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Improved Sub-surface Imaging by Pre Stack Merging and Multiple Attenuation of 3D Multi- Campaigns Land Data – A case history

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Summary

Cauvery basin in southern part of India is one of the pioneer sedimentary basins in the country that has posed a sustained challenge for nearly four decades to geoscientists looking for oil and gas. Over the years, the production of crude oil from onland wells in this basin has been going up. Recurring findings for hydrocarbons in this basin has meant acquiring a substantial amount of geoscientific data, reviewing them, undertaking three-dimensional seismic surveys and then discovering the hydrocarbon reservoirs.

In oil exploration activities, 3D Seismic data acquisition & processing has been a very vital mission for critical subsurface imaging. Considering the massive 3D seismic surveys in adjoining areas, many of today's exploration vicinities have been covered with multi-campaigned 3D surveys which have been recorded over a period of several years using a wide diversity of source types, recording equipment, grid orientation, spread lengths, bin dimensions, fold etc. These data have uniquely been processed using variable levels of processing technology with varying objectives in different span of time.

In this present work, an effort was made to merge 3D onshore seismic dataset of ten singular surveys into a single mosaic volume such that one consolidated 3D mosaic volume was produced to precisely accomplish the geological objectives of the massive merged area.

Introduction

The Cauvery Basin is one of the best exposed late Mesozoic-Tertiary basins in India and is located in the southeastern part of the Indian Peninsula. This basin extends over an area of 25,000 square kilometers onland and another 15,000 square kilometers in the adjoining continental shelf in the southernmost part of the east coast of India. The basin is nearly 400 kilometers long, in a NE - SW direction and is about 125 kilometers wide.

Among the other basin in India, Cauvery basin in Tamil Nadu is one sedimentary basin in the country that has posed a continual challenge for nearly four decades to geoscientists looking for oil and gas. This petroliferous basin has thus earned a place in oil & excessive gas production of the country. In 1989, it was promoted from being a Category II basin to a Category I basin; it was thus put on a par with basins such as Cambay, Upper Assam and Mumbai offshore. The basin has meant acquiring a substantial amount of geo-scientific data undertaking several three-dimensional seismic surveys. Application of seismic analysis is considerably increased the pace of exploration as oil and gas has been found in various sediments all the way from Oligocene, Eocene, Paleocene and Cretaceous to Basement sections in this basin.

In this present study, Prestack merging of ten 3D singular onland vintages proved as a feasible alternative to expensive and time consuming re-acquisition. This mega merged volume offered a convincingly superior integrated seamless data across prospects to meet the geological objectives well within exploration time frame.

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Geological backdrop of the study area

Cauvery basin is a pericratonic rift basin, divided into a number of sub-parallel horsts and grabens, trending in a general NE-SW direction. The basin came into being as a result of fragmentation of the Gondwana land during drifting of India-SriLanka landmass system away from Antarctica/Australia continental plate in Late Jurassic/ Early Cretaceous. The initial rifting caused the formation of NE-SW horst-graben features. Subsequent drifting and rotation caused the development of NW-SE cross faults. In terms of rock types, metamorphics and igneous rocks predominate throughout the basin which marks key events of volcanism, plutonism, metamorphism and sedimentation. Figure-1 shows the prospect map of the Cauvery basin along with the study area.

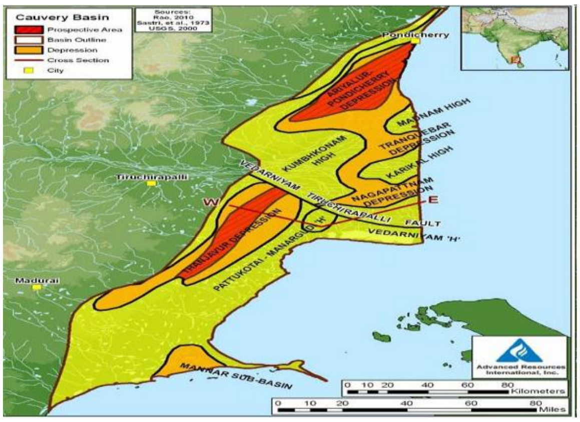


Figure-1: Prospect map of the basin showing the study area.

Reservoirs of Kamalapuram formation mostly occurs as fills with bottom cut surfaces and are typically limited in areal extent which is inferred from amount of fluid content and pressure profiles. Migration of hydrocarbons from source rock to shallow reservoirs is envisaged to be through faults and unconformities. Selective charging of only a few reservoirs may be due to favorable juxtaposition of reservoirs against fault conduits. Figure-2 represents the generalised stratigraphic sequences of the Cauvery basin. The schematic geological section through different tectonic elements of the Cauvery basin is depicted in Figure-3.

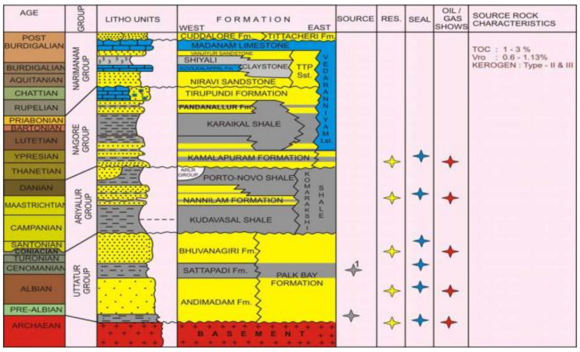


Figure-2: Generalised stratigraphic sequences of Cauvery basin.

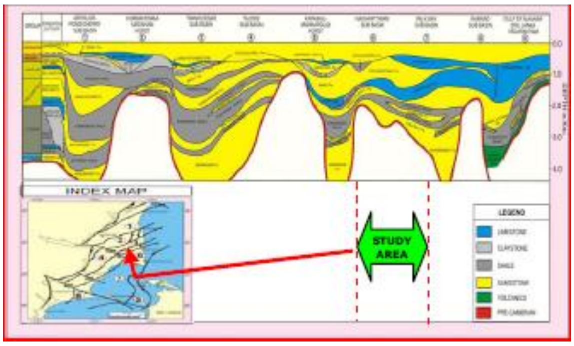


Figure-3: Schematic geological section through different tectonic elements of the Cauvery basin.

Methodology adopted for Input Data Conditioning

The mega 3D prospect of Pre-Stack Merging of ten vintages in South and North of Nagapattinam area of approximately 985 SKM pertaining to onshore area of Cauvery basin was assigned to fulfill the rationale to have a total understanding of the hydrocarbon prospectivity of the Nagapattinam sub-basin with respect to structural and stratigraphic features in the study area. The main objective of the survey was to bring out basement configuration and syn-rift sequences, to improve the basement sequence mapability above and below KT and to improve albian section.

The seismic data of all the ten onshore campaigns were acquired in different span of time over a long period of fifteen years (1994 to 2009) using a wide diversity of source types, recording equipment, grid orientation, spread lengths, bin dimensions, fold etc. The details of acquisition parameters of all the ten vintages are replicated in Table-1.

COMPARISON OF ACQUISITION PARAMETERS OF ALL 10 INVESTIGATIONS										
Campaign Nos.	M - 1	M - 2	M - 3	M - 4	M - 5	M - 6	M - 7	M - 8	M - 9	M - 10
Acq. Year	2008-09	2003-04	2007-08	1994-95	1995-96	1996-97	1999-00	1999-00	2000-01	2006-07
Instrument	I/O Scorpion	408 UL	I/O Scorpion	MDS-8	MDS-8	DFS-V	MDS-8	SN-388	SN-388	408UL
Channels	2560	864	2352	288	288	240	240	432	432	1620
Recv. lines	16	6	12	6	6	4	4	6	6	10
CI	40	40	40	50	40	40	50	40	40	40
SI	80	80	40	100	80	80	100	40	80	80
RLI	320	240	280	70	80	80	70	80	80	240
SLI	400	360	560	70	80	80	70	80	80	360
Fold	8X8	8X6	7X6	36	36	30	30	36	36	9X5
Far offset	6400	3600	5530	2500	2040	2600	3100	3000	3000	4200
Shooting Pattern	Orthogonal END ON	Orthogonal SPLIT SPREAD	Orthogonal SPLIT SPREAD	Swath ENDON	Swath ENDON	Swath ENDON	Swath ENDON	Swath ENDON	Swath ENDON	Orthogonal SPLIT SPREAD

Table-1: Comparison of acquisition parameters of all ten campaigns.

In the multi-campaigns of ten separate investigations shown in Figure-4, various acquisition geometries and instruments had been used in all these 3D vintages. During the lengthy fifteen years of acquisition span, 3D seismic data were acquired in this area using MDS-8 to I/O Scorpion system employing simple end-on swath shooting to orthogonal split-spread/end-on geometries. Wide variations of number of receiver lines per swath from 4 to 16 and also fold from 30 to 64 were put into operation in diversity. Offset and azimuth distribution too varied with far offset from 2040m to 6400m. Keeping these dissimilar distributions under a single merged hypothetical dataset was certainly a very critical and challenging task.

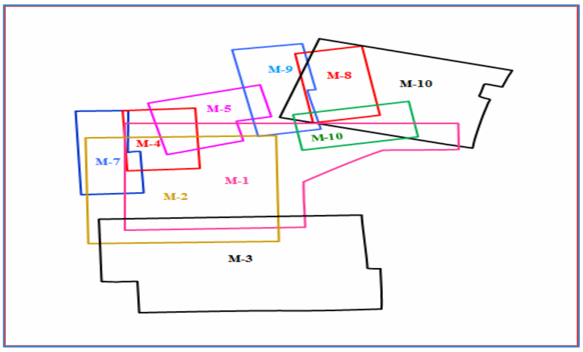


Figure-4: Merged layout view of all campaigns.

To begin with, a master grid was made to accommodate all multi-campaign data. Then, the signal conditioned CMP gathers of all individual vintages were loaded into the master grid. The fold map of the input CMP gathers in the master grid is shown in Figure-5. Due to differences in the orientations of different vintages, the fold seen in the master grid looks jittery. In the overlap zones, the fold was as high as 200-300 at some places. The entire azimuth and offset ranges were considered for PSTM processing.

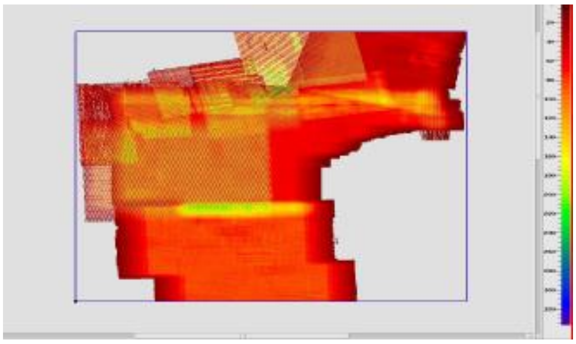


Figure-5: Merged CDP fold view of all campaigns.

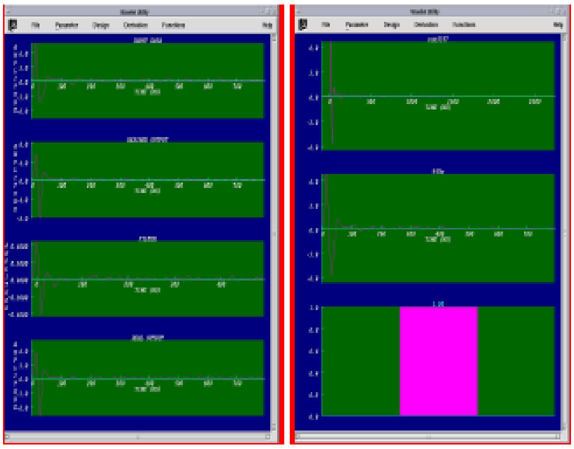
The aim of the 3D prestack merge leading to a mega combined volume was to establish a mean to combine these individual seismic vintages such that to use the merged data in totality to have a comprehensive understanding of the hydrocarbon prospectivity of the Nagapattinam sub-basin with respect to structural and stratigraphic features in the study area.

For merging of these multiple 3D surveys, the selection of base survey was a vital issue depending upon the input data superiority as well as to fulfill the specific interpretation requirements. The centrally located M-1 data was considered as the base seismic survey for the requisite prestack merging depending upon the input data quality as well as having suitable overlap with all other prospects being the central one.

All the data of different campaigns were individually processed in their distinct respective grid for standard signal processing. Consequently, after proper data conditioning of all the campaigns individually, they were put together and re-grided into a master common grid. Thereafter, in the common master grid, some further processing steps comprising bulk time shifts, scaling, static matching, amplitude matching, wave shaping were undergone to bring all the seismic data into the same level of outputs.

The critical task for prestack merging was to design suitable matching filters to match each data set comparing the chosen base survey data of M-1 3D volume. The matching filters of all data set were designed comparing the base survey M-1 through extracting wavelets from all datasets separately and thereafter applied on those data sets individually to bring up all the data to the same level of chosen base survey M-1. Meticulous quality-check had been done to design the matching filters by extracting wavelets from all the individual datasets as the improper designing of the matching filters do affect the quality of the merged data resulting in relative deterioration on the individual volumes especially with different orientations.

The designing of matching filters for all the individual data sets were done from their respective extracted wavelets to get the desired output equivalent to base survey data M-1. The extracted wavelets of input data and the desired output, the corresponding designed matching filter and their convolved real output on a representative surrounding 3D dataset are shown sequentially in vertical strips in Figure- 6(A) and thereafter the quality check for matching between the convolved output and also with the desired output of the base survey M-1 are shown in Figure-6(B) through pink coloured square bar diagram which replicating 100% normalized equivalence.

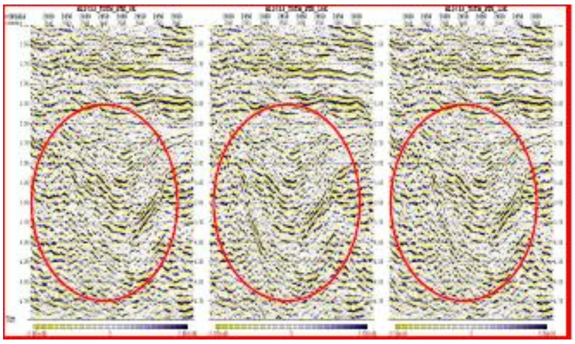


(a) (b)

Figure-6: (A) The footsteps of designing of matching filters and (B) Quality check of the desired convolved output with base data.

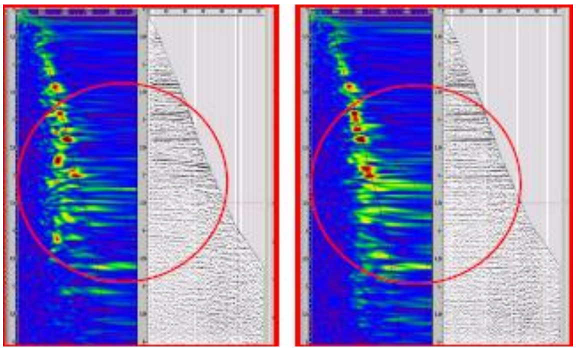
After application of matching filter, all the data were individually checked and then a unified mega-merged volume of all the conditioned gathers was prepared prior to perform Pre-stack Time Migration. The essential of a successful migration needs an adequate aperture and the aperture refers to the spatial range of the migration operator. The aperture required for migrating a seismic data depends on the maximum dip present, the depth and offset. For imaging to be successful the aperture must be widespread enough to capture the reflection raypath of any reflection of interest.

If the aperture is not wide enough, amplitude will not be migrated to the actual reflector position and imaging will not be successful. The consequence of too large an aperture is increased imaging time and conceivably increased noise. Figure-7 shows the response of varying migration aperture on PSTM stack outputs and it replicates that the migration with 16 km. Full aperture optimally imaged the dipping events more prominently in this merged data volume.



(A) (B) (C)

Figure-7: The impact on PSTM Stack for varied migration aperture with full aperture of (A) 8 km; (B) 16 km; and (C) 12 km.



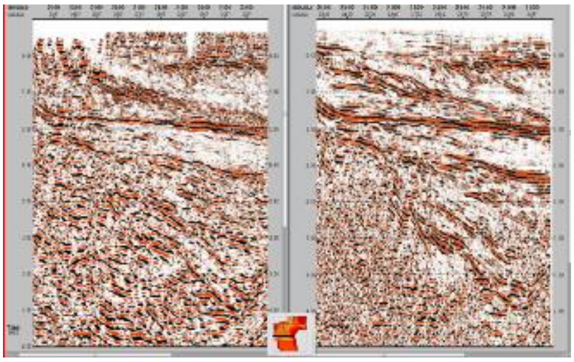
(A) (B)

Figure-8: The PSTM Gather output alongwith the semblance plot (A) Before removal of multiples & (B) After removal of multiples.

After running PSTM on the mega-merged singular conditioned gather, it was perceived from the PSTM gather output that some enduring multiples were vulnerably present in the data and the consequent migrated gathers were not flat (Figure-8A). The primary and multiples events could be distinguished and separated from their moveout differences. The primary reflection events were expected to be flattened and the multiple reflection events had residual moveouts. These moveout differences between primaries and multiples could be used to attenuate multiples and sequentially, de-multiple technique was applied using parabolic radon and the migrated gathers were made multiple-free (Figure-8B). The corresponding semblance plots were also compared and correspondingly revealed the removal of inter-bed multiples from the pre- stack migrated gathers thereafter. Successively, on the migrated stack data, post-stack deconvolution was also applied to remove the residual multiples.

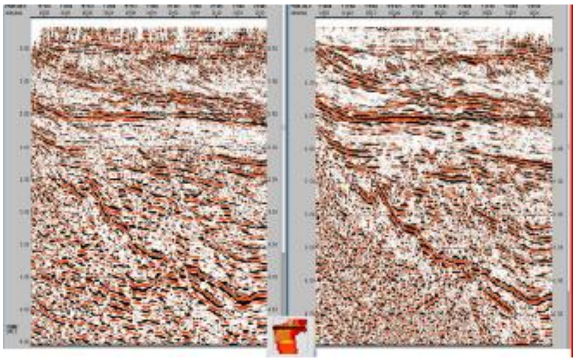
Results and Comparisons with Preceding Data

The level of confidence of correlativity was incredibly high in the final migrated output of the mega merged volume. The deeper reflections also had been clearly brought out providing lead to deeper exploration objective. The comparison of some outputs replicated in Figure-9 to 12 (showing locations of the extracted lines in black colour in the inset map) of the 3D pre-stack merged volume with earlier individual volume. It was observed a significant improvement in the stratigraphic as well as the structural complexities in the 3D pre-stack mega merged volume comparing to the earlier individual volume.



(A) (B)

Figure-9: Comparison of PSTM sections of Inline 2100. (a) Earlier 3D individual volume PSTM Stack and (b) 3D Pre-stack merged volume PSTM Stack.



(A) (B)

Figure-10: Comparison of PSTM sections of Inline 2200. (a) Earlier 3D individual volume PSTM Stack and (b) 3D Pre-stack merged volume PSTM Stack.

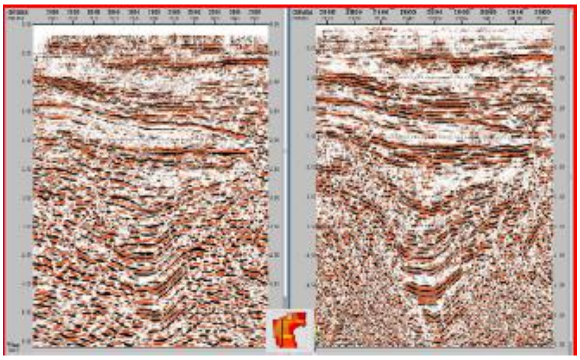


Figure-11: Comparison of PSTM sections of Crossline 2800. (a) Earlier 3D individual volume PSTM Stack and (b) 3D Pre-stack merged volume PSTM Stack.

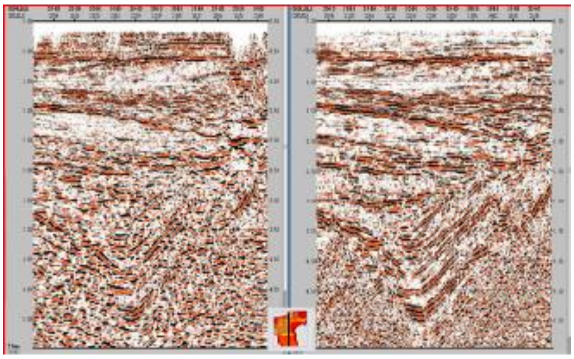


Figure-12: Comparison of PSTM sections of Crossline 3040. (a) Earlier 3D individual volume PSTM Stack and (b) 3D Pre-stack merged volume PSTM Stack.

In this study, the attempt of pre stack merging to merge ten different 3D survey data sets into a single mosaic which ultimately revealed an excellent & seamless mega merged volume. Successively, this process of 3D prestack merging achieved better geologic features as well as produces the perfect and most truthful image of the earth's subsurface for mapping faults & trap, fracture zones, channel edges, pinch-outs, unconformities and basement configuration.

Conclusion

The rationale behind the prestack merging of seismic data acquired in ten campaigns with varying acquisition geometry and parameters was a meticulous and critical process to produce the truthful and most accurate image of the Earth's subsurface in the study area. The merged output precisely revealed the improved imaging of the basement configuration with enhanced continuity and well-resolved syn-rift sequences. Application of parabolic radon and poststack deconvolution were very much effective to remove the multiples which were camouflaging the basement mappability thereafter reducing the interpreter’s confidence in the earlier volume.

The outstanding improvement in the migrated 3D merged seamless volume would definitely be pertinent for truthful interpretation to fulfill the effort to have a total understanding of the hydrocarbon prospectivity of the Nagapattinam sub-basin with respect to stratigraphic as well as structural intricacy. The signal stand-outs were better illuminated and well resolved in the zone of interest which in turn was liable to enhanced understanding of mappability of faults & trap, unconformity and basement configuration.

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Views expressed in this paper are that of author(s) only and may not necessarily be of ONGC.

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