the study

area, penetrated by Rengte-2, which was drilled to 3001m. The Surma Group is expected to exceed 4000m in this area. Continued collision and uplift of the Himalayas provided sediment from the north.

Communication through Survey Work

As such in the initial stage of the survey work, communication with the local people was a big problem. The most common local language is Mizo, which was not understandable to most of OIL employees. Sufficient number of skilled, unskilled labors and drivers were not available for carrying the project work. OIL regularly arranged training for skilled and unskilled labor, however, a large number of labors did not usually return for work after getting the training. During the operational period many jobs were offered to the unemployed educated and uneducated persons. Company established the necessary facilities like drinking water in the remote places. The Honorable Chief Minister and other officials of Mizoram provided full administrative support & cooperation throughout the field operations and visited the camp as well as field site. The Figure 3 shows the Honorable Chief Minister Sri Lal Thanhawla (left side sitting) and foreign experts (standing) for quality control of seismic data. Later on it has been a very pleasant experience to work with the Mizo people, who over the period acquired the sufficient knowledge to get associated all aspects of field work like Topographic Survey, Shothole Drilling, Cable layout, Geophone plantation and Seismic acquisition.



Figure 3. The Honorable Chief Minister of Mizoram (left side seated) visited the OIL seismic survey Camp Site. The Foreign Technical experts are also standing in the picture.



Figure 4: Location of explosive magazine



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Management of Logistics

(I) Camp establishment

The block / operational area remotely located south of Aizawl and north of Lunglai town. There is only one National Highway NH-54 passing through the block from Aizawl to Lunglei. The location of camp and its establishment for carryout out day to day field activities is itself a great challenge. Initially two Base camps are established very near to NH-54, one in Thenzawl (around 130 Km from Aizawl) and another in Chhiahtlang (around 100 Km from Aizawl) area, however a number of Fly camps were established as and when required near the profile for carrying out shot hole drilling, laying cable, geophone and other ground electronics in the line/ profile. Lot of men power required for building & upkeep of camps, providing necessary facilities and constant supply of provisions and material in each camp of more than 80 persons. Carrying out maintenance of geophysical equipment & accessories was a question mark in such a remote area. The lines are situated in so remote places that traveling takes more than 4-5 hours from the nearest camp site, killing the working time window. The operational area is lacking in basic facilities viz, drinking water, communication, medical, transportation, language and working labours. Frequent heavy rains, storms causing landslides, narrower and poor quality connecting roads further decreases the working time window. The explosives magazine has been established at Thenzawl. The location and magazine site has shown in Figure 4. The explosive vehicles are kept empty and park within the safe distance in the magazine site. Regular maintaining of explosives in Magazine and transportation from the Magazine to the operational area was taking very long time. Most of the necessary material related to technical and human requirements were arranged from the Silchar (around 180 Km from Aizawl) via road careers. The seismic data Quality Control (QC) facilities, Electronic workshop for maintenance of equipments, cables, geophones etc on daily basis, HF (High frequency) control room was established in Thenzawl and Chhiahtlang base camps.

(II) Approach for Topographic Survey

Most of the operation areas have no motorable road to reach the proposed lines for initial Topographic survey. The Line survey crews faced extreme difficulties for carrying

equipments along the lines due to deep gorges, frequent folds with low & high elevations and highly undulating surface. As most of the area was covered with thick forest and cutting of bushes for making approach path was itself a challenging task. Zoom cultivation was another challenge for survey work. The villagers put fires in the jungle and remains of cultivation which made survey approach impossible in the area. Meanwhile frequent landslides blocking the main & few available village kachha roads and foot paths caused delay in field operations. To carry out the survey work such kind of area was difficult; however, the accuracy of the topographic survey was maintained throughout the work. **Figure 5** shows some of the landslides happened in the survey area. Before start of Seismic data acquisition work, OIL established a network of more than 100 Satellite points/Reference points all over the entire operation area. The permanent Reference pillars were fixed at every line crossings, road crossing, river crossing and important cultural features with details engraved on the pillars. OIL carried out control survey and line implantation using latest survey equipment such as DGPS, total stations with EDM and data logger etc. with the accuracy less than 1 meter from the planned lines.

(III) Shot Hole Drilling

The experimental work has been carried out for estimation of shot hole depth in this area and decided to go for 25 m shot hole depth and 60 m depth for uphole survey work. Tractors were used as carriers for shifting drilling rigs, equipment and other accessories on available roads. As the surface strata vary from hard rock to soft formation and there was lot of scarcity of water compressor based dry drilling technique was used for Shot hole and Uphole survey. Total around 125 persons were used for each crew drilling. Rig movement and fixing was a difficult and risky because of the drastic terrain conditions and non availability of suitable place to fix the rigs. Most of the times rigs were kept near the profile at the field site and drilling work continued in shift to enhance the productivity. Drilling in this region required highly skilled manpower and through understanding of the logistic conditions. The tractor mounted portable drilling rigs and compressors are shown in **Figure 6**.



Figure 5. Land slides in the operational area.



Figure 6: Tractor mounted portable drilling rigs and Compressors

(IV) Field Communication Network

As mentioned earlier that due to highly undulating surface covered by forest, radio communication did not work properly. To overcome these problems, master stations were built at the hill top and then few communicators were kept at certain places where they may contact to the different crew members like seismic survey, shot hole drilling crew, shooting crew and uphole personnel using walky-talkies. The desired instructions were conveyed to the lineman for further instruction to control the line during shooting time. This technique also helped to search the people who were engaged in the field activity during urgency.

Recording Instrument

The Aram Aries SPM Lite instrument has been used by two numbers of crews for acquiring seismic data with more than 320 channels (maximum upto 500 channels) recording per shot. Initially the instrument was truck mounted but due to logistic,narrow paths and forest the same was dismantled so that to carry easily at the suitable position along the profile. Small vehicle carriers were used for shifting cables, geophones and other ground electronics on only available road In this hilly terrain every day laying cables and geophones was not possible, so the cables and geophones were left laid usually under security of Fly camp



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Figures 7 :Recording equipment (Aram Aries, the Blaster, Cable layout, and forest fire with burnt cables at the field site.

workers. There was tremendous risk of burning cables, geophones and other ground electronics laid for data acquisition due to frequent jungle fire by villagers as fire use to spread very fast in the area. The receiver and shot position were marked at every 12.5 m and 50 m of interval. Each crew had around 150 cables with length 220m each (with 4 takeout at every 55m) and around 600 geophones strings (with 12 geophones each string). The shooting pattern adopted was End on. More than 100 persons were engaged by each crew for laying cables, geophones, handling other ground electronics in the field. Figures 7 show the Aram Aries recording equipment, Blaster, Cable layout, and forest fire with burnt cables at the field site.

Acquisition of Meaningful Seismic Data

Prior to start of data acquisition faulty channels like dead channels, leaky, noisy traces, reverse polarity, background noise, cultural noise have been checked and minimized/removed as applicable. This could be done by proper coupling of geophones, proper connection of takeout, changing batteries fully, removing faulty cables and geophones. Faulty cables and geophones used to be sent to workshop on regular basis for repairs, where Cable Tester of M/s Aram Aries for analyzing the cables and SMT 200 /300 analyzers for geophones unit were used for testing

Field Parameter Selection

To meet the geoscientific requirement keeping in view of complex geology, faulted, trusted beds with extremely subsurface complexities, good reflection from the survey area was a major challenging task among the geoscientist. So proper geometry study was critical. Experimental survey

work was carried out and initially was decided to go for Split spread data acquisition with 25 m shot hole depth and 25 m of Receiver spacing and 50 m Shot spacing. Few profiles with Straight line geometry were shot, however, later on further through experimental survey was done for acquisition of more meaningful data over complex geology and tackling terrain condition. It was observed that the Crooked line geometry has given better subsurface image in place of Conventional straight line geometry. Few Crooked lines were acquired and it has been further analysed and observed that End-On geometry recorded profiles with group interval 12.5 m are further better quality with reasonably good S/N ratio rather than group interval of 25.m. Bad shots were re-shot and skipped shots were managed with proper offset shots prior to moving the next location.

Based on the observation made from the field records and on site generated Brute-Stacks, it was inferred that End-On using group interval of 12.5 mts, shot interval 50 mts with 320 or more receiver groups gave far better subsurface image. It was also observed that since straight line shooting is not feasible due to steep elevation, multiple hill ranges and poor quality of data, hence Crooked line geometry shall be adopted through available roads, rivers, nallas and valleys and foot paths / traces in the area.

End-On shooting has been carried out with the following seismic parameters as mentioned in Table-1.



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Pattern of shooting	Symmetrical split spread	End on Shooting
Group interval	25 m	25 m (initially)/12.5 m (finally)
Shot interval	50 m	50 m
Shot hole depth	25 m	25 m
No of channels	>320 nos.	>320 nos.

Table-1 : Seismic acquisition parameters

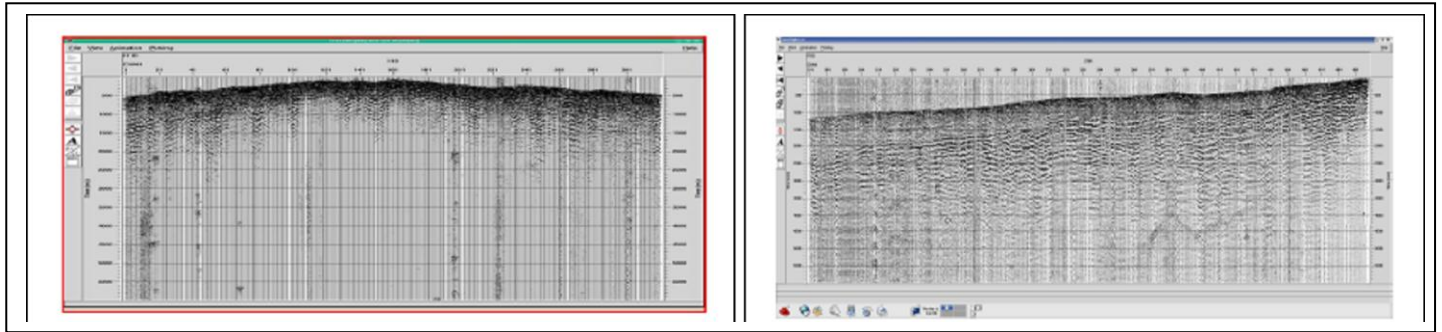


Figure 8 : Seismic data recorded on a Test line using Spit spread shooting (a) End on shooting pattern (b)

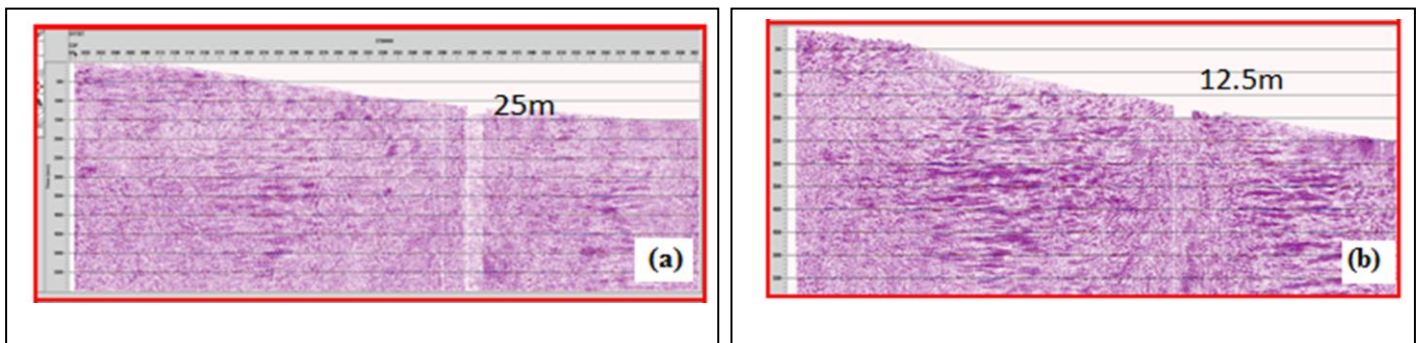


Figure 9 : Comparison of Stacks of a Test Line with (a) Receiver interval at 25m (b) Receiver interval of 12.5m.

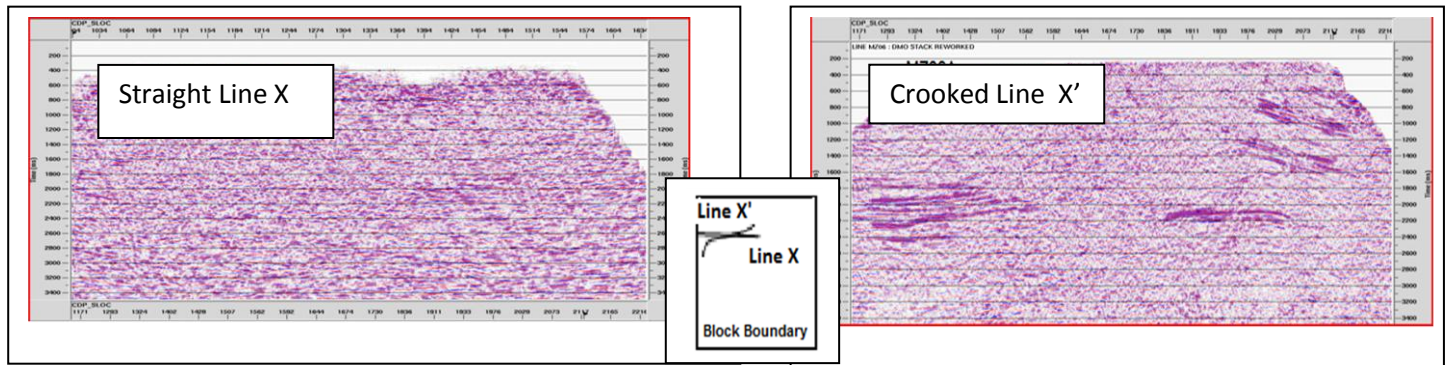


Figure 10: Comparison of (a) DMO Stack of Straight line X (b) DMO Stack of Crooked line X' very close to X Straight line X.



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The near surface velocity models were generated and shot hole depth was optimized accordingly to ensure proper energy penetration to the earth's interior. The shot hole depth is suggested 25 m with optimum 7.5 kg explosives. Uphole data has also been acquired in 60 m shot hole depths at all line crossings. The amount can be exceeds upto 10 kg in the case of extremely hilly terrain.

Processing of Crooked Profiles –Solution For Complex Geology

Seismic data has been processed at OIL's Processing Center at Duliajan, Assam using ProMAX software of CGG-Halliburton and paralleley outsourced to International processing company as the area is very challenging with typical thrust belt complex geology. Following two sequences were followed to obtain outputs for analysis and

Interpretation (Table 2). Except few straight 2D lines, most of the seismic data has been acquired with Crooked line geometry in the study area. A typical Crooked line binning has been shown in Figure 11 showing shot and receiver distribution, CDP distribution and averaged Track used for binning. Field computed statics, Elevation statics and Refraction statics were tested on data. Refraction statics computed using first break picking and up-hole information showed a better stack response both in the shallow and deeper parts of the section. It was decided to proceed with ProMAX refraction statics solution for further processing of these data sets. Surface and subsurface geology is complex so velocity picking was a challenge. Figure 12 shows the velocity analysis, semblance analysis, super gather, dynamic stack and constant velocity stack. Few processed stacked section of Line A and Line B are shown in Figure 13.

Data Processing DMO sequence

- Tape Transcription and Re-sampling
- Geometry QC and Seismic Navigation Merge
- Amplitude Compensation – Spherical Divergence Correction
- Noise attenuation in Shot domain
- Deconvolution before Stack (DBS)
- Static Application
- First Pass Velocity Analysis
- Residual Statics 2 Pass and Velocity Analysis
- DMO
- Final Velocity Analysis and NMO Correction
- Post Stack Migration
- Post Stack processing
- Dip filtering- Tau-P domain

Data Processing PreSTM sequence

- Tape Transcription and Re-sampling
- Geometry QC and Seismic Navigation Merge
- Amplitude Compensation–Spherical Divergence Correction
- Noise attenuation in Shot domain
- Deconvolution before Stack (DBS)
- Static Application
- First Pass Velocity Analysis
- Residual Statics 2 Pass and Velocity Analysis
- Pre-STM
- Final Velocity Analysis and NMO Correction
- Migrated CDP Stack
- Post Stack processing
- Dip filtering- Tau-P domain

Table -2 : Two processing sequences were followed to obtain outputs for analysis and Interpretation

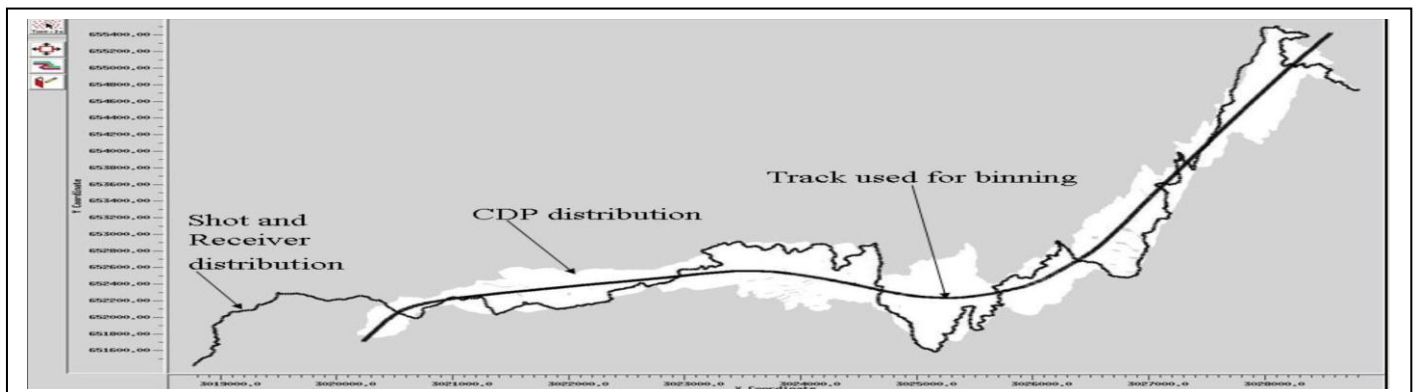


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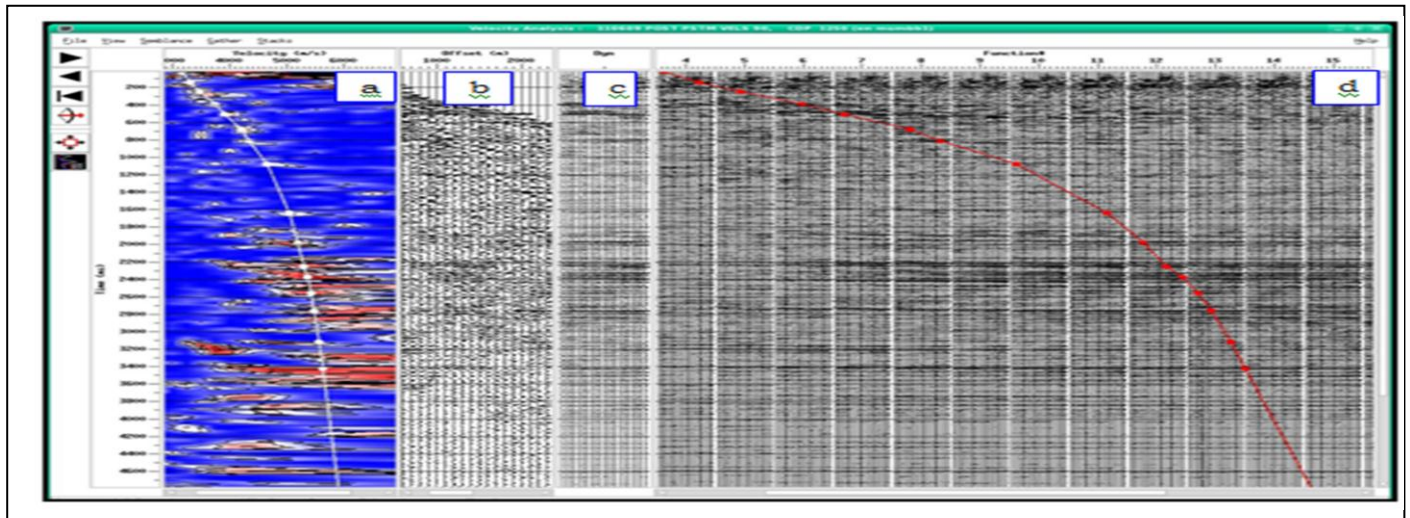


Figure.12: Interactive velocity Analysis (a) Semblance display, (b) Super gather (c) Dynamic stack (d) Constant velocity stack panel

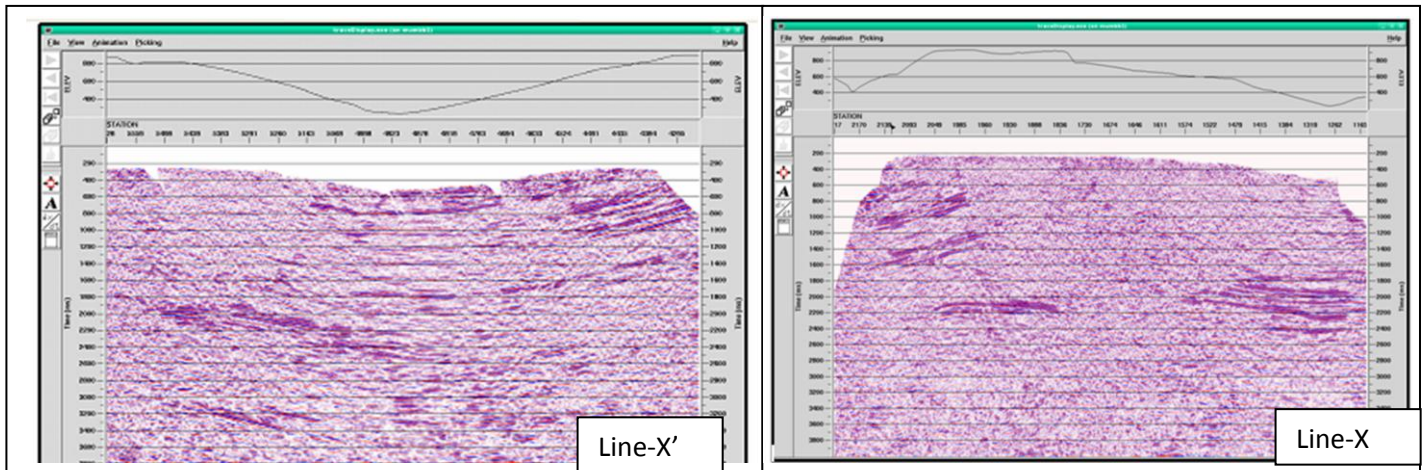


Figure 13: Processed Seismic stacked sections Crooked Line X' (a) and Straight Line X (b) from Mizoram study area

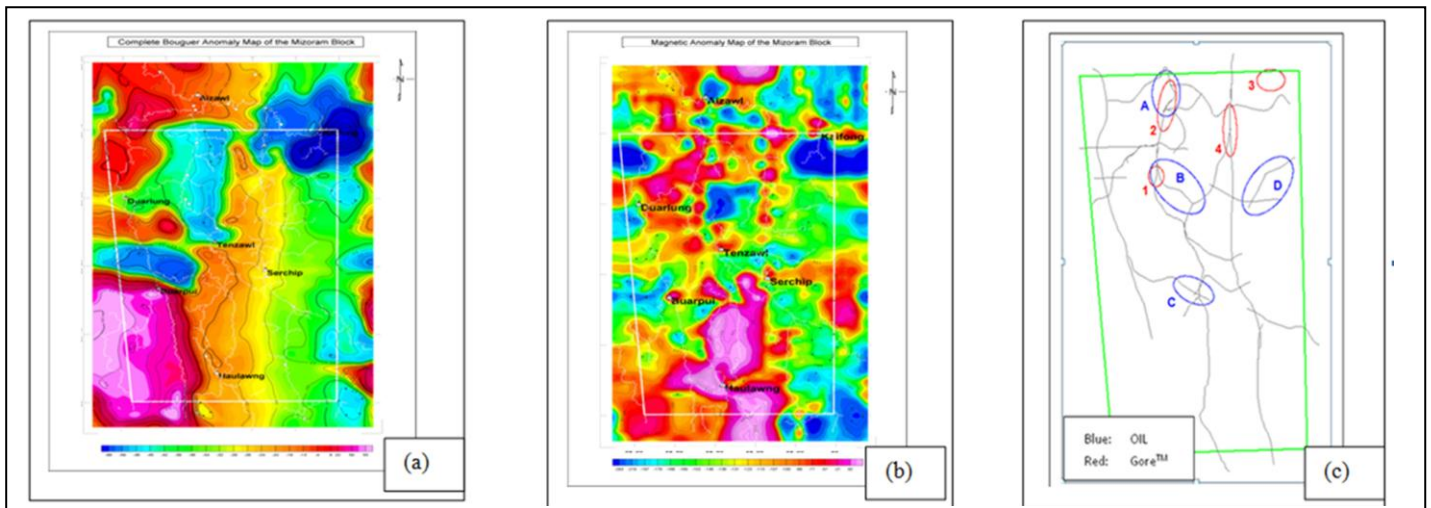


Figure 14 : (a) Bouguer anomaly map, (b) Magnetic anomaly map, (c) Geochemical leads marked in blue color identified by Oil India Limited and red color by an International company.



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Others Geo-Scientific Surveys: Gravity, Magnetic and Geochemical Survey

An Integrated Geological Modeling has been carried out for entire study area by an International reputed expert. Geological mapping/modeling on selected anticlines has been carried out. Along with seismic more than 2400 Gravity and Magnetic stations were covered in the study area. The Figure 14(a) shows the Bouguer Gravity and Figure 14(b) shows Magnetic anomaly map. More than 1400 Geochemical samples (GORETM, 2009) have been collected over the area and finally the high anomalous zone for oil and gas presence were identified which are marked as geochemical leads and shown in Figure 14 (c). Review of prospectivity of study area has been carried out on the basis of the results of various geoscientific works / studies engaging an internationally reputed exploration expert. Structural Restoration & Cross Section Balancing of few prioritized anticlines and adjoining area were also carried out in the study area.

Interpretation of Geoscientific Data : Prospect Identification

All the above data viz. Seismic, Gravity–Magnetic, Geochemical and Geological have been integrated for identification of prospects. During the seismic data interpretation a series of leads and prospects were identified on four (4) mapped horizons the Middle Bhuban, the Lower Bhuban, the Renji and the Jenam leads. The leads and prospects have been used to undertake geological risk analysis and estimate the prospective resources. The dominant trapping in the study area are compressional anticlines, combinational dip-closed anticlines against thrust faults and thrust footwall synclines/truncations. Additional combination dip closed culminations against faults exist against NW-SE faults with compressional and wrench displacement, for example, the Thenzawl fault zone.

Health, Safety and Environment

Safety precautions were taken all the time in field, at Fly camps and Base camps. Explosive magazines were kept at a safe distance and as per Explosive rules & Regulations. Only authorized personnel having training and licenses were allowed to handle the explosives. OIL's personnel used to monitor the Explosive stocks and verified with the

information maintained at the magazine. The detailed consumptions of explosives and detonators were recorded. The handling of equipments was by trained and authorized persons only. It was always emphasized to provide top priority for maintaining good health of the crew. Precautions were taken to maintain the environment, forests, not to damage flora and fauna in the region. OIL believes in No Injury, No pollution and No accident and strictly follow the International Standards in HSE management.

Conclusion

OIL has taken up exploration activities in such a logistically difficult area with typically varying topography without any major incident and successfully acquired reasonably good quality large volume of geoscientific data. During the field work, every effort has been made to satisfy all the criteria including environmental safety, health and hazard management with harmony with the local people and local Administration of Mizoram. OIL has effectively completed Seismic data acquisition, processing and interpretation, Gravity and Magnetic data acquisition, processing and interpretation, geological data acquisition, geochemical sample analysis using in-house and through international crews. Seismic data processing and interpretation have been carried out with in-house efforts as well through outsourcing to obtain more logical outputs for comparison, analysis, mapping and tying events/horizons across the area. It has been observed that during seismic data acquisition, the Crooked line survey has given better subsurface image in place of conventional straight line survey. Seismic data interpretation mapped different horizons like Upper Bhuban, the Middle Bhuban, the Lower Bhuban, the Renji and the Jenam. Through Integrated approach with all these geoscientific data including three well's data in the past towards north of the study area, few prospects and leads have been identified to undertake geological risk analysis and estimate the prospective resources.

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