3-D Seismic Survey in Gobindpur Area of Bengal Basin: A Paradigm Shift in Approach to Data Quality and Inter-regional Crew Mobilization in ONGC

A.Gangaiah*, Rakesh Kumar, M.P.Gupta, D.C. Baruah, P.B.Sharma, S.K.Singh & P.K Das
ONGC] Chennai
E-mail :a_gangaiah@yahoo.com

Summary

Encouraged by the proven presence of hydrocarbons during production testing of two objective levels within Jalangi Formation in the well G # 1 in Gobindpur area of Bengal Basin, a 3-D seismic survey was designed to delineate the extension of pay sands encountered in the well. One crew from the southern sector of ONGC was entrusted the task of acquiring 3-D seismic data in an area of approximately 70 square km (full fold migrated area) over the structure, making it as the first attempt in ONGC for inter-regional crew mobilization so far as acquisition of 3-D seismic data is concerned. State-of-the-art technology was deployed at all stages of acquisition starting from planning and designing suitable survey geometry to data collection in the field, real time data quality monitoring in the field and in-field data processing for quality check. The 3-D survey geometry was designed by MESA software package while the data was acquired by SN408UL recording instrument. Data was recorded with 1176 channels utilizing orthogonal geometry consisting of 12-receiver lines. The SQC Pro was utilized for real time QC check and data analysis. Quality norms in accordance with ISO 9001 standard procedures were strictly adhered to for achieving good quality data. Preliminary processed stack sections show high-resolution seismic reflection data that can now be interpreted to image the structural and stratigraphic features of the subsurface with greater certainty. The thrust of the work was on quality aspects of data acquisition. The systematic planning, execution and successful completion of the project are documented as a ‘case study’ in this paper.

Introduction

Based on 2-D seismic information, an exploratory well G # 1, was drilled in Gobindpur area of Bengal Basin to test hydrocarbon prospects of a fault aided structure in the Cretaceous, Paleocene and Eocene sediments. The recorded well logs, cuttings and cores from G # 1 indicated presence of gaseous hydrocarbons at different levels within Jalangi and Ghatal formations, which was confirmed by subsequent production testing with non-commercial quantity of gas produced from the well. In another well C # 1, about 22Km towards North-west from G # 1, hydrocarbon shows were also observed below the Kalighat Lime stones in Paleocene-Cretaceous section. Sands encountered in the well G # 1 are thin up to 7m. Hence, mapping of such thin sand bodies within Jalangi and Ghatal Formations requires a high order of vertical and horizontal resolution at all stages of acquisition as well as processing. The quality of the seismic data acquisition in Gobindpur area in the light of above exploration objective in Gobindpur area therefore, assumes great importance. A systematic process-based approach to quality guided by ISO norms has been adopted during all stages of acquisition work in Gobindpur area. This study aimed mainly at enhancement of S/N ratio as well as frequency content and was practiced in the field using SQC Pro and Field Processing Unit to better understand the effects of variations with respect to near surface, logistics and the geological setup.

Following the encouraging results of the G # 1 well, a 3-D seismic survey was designed to delineate the extension of pay sands encountered in the well G # 1 within Jalangi formation. One crew from the southern sector of ONGC was entrusted the task of acquiring 3-D seismic data in an area of approximately 70 square km (full fold migrated area) over the structure, making it as the first attempt in ONGC for inter-regional crew mobilization so far as acquisition of 3D seismic data is concerned. State-of-the-art technology was deployed at all stages of the acquisition from planning and designing suitable survey geometry to data collection in the field, real time data quality monitoring and in-field data processing for quality check. The 3-D survey geometry was designed by MESA software package while the data was acquired by the state-of-the-art recording instrument SN408UL using wireline telemetry system. This instrument is 24-bit sigma delta technology equipment. Several geometries were tested before finally deciding with a 12 receiver lines, orthogonal symmetrical sampling geometry utilizing a total of 1176 channels. The SQC Pro was utilized for real time QC check and data analysis. Quality norms in accordance with ISO 9001 standard procedures were strictly adhered to for achieving very good quality data that would ultimately help the interpreter for reliable interpretation. Field Processing Unit with Geocluster software was utilized to regularly monitor data quality and this helped in overall achievement of the goals of the project. Final processed data show high-resolution seismic data that can now be interpreted to image the structural and stratigraphic features of the subsurface with greater certainty. This paper documents the step-by-step approach of meticulous planning and execution of the project till its successful completion with particular emphasis on data quality and giving an account of the viability of such inter-regional acquisition projects to be taken up by ONGC in future.

Study area

The operational area is shown in Figure 1. Figure 2 is a two-way time structure map of the area, on which the full fold migrated area for the project is also shown. The major tectonic zones identified in the Bengal Basin are stable shelf, hinge zone and deeper Basin. The stable shelf is further divided into the structural elements viz, the Radha monocline, the Baidapur depression and Contai terrace from North to South. The area was affected by ENE-WSW to NW-SE trending basement faults.

Fig. 1: Location map of study area

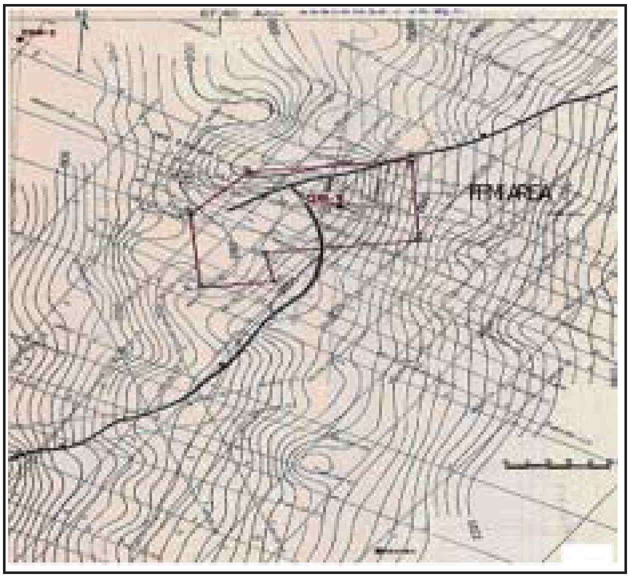


Fig.2: Two way time structure map at a level near top of pay sand. Study area (Full fold migrated) is also shown.

The Pre-Trappean sedimentation took place in a typical horst-graben setup during Gondwana (Permian to early Cretaceous) period. The Post-Trappean sedimentation that took place during Late Cretaceous to Recent period is mainly Clastic and Limestone deposit. The Post-Trappean sedimentation took place in the monoclinic dipping basin. The break up of Gondwana geochronologically coincided with the emplacement of Basaltic Rajmahal Trap during Late Jurrasic to Early Cretaceous time. The Pre-Trappean sediments were deposited in continental and Post-Trappean sediments in marine environments. Stratigraphically, Jalangi Formation with thickness ranging between 150-700m in the basin is characterized by coarse to medium grained sandstone in the basin margin and sandstone to limestone in hinge zone deposited under fresh water to warm shallow water environment and deposited during Paleocene to Upper Cretaceous period. Similarly, Ghatal Formation with thickness ranging between 0-150m is characterised by inter-bedded black calcareous shale and pink to grey shaly limestone with sand, silt & oolite etc deposited under lagoonal to littoral environment during Upper Cretaceous period (Gangaiah, 2005).

In the study area, two exploratory wells namely G # 1 and C # 1 have been drilled. The well C # 1 is about 22 Km from G # 1 drilled up to a depth of 3862m penetrating lower Gondwana sediments. G # 1 drilled up to a depth of 3330m bottomed at Gondwana sediments. The well G # 1 flowed dry gas at @ 62-70m^3 / day in Palaeocene section belonging to Jalangi formation. The well C # 1 was drilled over a fault closure in Paleocene – Cretaceous section near the adjunction of two normal faults trending NE-SW and NNW-SSE directions. Oil shows were observed in the cores and cutting within Paleocene and Cretaceous sections.

Project planning

To achieve desired objective of completing a data acquisition task successfully, particularly in view of the first attempt of the crew to go far beyond the state boundaries to West Bengal and work in a totally new environment, meticulous planning at every stage of the project is extremely important. The various stages of such planning can be briefly stated as below:

- Collection and detailed analysis of all the available geoscientific data pertaining to the assigned project area and a thorough reconnaissance of the survey area.
- Formulation of a suitable 3-D survey design in accordance with the given exploration objective for which the 3-D data is planned. The 3-D survey design should aim at fulfilling all the technical requirements viz. sufficient multiplicity, good signal to noise ratio, higher frequency bandwidth for better temporal resolution. Combined with theoretical calculations for meeting the above objective, thorough field experimentation to optimize charge size, charge depth etc is also essential to optimize field and instrument parameters.
- The survey should be designed such that while meeting all the technical requirements of the project, it should be economically cost effective with adequate TQHSE measures as per standard stipulations laid down by ISO.

Survey design

The primary objective of the 3-D seismic survey in Gobindpur area was to delineate extension of pay sands within Jalangi Formation encountered in the well G # 1. Sand bars / lenticular sand bodies of limited areal extent deposited under upper deltaic environmental conditions are expected to be encountered in the area which are supposed to be reservoir facies. The thickness of pay sand encountered in G # 1 is around 7.0m. For the temporal resolution of these thin sands, frequency of much higher order is required. The frequency content of the source depends on the accurate optimization of source depth and charge size. For proper spatial resolution of pay sands, which directly depend on shot and receiver station intervals, 25m square bin symmetric sampling geometry was chosen (Gangaiah, 2005).

Figure 3 is a seismic line from the most recent available 2D campaign in the area and figure 4 shows the correlation of VSP data from well G # 1 with line WB136-07. The required dominant frequency to be achieved in the zone of interest was calculated from the VSP data of G # 1 well. Since the area was logistically found to be full of water bodies, fishponds and paddy fields, causing large no. of skip points due to inaccessibility, it was decided that 42 fold 3-D data would enable to achieve the effective foldage of 36. Keeping this in view, the geological objective was transformed into

Table-1: Seismo-geological parameters

Seismo-geological parameters	Range/Value
Time of zone of interest (TWT)	2000-2600 ms
Depth zone of interest	2500 – 3500 m
Range of dips	Less than 5 ^{0}
Average velocity at 2860m	2700 m/s
RMS velocity for deepest reflector	3394 m/s
Two way time for deepest reflector	2600 ms
Maximum frequency considered	70 Hz
Minimum frequency considered	40 Hz
Depth of shallowest reflector	500-550m
Two way time of shallowest reflector	450-500 ms
RMS Velocity of shallowest reflector	1750 m/s
Mute percentage considered	10%

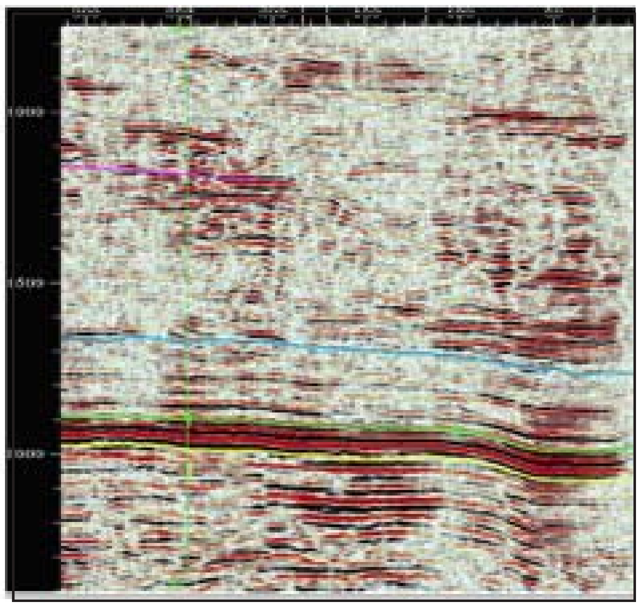


Fig. 3 : 2-D seismic line of earlier vintage WB136-07

its geophysical components, which are given in Table-1(Gangaiah, 2005).

Survey geometry

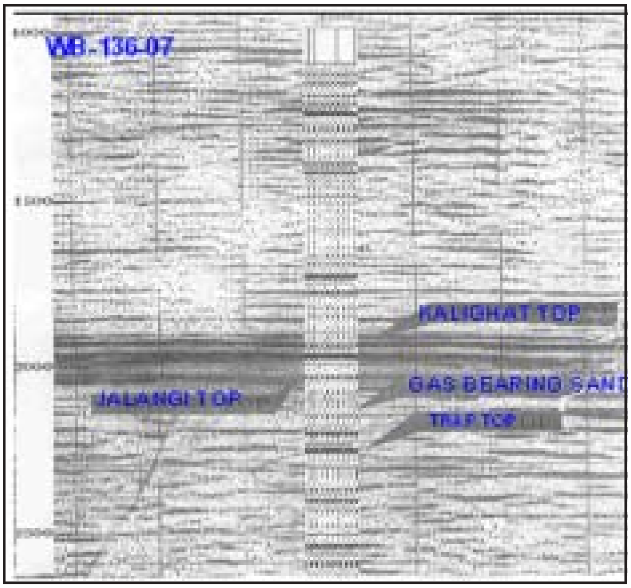


Fig. 4 : VSP data from well G # 1 correlated with WB136-07

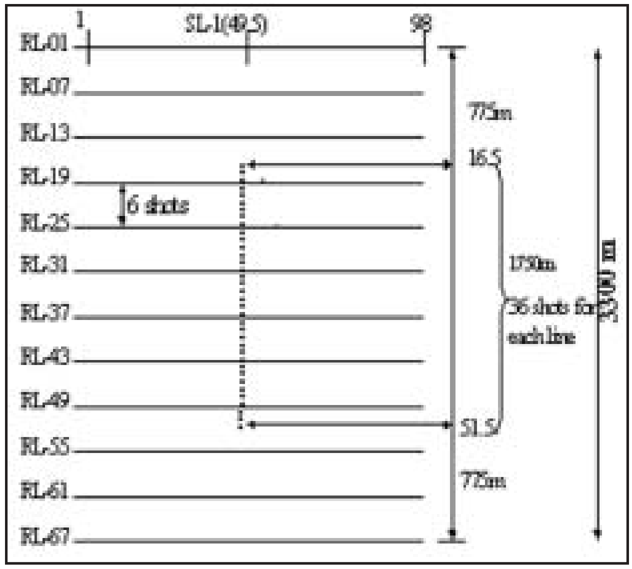


Fig. 5 : Unit template for the survey

Acquisition of high quality 3-D data depends upon survey geometry. The quality of imaged result should meet the interpreter's requirement while at the same time; total shots and active channels per shot should be optimum. Hence, a smart design of the acquisition geometry becomes very important. 3-D geometry simulation play a vital role in 3-D data acquisition and depends upon the available seismic input, logistics in the area, bin size, fold requirement and budget allocation for the survey (Stone, 1994). A cost-effective seismic survey design is decided by working out different 3-D geometries.

The orthogonal geometries are preferred since they provide uniform & flat distribution of offsets in a bin and sufficient no of traces of various offsets in the zone of interest and are proved to be cost effective. Several 3-D geometries of square bin were simulated with the help of MESA software package to study the offset and azimuth distribution within the bin and fold distribution in the zone of interest. These geometries were with orthogonal symmetrical split spread and all were designed to have a maximum far offset in the order of 3800 m, keeping in view the target depth range 2500m - 3500m. Fold plots in different offset ranges 0 – 1000 m, 1000m – 2000m and more than 2000m; offset distribution, azimuth distribution across bins and individual bins were generated and studied. Rose diagram plots (azimuth – fold distribution), fold – offset distribution and full area trace - offset distribution plots over entire survey area were generated and analysed for merits and demerits of each individual geometry. The geometry with the following attributes (Table-2) was finally selected for the survey (Gangaiah, 2005).

Table-2: Attributes of the final geometry

Active channels	98 channels x 12=1176	Fold (>2000m)	14-20
Geometry	Sym-Sam orthogonal	RLI	300m
Fold	7 x 6	SLI	350m
Bin size	25m x 25m	X-line swath roll over	1800m
Unique fold	26-42	Shot/salvo	36
Fold (0-1000m)	3-8	Max. far offset	2757-3635m
Fold (1000-2000m)	10-18	% traces (1000-3000m)	80

The candidate geometry was adopted (unit template shown in figure 5) for the survey due to its following merits:

a) More uniform fold across lines in different offset ranges.
b) More even distribution of offsets across bins and within individual bins.
c) 360 degree azimuth coverage in the offset ranges of 0-3000m.
d) Full area offset distribution: Fold built up is more uniform and flat in the offset range 500-3000m.
e) Around 80% of the traces are in the offset range of 500-3000m and they are expected to provide good stack response in the zone of interest.

f) Foldage 42 with Aspect Ratio 0.63 and maximum far offset 3635m.

Field experimentation

Near surface model behaviour is a very critical component in seismic surveys. Precise delineation of near surface model based on a close grid sampling of the study area (1.5 km X 1.5 km) by a total of 151 nos. of uphole surveys was carried out during the survey. This would help in precise determination of statics corrections during final processing of data. Moreover, from advanced uphole surveys, litho logs, near surface cross sections along dip and strike profiles (figure 6) and depth contour map for the top of sub-weathered layer (figure 7) were prepared to place the charge at optimum depth. Placement of optimal charge size at optimum depth brings out broad amplitude-frequency spectrum within the recording dynamic range and improves the S/N ratio. Detailed charge size and charge depth experimentation for the dynamite source was carried out before start of regular production work and based on the analysis of the spectral response of the experimental data; charge size was optimized at 2.5 kg - 3 kg. The amplitude and pulse shape of the uphole data at each recorded depth was carefully studied and results were utilized in conjunction with lithology data as well as the T-D curves before fixing the optimum depth that varied in the area between 30 m to 35m.

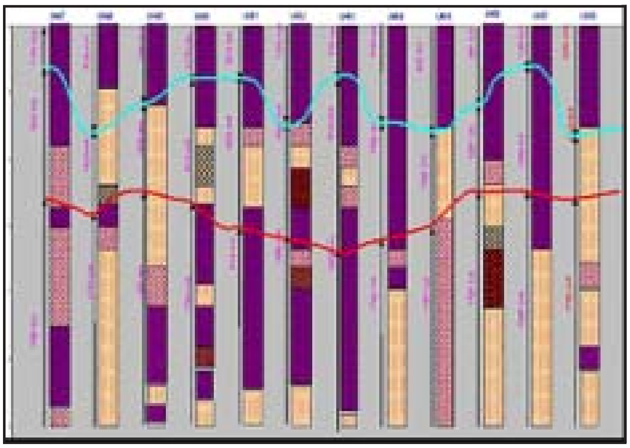


Fig. 6 : Near Surface Model along receiver line 91

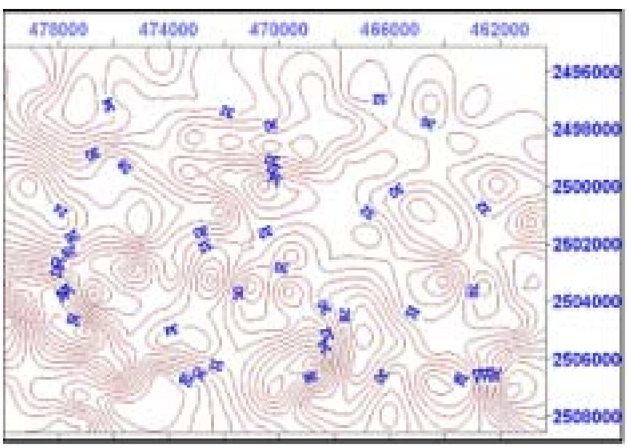


Fig. 7 : Top of sub-weathered layer in Gobindpur area

Combining the results from the theoretical computations based on available data, analysis of the survey geometry and detailed field experimentation, the final field and instrument parameters as adopted during the survey are given in Table-3 (only those parameters that are not given in Table-2 have been included here).

Table-3 Final acquisition parameters

Field parameters			
Min offset	425 m - 2757m	Direction of Shooting	N - S
Group interval	50m	Receiver line orientation	W – E
Shot spacing	50 m	Geophone array	Bunched
Type of spread	Sym. sampl. Split spread	Charge size	2.5–3.0 kg
Total no of channels / shot	98 X 12= 1176	Charge depth	30–35 m
Instrument parameters			
Record length	5.0 sec	High-cut filter	0.5 of Nq. Freq. (125 Hz)
Sampling interval	2 ms	Notch filter	OFF
Low-cut filter	N.A	K-Gain	0 dB

Topographic survey

Three-dimensional imaging requires precise positioning of source and receiver combinations. A total of 98 DGPS stations were established in the operational area to make a very close grid network of control points. A total of 48 receiver lines and 54 shot lines were staked with the total quantum of work being 1766.332 km and 1846.371 km for staking and leveling respectively. The corners of the 3D block were controlled by EDM traverse. For EDM traversing, references were taken from Survey of India GTS marks and DGPS control points. Orientations of seismic lines were controlled with the help of Electronic Total station and Theodolite. Leveling or vertical control was carried out with the help of Auto-level taking the references from permanent

Bench Marks of Survey of India. For future reference permanent departmental survey pillars were erected at both the ends of every fifth line. All the pillars and drilled wells were connected by EDM traverse. The entire topographic survey took only a total of 107 days.

Seismic Data Acquisition

After finalization of acquisition parameters (Table-2 & 3), and after initial progress of topographic survey work as outlined above, the seismic production work commenced by ensuring full cooperation from local authorities and villagers by maintaining good public relations. Seismic workers were properly trained and counseled regarding handling of ground electronics and line laying etc with the new state-of-the-art equipment of SN408UL before start of actual production work. Standard quality measures viz. geophone plantation, maintenance of geophones and cables, cultural noise control in the active line were also adhered to. Similarly drilling and shooting crew were trained to ensure proper shot hole condition and proper tamping etc. Due to sincere and coordinated efforts of the entire crew, utilizing only 110 production days, a total of 10,757 nos. of shots were taken covering an area of 225.295 square km.

Data quality monitoring

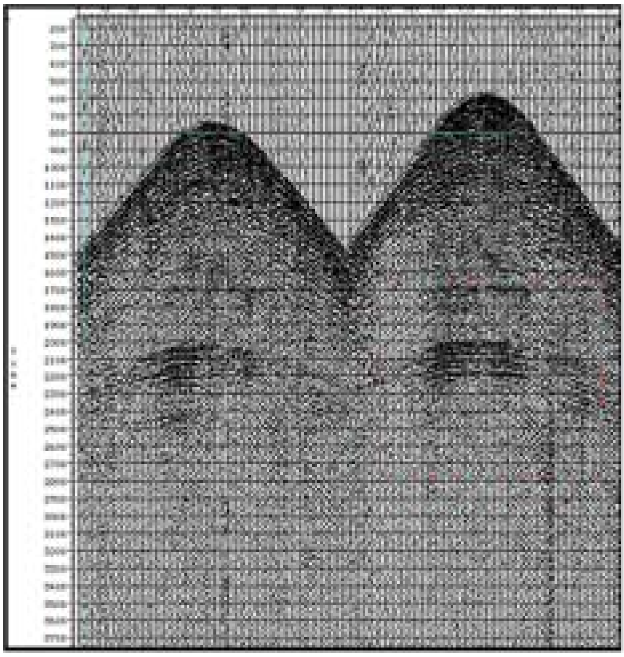
At different stages during data acquisition, the quality control checks were carried out including quality monitoring through the available onsite field QC/ processing system. These along with standard quality measures helped in better understanding of the sub surface reflection pattern and thereby bring out better reflection strength, continuity and correlatability of the events.

Regular instrument tests viz. Distortion, CMRR, Crosstalk, Noise, Gain & Phase Error tests were taken daily to monitor the health of the instrument and ground electronics. There are four field tests in 408UL instruments for resistance, leakage, tilt and noise which were regularly conducted on the line both before start of each day's production as well as during production work of the day and immediate action was taken to correct the faulty traces immediately.

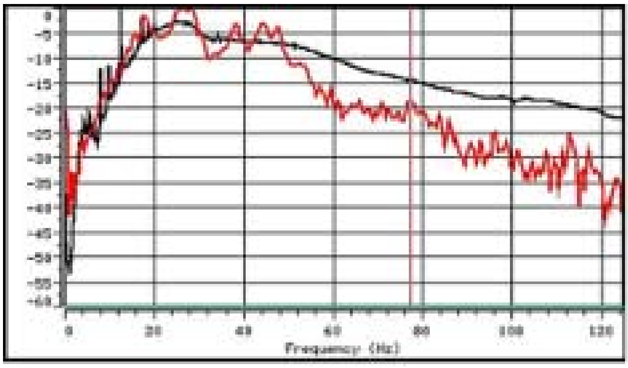
Perfect coupling of sensor to the ground is of utmost importance to achieve good resolution. This was given added focus by digging about one feet pit in each geophone group location and maintaining strict control in the field.

Factors which affected fold from logistic point of view were obstacles viz. villages, ponds & paddy fields etc. Proper recovery shots were taken to minimize the effect of skips due to logistics. With the help of the SQC Pro provided along with the acquisition unit, each and every shot record was monitored on real time basis for on the spot quality analysis. Frequency bandwidth of field data was monitored through spectral studies of the acquired data which reveals that the frequency content is of the order of 20 to 60Hz (Figure 8), which may further be enhanced at the time of final processing. This was carried out in the Field Processing Unit stationed at the base campsite.

Value addition



(a)

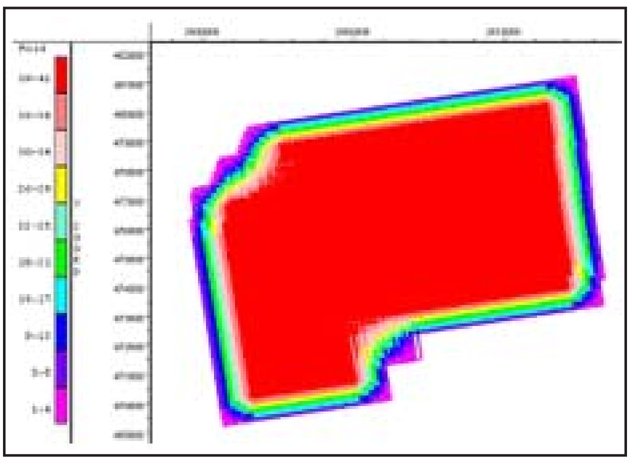


(b)

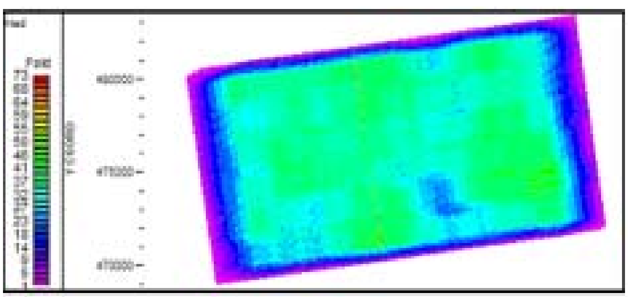
Fig. 8 : (a) Raw data; SW 2, SP 2145; (b) Frequency spectra of raw data of (a)

The effectiveness of any scientific project is judged by the value addition it makes to the already available knowledge about the area. In this context, the survey design as envisaged during pre-survey stage was put to test in difficult logistic conditions in Gobindpur area and the survey was conducted in such away that it met the simulated benefits of the 3-D acquisition geometry originally designed in the area. The actual data after the completion of the survey was put as an input in the MESA software to ascertain whether the actual results after the completion of the survey matched with the initial design. Various attributes were again generated from actual data and are compared with the corresponding theoretical results simulated from the proposed geometry.

As we can see, the effective foldage as obtained finally varies between 36 fold to 42 fold (figure 9b), which is comparable to figure 9a (theoretical design). Similarly, other attributes compare very nicely with the initial theoretical design. Rose diagram (figure 10a & 10b) show the pre-survey theoretical simulated result and post survey data respectively. Percentage of traces Vs. offset is one important attribute 3D surveys, figure 11a is the pre-survey design and figure 11b shows the result after completion of survey.



(a)



(b)

Fig. 9 : (a) Foldage diagram (theoretical, before survey); (b) Post survey foldage diagram

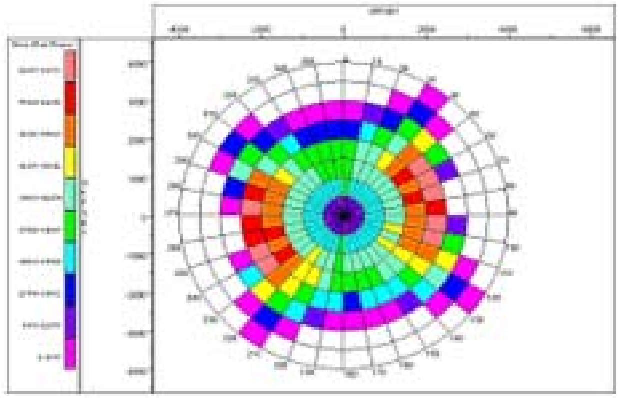


Fig. 10 : (a) Rose diagram (theoretical, before survey)

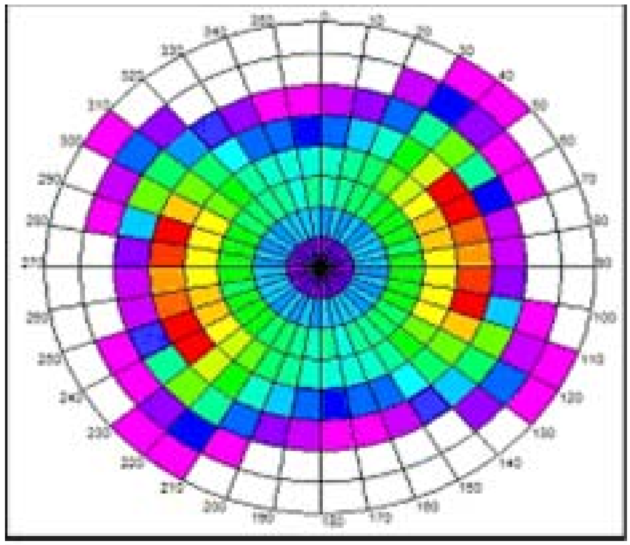


Fig. 10 : (b) Post survey rose diagram

In terms of value addition, the utilization of an advanced geometry simulation package and matching the actual data with theoretical data is one major achievement that contributed to the existing knowledge in the field of 3D seismic data acquisition. Success of any survey depends on how best we can achieve such coverage as planned during survey design. The other important contribution of the project has been in terms of three dimensional data gathered for the first time in this part of the basin. The successful implementation of a 3D data acquisition project by one seismic party operating in a far away basin under administrative control of a different region altogether is going to prove a trend setter for the policy of taking up similar challenging tasks.

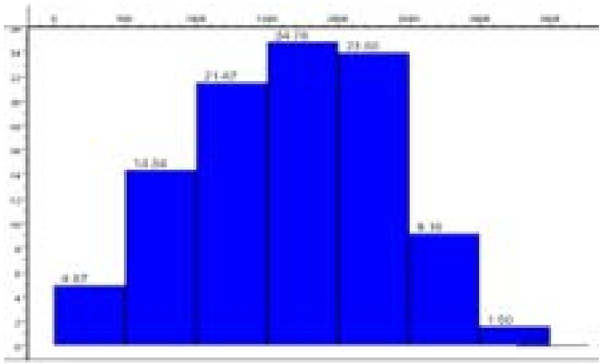


Fig. 11 (a): % of traces Vs. offset distribution (theoretical)

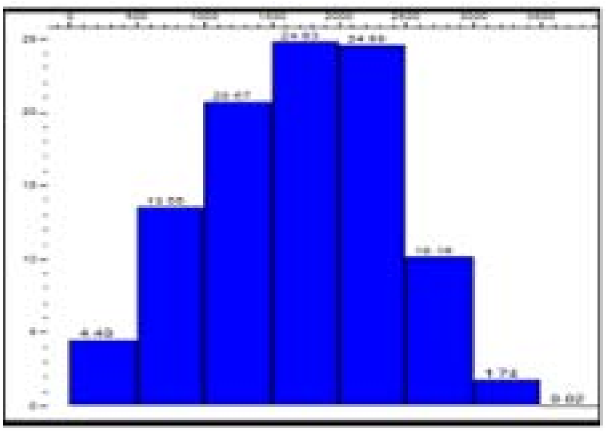


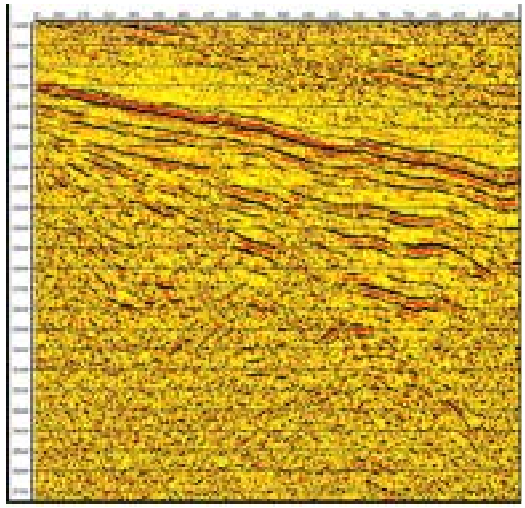
Fig. 11 (b) : Post survey % of traces Vs. offset distribution

Preliminary processing of 3-D data in field

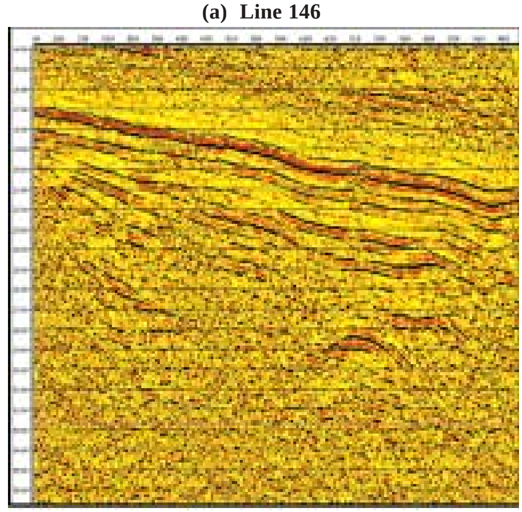
Once each swath was completed, the recently acquired Field processing Unit was utilized to process the data in the field campsite itself up to brute stack stage. The Geocluster software was utilized to process the data. This process was aimed at having a strict control on data quality by analyzing the preliminary processed out put and take any mid course correction if required. Some of the representative processed sections are shown in figure 12. Preliminary processed sections show good reflection characteristics viz. amplitude, frequency and continuity. However, final processing would enhance the data quality further to meet desired objectives.

Conclusions

Gobindpur area of Bengal Basin could prove to be a highly promising hydrocarbon province as indicated from the gas strike in the well drilled in the area G # 1. Therefore, the recently acquired 3-D seismic data over the Gobindpur



(a) Line 146



(b) Line 156

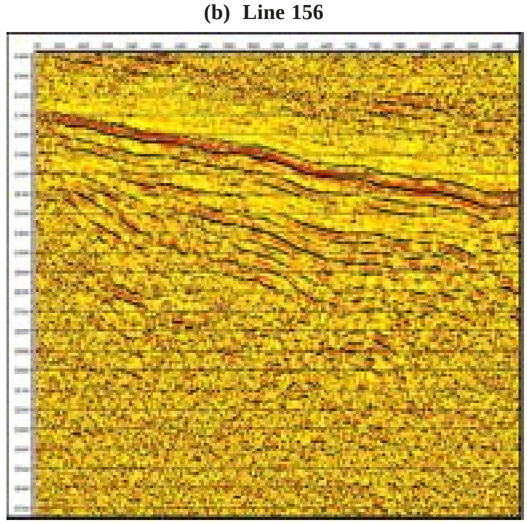


Fig.12 : Preliminary processing carried out in Field Processing Unit (Geocluster) in field

prospect could give the much-needed thrust in further exploration in the area.

The approach to quality and operational efficiency during 3-D data acquisition at all stages as discussed in the paper helped in achieving the desired objective for the survey. This was possible by implementing a continuous process of check and balances both in real time QC and through monitoring in preliminary processed sections in field itself. The detailed subsurface image that is now possible from the results of the 3-D seismic survey over the structure could trigger the much-awaited big success in Bengal Basin.

The project had four major successful components in terms of (i) utilization of MESA software package for survey geometry design, (ii) application of the advanced 24 bit sigma technology in seismic data recording, (iii) real time quality monitoring in SQC-Pro and (iv) field processing at camp site by Field Processing Unit with Geocluster software technology.

Also, the first ever successful completion of a 3-D seismic data acquisition project based on a meticulously planned and executed work schedule by a crew drawn from inter-regional stations within ONGC would be the beginning of such challenging tasks to be taken up by ONGC in future seismic surveys.

Acknowledgement

The authors gratefully acknowledge Shri P.S.N.Kutty, GGM & Basin Manager, Cauvery Basin and Shri Dipankar Dutta, GM (GP) & HGS, Chennai for the challenging task given to the team to venture far beyond the Cauvery Basin limits to Bengal Basin to complete a 3-D data acquisition project. They have reposed faith and confidence amongst the crew members which boosted the morale of the entire team. The authors gratefully acknowledge the sheer vision and forthrightness of Shri Apurba Saha, ED and CGS who was instrumental in not only implementing state-of-the-art technology in field data acquisition in a big way but also in venturing into far flung areas to meet larger exploration objective of ONGC Limited. The authors express their heartfelt gratitude and sincere thanks to Shri C.V. Varadarajan, CG (S) and Shri Chaman Singh, DGM (GP) for their valuable suggestions and guidance throughout the course of the project. The authors thank Shri K.Ramakrishna, SG(S), Chennai for the help extended with MESA application. Sincere and dedicated efforts of the entire survey crew, geophysical crew and support staff of Geophysical Party No. 39 was the force behind successful completion of the assigned target to the Party and authors record their special thanks to all of them. The crew could not have achieved the goal had it not been for the moral and logistical support provided by the Bengal Basin team and the authors also express their heartfelt thanks to S.K.Biswas, DGM (GP) & HGS and Shri A.K.Biswas, GM and Basin Manager of Bengal Basin. Authors also thankfully acknowledge ONGC Limited for permission to publish this paper.

References

Gangaiah, A., 2005, Project report on 3-D seismic survey in Gobindpur area of Bengal Basin, *ONGC Unpublished report*.

Stone, D.G., 1994, Designing seismic surveys in two and three dimensions, *Geophysical Reference Series No. 5, SEG Publication*