8th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2010"

P-201

Improving sub-surface image with conventional wisdom & innovative approach – Case study from Krishna-Godavari Basin, India

Sridharan K*, ***Purushottama Rao, Mukkamala,*** *ONGC, Chennai*

Summary

The Krishna-Godavari Basin, in the East coast of India is a passive margin basin which belongs to a unique poly cyclic extensional province. Geologically the basin exhibits a very complex sub-surface picture, especially in the west Godavari sub-basin area. The sub-surface imaging becomes a challenge because of the thick basaltic layer at the shallow level in this part of the basin. Many 2-D and 3-D seismic campaigns were conducted in this area. But the sub surface could not be mapped satisfactorily including the basement. The acquisition efforts were hampered further because of the logistic problems due to presence of large water bodies, aqua culture and dense population. A systematic approach was made to study the problems associated with data acquisition and suggest optimum parameters for undertaking a large carpet 3-D campaign. The studies included modeling, synthetic data generation & processing and other studies drawn from the collective wisdom of experienced campaigners & domain experts. Efforts were made to compute the foldage required, from the study of vintage data. The integrated study resulted in optimizing the parameters like far offset requirement, type of shooting geometry, foldage etc. to facilitate better imaging of the sub-surface.

Innovative recovery programs were made with the help of software tools and detailed survey data to plan acquisition over the logistically challenged areas. The data acquisition campaign was carried out successfully as per plan by deploying 6 parties over an area of 1500 Sq.Km. The efforts culminated with the best in class sub-surface image in one of the most challenging on-land portions. This is evident from the comparison of vintage data with the data extracted from the 3-D volume.

Introduction

Krishna-Godavari Basin : The K-G Basin in the East coast of India, is a passive margin basin which belongs to a unique poly cyclic extensional province. It is analogous to geological set up of Continental margin of Black Ridge in Arctic ocean and Beaufort Sea of Atlantic Ocean. The basin evolved over the eastern Ghat tectonic grain in consequence of Indo-Antarctica plate separation and the influence of oblique extension during Jurassic period. The Basin consists of two parts - the peri-cratonic passive margin superimposed on the orthogonal Pranhita Godavari basin.

The origin of the basin is related to three stages of rifting. The Proterozoic Proto-rift (NW-SE) accommodated the Purana group of sediments. Thereafter the Gondwana rifting followed and superimposed on the Proterozoic graben and accommodated the Gondwana group of sediments. The final rifting (NE-SW) took place during the breakup of the Gondwana land and was followed by drifting of the separated part of the Gondwana land. The drifting was also accompanied by south easterly tilting of the basin. This tilt is clearly manifested by the monoclinal dip of the basaltic flow towards the basin. The basaltic flow (Razole formation) is further affected by a fault system called the Matsyapuri- Palakollu fault which divides the basin into two distinct regimes for exploration as well as the on-shore & off-shore part of the basin. (The target for exploration to the north of this fault are the pre-trappeans (Cretaceous and older) and to the south of it are the Post – trappeans (Paleogene & Neogene).)

KG-PG Basin, ONGC, 8th West, CMDA Tower-I, Egmore, Chennai -08; E-mail : ksridharan_z@yahoo.com

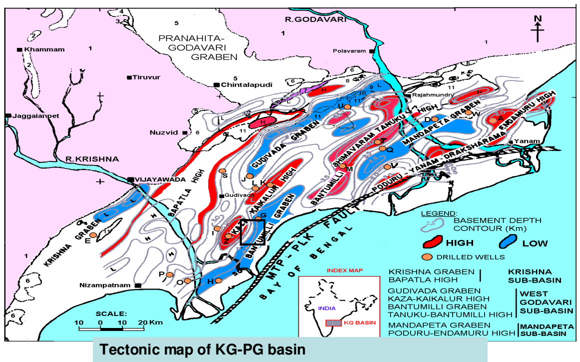

Figure 1: Tectonic map of KG-PG Basin. The Box indicates the location of the study area.

Basin configuration : The basin is marked by three grabens – Krishna sub basin, West Godavari sub-basin and East Godavari sub – basin, separated by two horsts – Bapatla high & Bhimavaram-Tanuku high (Fig-1). The West Godavari sub-basin is further sub divided into Gudivada garben & Bantumilli graben separated by Kaza-Kaikalur high. The basin displays a dispersed hydrocarbon habitat containing hydrocarbons at different stratigraphic levels ranging from oldest Mandapeta Sand to the Youngest Godavari clay in the off-shore.

Imaging challenge

Geologically the basin exhibits a very complex sub-surface picture, especially in the West Godavari sub-basin area. The sub-surface imaging becomes a challenge because of the thick basaltic layer at the shallow level in this part of the basin. The basaltic layer varies in thickness from 50 m to 160 m with depth of 500 m to 1500 m in this part of the basin. Further the area is infested with aqua and agricultural farms and water bodies which pose severe logistic challenge for the acquisition efforts. This results in in-adequate sampling of the sub-surface.

A no.of prospects have been identified in the West Godavari sub-basin on the basis of available seismic data and the drilled wells. No. of 2-D & few 3-D campaigns were undertaken for extending the prospects. Because of poor imaging of the sub-surface, proper delineation of the prospects could not be done. Clear & unique picture of the sub-surface, comprising of the basement, basement related faults, thin lenticular sands within the older sediments below the basalts etc. could not be mapped unambiguously so far. A list of the seismic campaigns done so far is listed in Annexure -1.

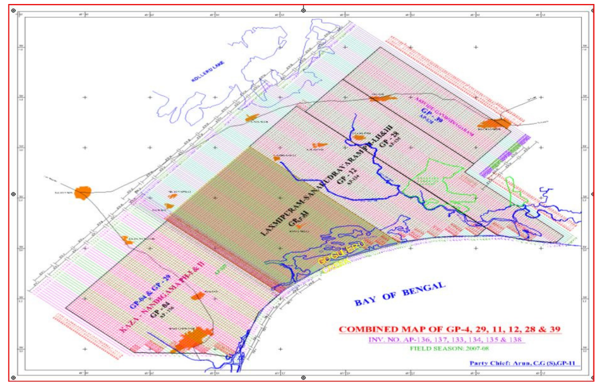

Figure 2: Areas identified for carpet 3-D

In this block, four areas were identified for detailed and satisfactory mapping. It was decided to acquire a carpet 3-D with seamless integration of the areas (Fig, 2) . It became important to adopt a systematic approach to understand the sub-surface, optimize the acquisition parameters and use proper geometry to improve the data.

Analysis of older campaigns : A thorough analysis of the earlier campaigns (Annexure-1) indicated that there were problems related to multiples, identification of basement and other horizons, clarity of the tectonic features and the structural aspects. The main reasons for the seismic imaging failure were identified as,

- Improper / In-adequate offset selection
- Poor signal to noise ratio
- Less than adequate foldage
- Logistic challenges
- Poor recovery planning for logistic gaps

Once the reasons were identified it was decided to find solutions using a systematic approach.

Methodology

A. Modeling studies : A systematic modeling study was undertaken. Models were prepared along dip & strike directions (Fig 3). For various geometries ray tracing was done and synthetic data was generated. The synthetic data was processed and analyzed. The studies indicated that there were no shadow zones or illumination problems associated with basalts and reasonably good image of the sub-surface upto basement could be obtained (Fig 4).

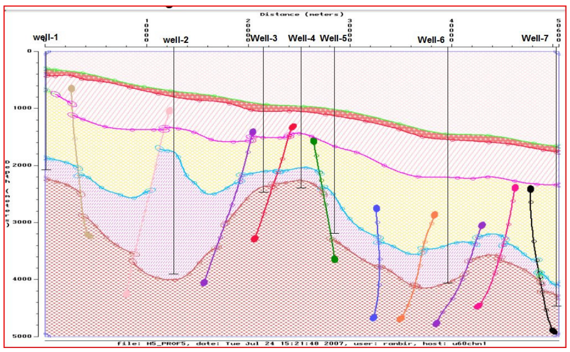

Figure 3: The digital model generated in computer using the geological model

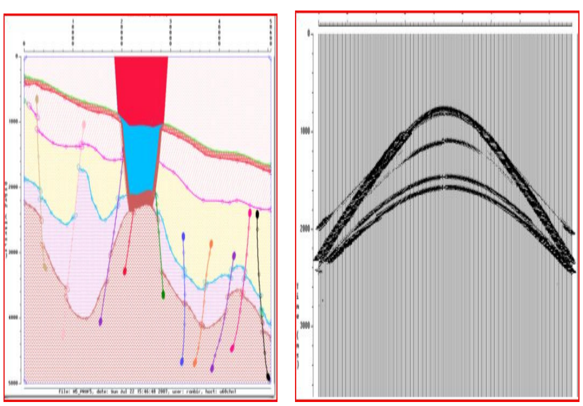

Figure 4: Synthetic shot record for sym.split spread , 5500m Offset

B. Far offset selection : One of the important parameters for data acquisition was the proper far offset for mapping the basement / deepest reflector. It was seen that the earlier investigations were woefully short of the proper far offset. With the help of modeling studies, well data and available seismic data the maximum offset needed for 30 % NMO stretch criteria was computed (Table No. 1).

Depth	V int	Vrms	2-T	Xnmo
(m)	(m/s)	(m/s)	(Seconds)	(m)
0	2000	2000	0.00	0
53	2500	2480	0.05	72
1467	3750	2533	1.18	1643
1544	3000	2597	1.23	1743
1814	2800	2603	1.41	2004
1874	3000	2674	1.45	2121
2313	3500	2875	1.74	2741
3166	3750	2954	2.23	3606
3527	3900	3051	2.42	4045
3990	3700	3073	2.66	4475
4150	5000	3341	2.74	5023

Table-1 Computed travel times, Vrms & far offset for 30 % stretch mute

C. Improving S/N ratio : The S/N ratio had been a serious concern in this area because of the basalts and logistic problems. Because of the sharp velocity contrast at the top of the basalt, most of the impinging energy is reflected back, making the transmitted energy weaker, which is further weakened at the other interfaces. More complications are brought in because of absorption & scattering within the basalt, refraction along the basalt top, multiples between the basalt & the low velocity near surface layers and interference between direct arrivals & the reflected arrivals from deeper zones at far offsets. Because of the dense population and intense human activities, the ambient noise conditions were very high. Since explosives are the best option as source, it was decided to use proper charge size & depth on the basis of experiments.

D. Optimum foldage: It was realized that one of the reasons for the poor data quality was the low foldage, to offset the lack of adequate S/N ratio. So it was important to determine the optimum foldage required. Many authors have suggested ways to compute the optimum foldage requirement from the field data. A methodlogy based on correlation functions to compute

S/N ratio and the foldage (*Mike Galbraith, Seismic Image Software)* was used as follows *:*

$$AC/XC = (S^2+N^2) / S^2$$

Re-arranging we get:

$S/N = 1 / \mathrm{sqrt}((AC/XC) - 1)$ where AC,XC were the correclation co-efficients, S & N were signal & noise .

The field records for various campaigns were studied. The auto-correlation & cross-correlation coefficients were computed. The S/N ratio for the raw data was calculated for various campaigns for different values of detectability % in terms of the acoustic contrast (fig 5).

From these Foldage can be computed as,

$$\mathbf{Fold_{required} = (S/N_{required} / S/N_{raw})^2}$$

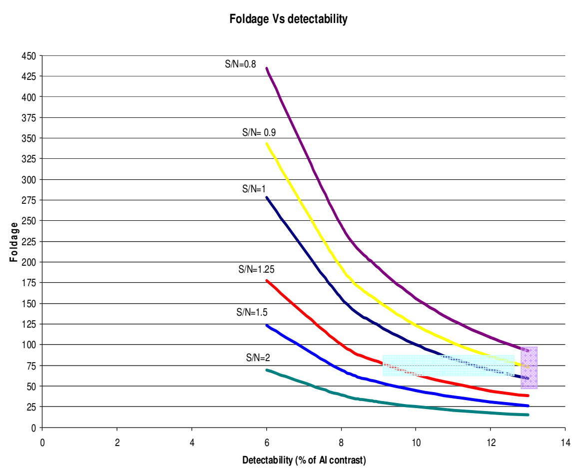

Figure 5: Foldage Vs Detectability for different S/N ratio ranges for optimizing foldage parameter

E. Logistic challenges : The biggest factor in this area of operation was the logistic problems posed by the rich agri & aqua cultural tracts and huge water bodies.. These are inaccessible areas where laying of receivers could not be done as per plan and taking shots was impossible. This resulted in data gaps & poor / insufficient sub-surface sampling of data. So it was necessary to prepare proper recovery plans to adequately cover these areas.

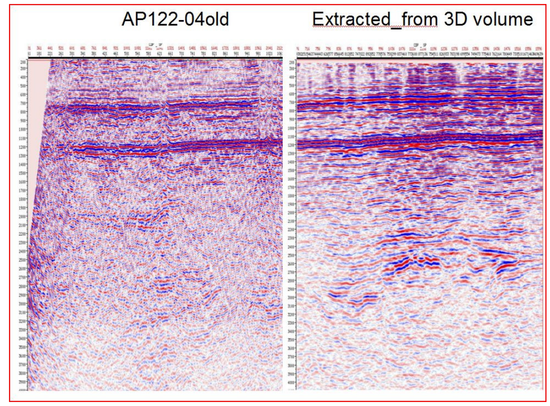

Figure 6: Comparison of vintage data with the recently acquired 3-D data

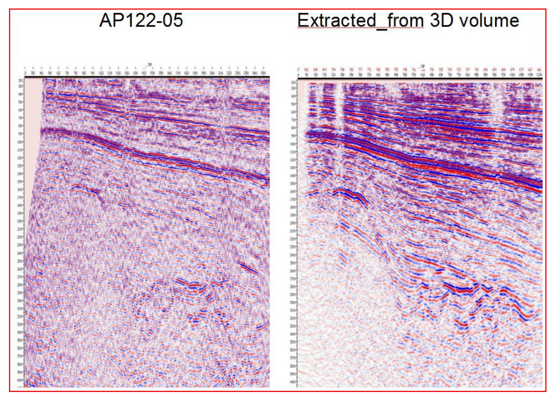

Figure 7: Comparison of vintage data with the recently acquired 3-D data

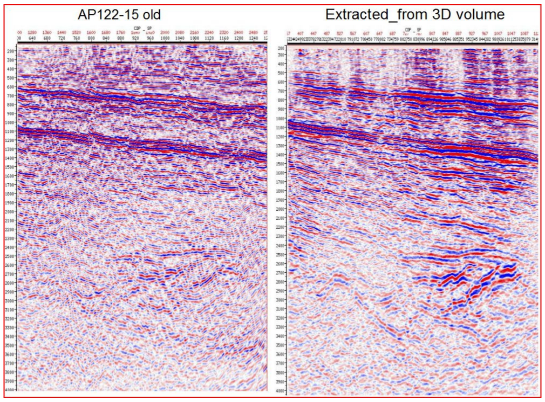

Figure 8: Comparison of vintage data with the recently acquired 3-D data

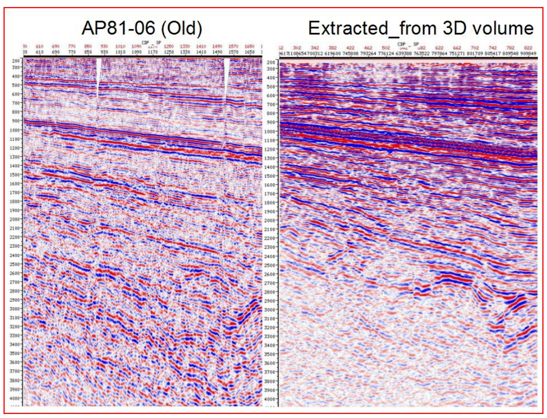

Figure 9: Comparison of vintage data with the recently acquired 3-D data

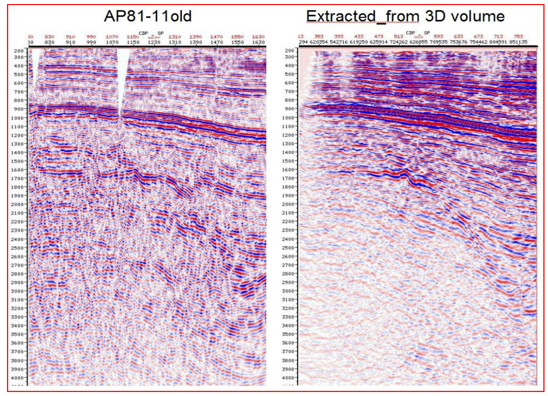

Figure 10: Comparison of vintage data with the recently acquired 3-D data

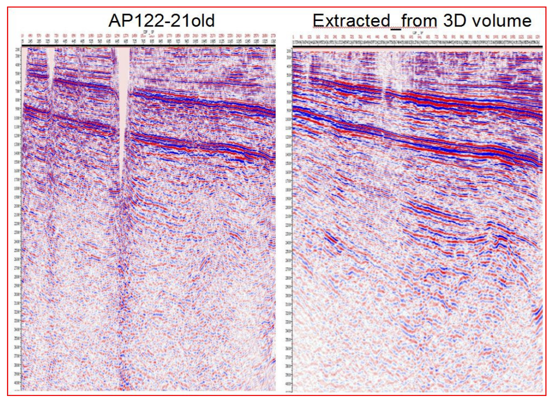

Figure 11: Comparison of vintage data with the recently acquired 3-D data

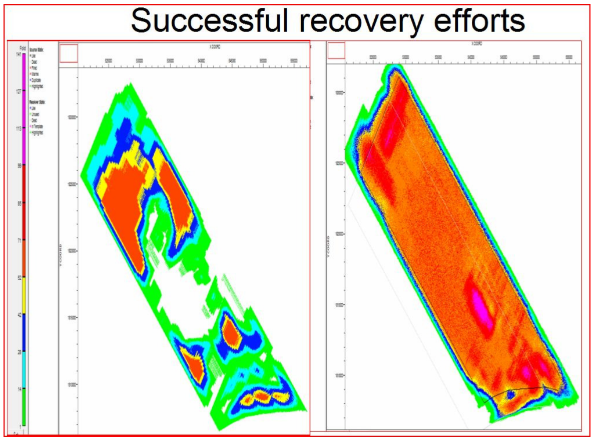

Figure 12: Foldage improvement before and after recovery management

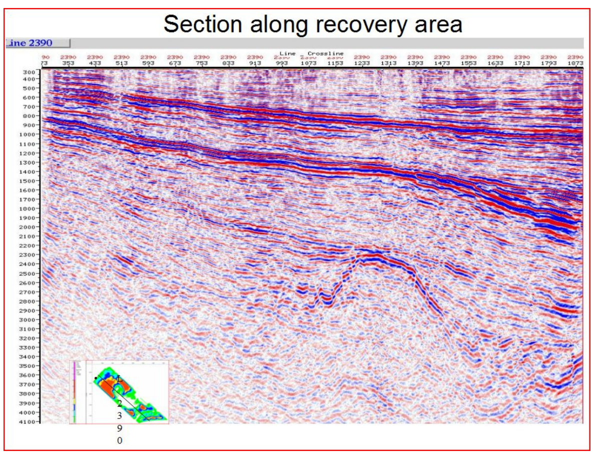

Figure 13: Section along the recovered portion shown above.

Observations & Discussion

Based on theoretical considerations and the modeling studies, asymmetric split spread type of geometry with a maximum offset of 5500 m was chosen. The most crucial parameter was to decide the optimum foldage required. The study of vintage data indicated that the S/N ratio varied from 0.8 to 2.0 in the study area. The detectability, which could be expressed as a percentage of Acoustic Impedance was found to vary from 9 to 13 % for the fulfillment of the G & G objectives. Based on the chart in Figure 4, the foldage required under various ambient noise conditions was varying from 48 to 96 for achieving the above detectability. So it was decided to go for a coverage of 8000 % which would be optimum under various field conditions, to provide the proper sub-surface imaging. The higher foldage might also provide the proper cushion for any loss of foldage due to tough logistic conditions. Other field parameters were optimized based on the field tests. Logistic challenges were addressed by suitable recovery plans based on the survey data. The planned recovery programs resulted in near recovery of the necessary offsets which otherwise would have been lost (Figure12,13). During processing suitable noise elimination programs were used for reducing the effect of cultural noise. Harmonization of offsets, amplitudes and foldages further improved the data quality.

Conclusions

The systematic approach to design the proper 3-D acquisition geometry based on the industry standard principles helped in finalizing the critical parameters. For the first time the optimum foldage required, was computed based on the methods suggested by experts, in this part of the basin. A scientific recovery management was undertaken using the proper software, which resulted in good coverage of the areas (Figures 12-13), which otherwise would have been data gaps. The result was a dramatic improvement in the quality of the data acquired. The sub-surface image provided a clear picture of the basement configuration for the entire 3-D carpet area (Figures 6-11) . It is hoped that new prospects and leads can be obtained from this data.

Acknowledgements

The authors wish to acknowledge the encouragement and guidance given by the Basin Manager (KG-PG), Block Manager (Onland – KG-PG Basin) for this study. Geological and well log data provided by Sub-Block Manager (KG- Onland) and Acerage Manager (West Godavari sub-basin) is thankfully acknowledged. Help rendered by Head, geophysical services, ONGC, Chennai, Head, RCC, ONGC, Chennai & Sri C.R,Chadrasekaran, CG(S) RCC,ONGC, Chennai for spectral studies is gratefully acknowledged. The authors express their gratitude to ONGC authorities for permission to publish this work.

References

Mike Galbraith, Seismic Image Software – A Division of GEDCO, Calgary, Alberta, Canada - A new methodology for 3D survey design.

Sridharan,K, and Kukreti, Om Prakash, ONGC, Chennai - Optimizing acquisition geometry to improve sub-surface image using modeling studies – Case study from Krishna-Godavari Basin, India

Hassan Masoomzadeh and Penny J. Barton, University of Cambridge, Satish C. Singh, IPG Paris - Advanced processing of long-offset seismic data for sub-basalt imaging in the Faeroe-Shetland Basin.

Daniele Colombo, Geosystem Srl, Vittorio Zucconi and Alessandro Bruin, Gas Della Concordia,S.P.a, marco martovani, Geosystem Srl, Seismic Long ofsets for imaging below complex overburden, SEG International Exposition & 74th Annual meeting – Denver, Colorado, 2004

H Zhou, University of Houston; P L Stoffa, University of Texas at Austin - Long-Offset Seismic Aquisition, Processing, and Imaging

Internal Reports of KG-PG Basin, ONGC

Annexure- 1

Details of geophysical campaigns (2-D)

YEAR / PARTY	AREA	GI	SI	NEAR OFFSET	FAR OFFSET	FIELD LAYOUT	CHANNELS / FOLDAGE
89-90 / GP-11	KAIK'LR-BANTUMILI	30	30	150	3000	END-ON	96 / 48
86 / GP-11	KAIKALUR	25	25	300	2675	END-ON	96 / 48
92-93/ GP11	KAIKALURU	25	25	150	2525	END-ON	96 / 48
95-96 / GP-04	KAZA-NIM'KURU	30	30	180	3030	END-ON	96 / 48
91-92 / GP-04	TANUKU-PALAKOLU	30	30	180	3030	END-ON	96 / 48
91-92/ GP-12	E OF BHIMAVARAM	35	35	175	3500	END-ON	96 / 48
91-92/ GP-28	W OF BHIMAVARAM	35	35	175	3500	END-ON	96 / 48
92-93 / GP-04	SW OF BANTUMILI	35	35	175	3500	END-ON	96 / 48
93-94 / GP-11	NSP-LANKAPALEM	25	25	300	2675	END-ON	96 / 48
94-95 / GP-04	NANDIGAMA	30	30	180	3030	END-ON	96 / 48
94-95 / GP-11	GAJALAPUDU	30	30	180	3030	END-ON	96 / 48
94-95 / GP-12	BHIMAVARAM	35	35	175	3500	END-ON	96 / 48
95-96 / GP-04	KAZA-NIMAKURU	30	30	180	3030	END-ON	96 / 48
96-97 / GP-04	MAHADEVPAT-BANTUMILI	30	30	180	3030	END-ON	96 / 48
98-99 / GP-11	BANTUMILI-LAXMIPURAM	35	35	175	3500	END-ON	96 / 48
99-2000 GP-11	KESNAPALI-SUKNETUPALI	35	35	175	3500	END-ON	96 / 48
2002-03 / GP-11	BHIMAVARAM-PENAMANDA	30	30	180	3030	END-ON	96 / 48
2003-04 GP-11	BANTUMILI-PADATADAKA	30	30	180	3750	END-ON	120 / 60
2004-05 / GP-11	MOKULU-PEYYURU	20	40	120	5220	END-ON	256 / 64

Details of geophysical campaigns (3-D)

YEAR / PARTY	AREA	GI	SI	BIN SIZE	GEOMETRY	FOLD	RLI	SLI	CHANNELS
95-96 / GP-28	KAIK'LR-LINGALA-PH I	40	80	20X40	PARALLEL SWATH	14X3	240	320	336
96-97 / GP-28	KAIK'LR-LINGALA-PH II	40	80	20X40	PARALLEL SWATH	14X3	240	320	336
97-98 / GP-28	KAIK'LR-LINGALA-PH III	40	80	20X40	PARALLEL SWATH	14X3	240	320	336
2000-01 / GP-12	SURYARAOPETA	50	50	25X25	ORTHO-BRICK	6X5	300	450	540

Table 2 : Details of previous geophysical campaigns in the area

Annexure- 1I

3-D ACQUSITION PARAMETERS	
Bin size	20 X 20 m
Foldage	10X7=70
Group interval:	40 m
Shot Interval	40 m
Geometry (Receiver & Shot point arrangement)	Assy.Split.Spread Orthogonal
No. of receiver lines	14
No. of channels / line:	120+40
Total active channels:	2240
Receiver line interval:	280 m
Shot line interval	320 m

Min Offset	28
Max.Offset	5530
Record length	6.0 sec
Sample interval	2.0 ms
Pre-amp gain	0 dB
Offset Distribution:	% of traces
0 - 1000	11.03
1000 - 2000	27.95
2000 - 3000	24.99
3000 - 4000	18.9
4000 - 5000	15.69
>5000	1.86

Table 3 : 3-D data acquisition parameters used for the carpet 3-D area

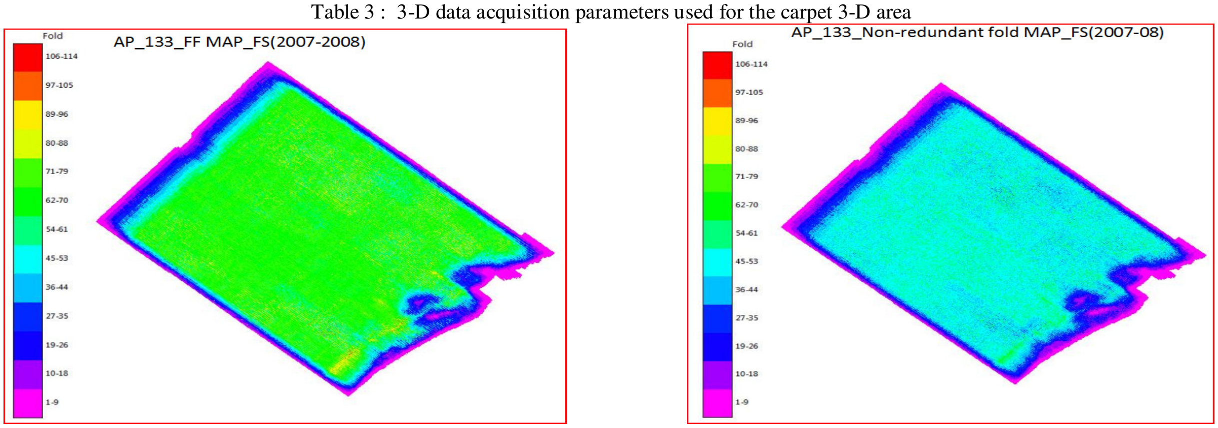

Figure 14: Full fold distribution (Left) & Non- redundant fold distribution (Right) in the 3-D area.

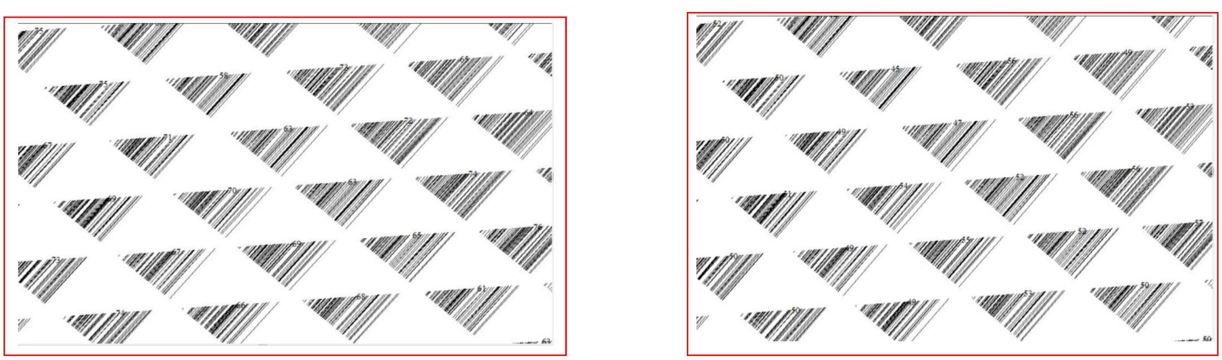

Figure 15: Offset distribution in full fold area (Left) & offset distribution in Non- redundant fold area (Right) within Bin