MERGING OF DIFFERENTLY ORIENTED 3D SEISMIC DATA SETS

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Introduction:

The 3D surveys of Nannilam, Kuttanallur and Adiyakkaniangalam overlap with North-Kamalapuram 3D area. They were planned independently and hence the grid orientations and bin sizes were chosen to meet their respective objectives at the time of planning these surveys. The grid orientation, in-line and x-line directions of these 3D data sets are shown in figure 1. The bin size for Adiyakkamangalam and North-Kamalapuram is 20m x 40m and the bin size for Nannilam and Kuttanallur is 25m x 35m. They were processed and interpreted separately.

The interpretation of the seismic data sets and later drilling results showed that Kamalapuram formation of Paleocene-Eocene age contain a number of hydrocarbon bearing sands that are good producers with limited aerial extents. This has necessitated a re-look into the various seismic data sets comprehensively along with well data to understand the sand geometry and depositional environment and bring out a geological model for further coloration. As can be seen from fig. 1, most of the wells are at the boundaries of the individual 3D areas where the confidence level in correlation and mapping the prospective areas is low. Therefore it was decided to merge these four overlapping 3D data sets into a single master grid encompassing them, to look at the area as a whole for interpretation (1). In doing so, the orientation and the bin-size can be conveniently chosen to meet the new requirement. The advantage of a single 3D volume is that one can use the interactive interpretation tools effectively by the use of time/horizon slices, RC lines, cube displays, fault correlation, correlation of well log data with sequence attributes etc.

Integration of the independently acquired and separately processed data sets require matching of the amplitudes, time shifts and phase shifts besides interpolation of the traces to the differently oriented bin centres of the chosen master grid without smearing the dipping events. But most of the 3D data binning programs re-compute the line and trace numbers with respect to master grid and vertically sum the traces falling in each bin to generate the merged data. The quality of such output depends on the choice of the master grid and its bin size because of the non-uniform distribution of the input bins of different orientations and sizes with respect the master grid. In other words the variation in the number of traces falling in each output bin affect the quality of the merged output traces. Another problem is that the trace interpolation programs work on regular 3D data to change the bin size in either in-line or cross-line or both directions, but do not reorient the bin during interpolation. Therefore it was not possible to merge the four data sets using the seismic software packages available on our interpretation Workstation/Computer centers. Therefore it became necessary to devise a method and develop custom-made soft-
ware for this purpose. The work was carried out on the HWS at SRBC, ONGC, Chennai without hampering the on going interpretation projects. “The overall method including data conditioning and merging will be illustrated using the results at different stages in the following sections.

Reference data & Master Grid

Figure I gives the outline of the live data of the four grids showing their orientation and the overlapping areas. The only data set that is overlapping the other three data sets is North-Kamalapuram. Hence it was chosen as the reference data set and it’s orientation as the orientation of the master grid as it suited best for mapping Kamalapuram formation. The master grid was chosen to encompass most of the data from all the four 3D data sets as shown in fig. 1. It was limited towards the East with the boundary of North-Kamalapuram and beyond that only part of Adiyakkamangalam data exists.

A square bin of size 20m X 20 m was chosen for the master grid as it provides better perspective displays and better suited for computation of volume based attributed for further analysis.

Overall Methodology

The various steps involved in the methodology chosen are listed below.
1. Generation of Re-Construction lines from the reference data set corresponding to few in-lines and cross-lines of the other three data sets in the overlapping area.
2. Computation of frequency spectra and selection of common frequency bandwidth for matching the four data sets.
3. Computation of residual amplitude decay and least squares fit to obtain the exponential gain in the zone 1.0-2.5 sec.
4. QC of the decay functions and application of exponential gain and scale factors to match the amplitudes.
5. Deriving the time shifts and phase shifts required for each of the three data sets relative to the reference data set.
6. Cross-line sort and trace interpolation of the data sets in the cross-line direction to reduce the bin size close to that of the output bin dimension.
7. Estimation of individual contribution at each output bin center from the nearest four overlapping interpolated input bin traces using linear prediction coefficients, (the method is described under section Re-orientation of bins to master Grid.)
8. Linear tapering of individual output traces at the boundaries of the input data sets in the overlapping zones and obtain the output traces as a weighted sum.
9. Checking for the improvement of frequency bandwidth using predictive deconvolution on the final output.

Generation of RC lines :

For the purpose of deriving parameters to match the seismic data traces of Nannilam, Kuttanallur and Adiyakkamangalam 3D data volumes with the reference data volumes with the reference data volume i.e. North-Kamalapuram, we choose one inline and one cross-line from each one of the above three data sets. These section fall within the full fold mi
grated area of North-Kamalapuram and their respective areas. The convention followed in assigning names for the sections is NKM - for North Kamalapuram, NLM - for Nannilam, KTM - for Kuttanallur, ADK - for Adiyakkamangalam _T for cross-line, _L for in-line, _RC for reconstruction-line.

For example NLM_T290 is a cross line from Nannilam 3D data volume, while RC_NLM_T290(or simply RC_T290 if the context is understood) is the reconstructed cross line equivalent to NLM_T290 from reference data set.

Comparison of Input Data

Figures 2, 3, and 4 represent three sections NLM_T290, KTN-L52 and ADKJL225 respectively chosen from Nannilam, Kuttanilur and Adiyakkamangalam data sets. The RC lines corresponding so these sections, generated from North Kamalapuram data set, are also shown side by side. Tune variant gain is not applied so that the input can be compared as it is. In case of Nannilam, high frequency noise is seen. Amplitude variation with respect to time is more in case of Nannilam and Adiyakkamangalam.

Selection of Frequency Bandwidth

As the frequency bandwidth and phase decide the width and shape of the wavelet that has to be matched before merging, it was decided to keep usable common bandwidth for all the four data sets. The frequency spectra of the four input data sets, shown in figures 5, were generated in the window of 1.0 to 2.0 sees which contains the events corresponding to kamalapuram formation.

From the figure one can see that for all practical purposes the usable bandwidth common to all data sets can be taken as 8hz-40hz with a maximum usable frequency around 75 hz will reduce the frequency amplitudes in this range, especially in case of Adiyakkamangalam. But these amplitudes can be retrieved and the frequency bandwidth can be improved up to 6hz-60 hz through post stack predictive deconvolution that will be shown later.
Residual Amplitude Decay

It is not possible to normalize the amplitudes of the four data sets without considering the variation of the amplitude decay. It was observed that the contribution to RMS level from random noise was considerable in the case of Nannilam data, and hence the decay curve was computed after filtering the noise. The residual amplitude decay functions averaged over the individual data volumes are shown in figure 6a. In case of Nannilam and Adiyakkamangalam, the amplitude decay to be compensated was considerable while in case of Kuttanallur and North Kamalapuram it was marginal. The decay curves of the individual lines were quite close to the average trend for the entire volumes. There is a large variation from 0 to 600ms due to the differences in the near trace offset and mute functions for the four data sets. Therefore 0 to 600ms time window was excluded from the least square fit to compute the exponential gain constant. Table 2 shows the gain constants for the four data sets that were used to compensate for the decay. Figure 6b shows the variation of amplitude with time after application of the exponential gain. The average RMS levels were computed from the live samples of the entire data set to be used for normalization of the four data sets. The Scale factors were chosen from the RMS levels for each of the data sets so that the maximum amplitude does not exceed the 16bit limit i.e. +/- 32565. But at this stage they were not applied, as they could be refined during the seismic balance stage where we derive the time and phase shifts.

Table 1.

<table>
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<tr>
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<th>NLM</th>
<th>KTN</th>
<th>ADK</th>
<th>NKM</th>
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Deriving time shifts and phase shifts

Due to the differences in the acquisition and processing parameters the traces from different 3D data sets corresponding to the same ground location will exhibit differences i.e. they do not tie with one another. The more the differences, the more the miss-tie of corresponding events in terms of amplitude, bulk time shift and phase shifts. The bulk time shift could be genuine or caused by lateral imaging problems. But within the fully migrated area, we assumed that the differences due to one-pass time migration in case of KTN&NKM and two-pass time migration in case of ADK & NLM, were minimal as the smoothened DM0 corrected velocity field had been used in migration in case of KTN & NKM and two-pass time migration in case ADK & NLM, were minimal as the smoothened DM0 corrected velocity field has been used in migration process. We also assumed that the shape of the wavelet over the entire volume of each of the
data sets was consistent and that they differ from one data set to another by a constant phase shift for all the frequencies within the signal bandwidth. This was another reason to choose the common range of frequencies 4-8-40-75 within which we were confident about the signal.

With these two assumptions one can use the Seismic Balance (2) utility available on HWS, to derive the bulk time shift, constant phase shift and a scalar, and try to adjust a) the time shift in the events, b) shape of the wavelet and C) the amplitudes. In case the second assumption fails, it is still possible to design a matched filter to apply frequency dependent phase shifts. On the other hand, if the first assumption fails, then post migrated data can be merged and it becomes necessary to merge DM0 stack data and then migrated the merged DM0 Stack volume.

Using the interactive facility within the seismic balance, the bulk time shift, the constant phase shift and the scalar were obtained with four different sets of traces in each of the three cases of Nannilam, Kuttanallur and Adiyakkamangalam. All the four sets of traces gave the three parameters consistently. These parameters are given in table 1. To verify the quality of match, the parameters were applied on several in-line sections of the other three data sets and compared with their corresponding reconstruction lines from the reference data volume. For an easy comparison the sections NLM_T290, KTNJL52 and ADK_L225 and their corresponding reconstruction lines were juxataposed and presented in figure 8, 9 and 9.
respectively before and after the application of the derived time and phase shifts in the window 1.0 to 2.0 sees. The mismatch seen (top) in the original data sets is almost nil after application (bottom) of the time shift and phase shift. There is a good match of the events from the three data sets with that of references data.

**Application of Parameters, Resampling**

During the application of these parameters, we considered the data management aspect for all the steps to follow. Once the phase shift filter is applied with the maximum frequency to pass as 75 hz, the sample rate of the filtered seismic trace can be increased to 4ms. Similarly, after application of the scale factor, the common RMS level for the four data sets can be conveniently chosen so that the amplitudes can be presented in 16 bit-integer format, which is also a SEGY standard. With these two measures, the total data volume reduces to one fourth of the original data without any loss of generality. With the application of the derived exponential gain, time shift, phase shift and scalar, the four data sets are conditioned and were ready to construct the traces of output grid.

**Re-Orientation of bins to Master Grid.**

As mentioned in the introduction, it is not so straightforward to bin the traces corresponding to different grid orientations and bin sized to a common grid. The tree-step procedure developed in-house (3) was adopted in computing the integrated 3D data set. The steps are described below.

**a) Cross line Sort & Interpolation**

One of the major problems of trace interpolation is the spatial aliasing of dipping events. The higher the frequency the more the spatial aliasing. In the present case, the highest frequency preserved was 80 hz and at that frequency, spatial aliasing occurs for those events who's dips are greater than 6 ms per trace. After scanning through several in-lines and cross-lines from the different data sets, it was found that the events of interest have dips less than 6ms per trace. When spatial aliasing is not a problem as in the present case, interpolation of traces using 'SINC' functions in frequency-space (f-x) domain provides accurate solution. This technique works with traces of uniform trace spacing and can be used for crossline interpolation of each data set.

During the cross-line, sort, we did not change the nomenclature of in-lines and cross-lines, so that after interpolation the line spacing...
of the output interpolated data becomes half of the original line spacing. The traces from each cross-line were converted to frequency domain and the interpolated traces were generated using the eight point ‘SINC’ interpolator for mid point interpolation.

Figures 10 a and 10 b show a reconstruction line equivalent to NLM_L152 form North Kamalapuram data before crosss line interpolation (left) and after cross line interpolation (right). One can see the improved quality of the reconstructed line generated from cross line interpolated data due to the availability of more traces close to the reconstruction path. This step was important because ‘reorientation of the grid essentially means reconstruction of lines in the desired orientation. After cross-line interpolation, the average distance of the nearest bins of the output grid form any of the input bins is less than 8m and the input bins (400sq.mt for NKM and ADK, 437.5 sq mt. for NLM and KTN) and output bins (400sq.mt) are almost of the same size.

b) Re-Orientation to output grid

On a time slice, the seismic trace amplitudes appear as contours and they represent several horizons of varying dips. The amplitude data of the time slice are already arranged in a grid of control points. What we want is another set of control points arranged in the required orientation and spacing. This can easily be achieved by trend-fitting techniques. The output grid amplitudes also represent the same time slice as if the time slice is generated from the input grid control points. Therefore we can generate output time slices from input time slices at every time sample. Now it is a matter of collecting the amplitude values from all time slices at each of the output grid control points to generate traces corresponding to the output grid locations. The actual implementation of this method is described below. Figure II shows part of the location map of an input grid locations. The thick blues lines are the in-lines of the input grid with red dots showing the actual trace locations. The thin blue lines correspond to the interpolated in-lines with the blue dots showing the x-line interpolated trace locations. Obvisouly the dotted blue lines are the input x-lines. The output master grid bin locations are shown as green dots. Generation of sample values at the output bin locations require interpolation from the input sample values around each output bin. Let dx and dy are the relative coordinates of an output bin location with respect to the lower left bin of the four surrounding input bins. The area enclosed by the four input bins contains the output bin and within this area one can safely assume that at any given time level there will be only one event without any restriction on the dip of that event, i.e. the events at different time levels can have different dips. Considering the small area of a bin, it is also very much valid that the trends within the area of a bin are linear. Therefore the sample value for any given time at the output bin location can be computed using linear amplitude trends. These trends are defined by the amplitude derivatives taken along the in-line and x-line directions. After re-arranging the terms, it so happens that in the case of linear trends, the output sample value can be rewritten as a weighted sum of the four surrounding input sample values. The weights which we call the linear prediction coefficients depend only on the relative coordinates (dx,dy) and not on the actual sample values. This is very significant because the same prediction coefficients are valid for all time samples and instead of working with time slices one can work with traces. In this way at each output bin location falling within an input 3D grid, a trace can be computed from that 3D input trace data. The output trace headers have
**Fig 12.** In-line L260 from the merged 3D volume passing through the Nannilam, North-Kamalpuram, Kuttanallur and Adiyakkamanaglam

**Fig 13.** X-line T230 from the merged 3D volume passing through Nannilam, Kuttanallur and North-Kamalpuram
Fig 14. Time Slice from Merged Data
to be updated with respect to the output master grid. In overlapping areas, there will be more than one output trace per bin, but all of them represent the same sub-surface location and therefore they can be summed by assigning weights to them.

c) Output integrated 3D volume

The overlapping boundaries of the input data sets were not always full fold migrated. At places the overlap is within the low fold zones. The migration artifacts at the boundaries of the data sets were different for the four data sets. Therefore we analyzed the area where only the edges were overlapping to choose the cutoff and taper, if the overlapping area falls within the full fold migrated zones of the input data sets, equal weights were given to the contributing traces. The output traces were normalized depending on the number of contributing traces and the edge taper. After generating the output integrated 3D volume, the first 12 samples of each trace were filled with the following information to enable the user to adjust / re-calibrate the amplitudes if required. Samples 3, 5, 7, 9 of each trace contain the RMS level in the window 800-2800 ms and samples 4, 6, 8 and 10 contain the percentage contribution/weight factors from the data of Nannilam, North Kamalapuram, Kuttanallur and Adiyakkamangalam respectively. The RMS level and multiplicity of the combined trace are stored in samples 11 and 12 respectively.

Figure 12 shows the inline L260 from the merged output 3D data set which passes through Nannilam, North Kamalapuram, Kuttanallur and Adiyakkamangalam areas. Figure 13 shows the cross-line T230 passing through Nannilam, Kuttanallur and North-Kamalapuram. They show excellent continuity and consistency across the data sets and hence the confidence in using the merged volume.

A more comprehensive way of looking at the entire volume is by way time slices. Time slices from 1620ms to 1760 ms are shown at intervals of 20ms and 40ms alternately, to show the excellent continuity and consistent match through out the data volume. The final overlap areas of the input data sets after trimming the edges can be obtained from time slice at 48ms corresponding to multiplicity of merged data. This helps in identifying any trends in the attributes extracted from the integrated data, which may coincide with the transition zones from one data set to another.

Improving the Bandwidth

As we have taken the usable frequency bandwidth as 8hz - 40hz and 75 hz as the maximum frequency to be retained for the purpose of merging the data sets, we tried to see if we can use the simple predictive decon to improve the frequency bandwidth. The frequency spectra of the merged data (blue) and the frequency spectra of deconvolved (red) merged data are presented in figure 15 (predictive deconvolution with 20ms prediction distance and 240 ms operator length). They show the kind of improvement in bandwidth one can get.

Conclusion and Recommendations

The intermediate results at different stages and the time slices from the final output presented in the previous sections show that the misfits between the input data sets could be corrected and an excellent consistency could be obtained for the output merged data. This gives us the confidence to use the data not only for mapping to the horizons of interest but also to make use of the amplitudes, generated volume/sequence attributes etc to derive an appropriate seioeological model as envisaged. From the encouraging result shown in figure 15, we suggest that an appropriate frequency enhancement program
should be tested and applied to the merged 3D volume asper the interpreters requirement.

References


3. Meiging of Differently Oriented 3D Seismic Data Volumes, Project Report by Dr. J.V.S.S.N. Murty and T. Shankar

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