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Low Frequency Migration Technique to image fractures below Sub Basalt or Trap - A Brief Analysis

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Summary:

Seismic data imaging quality mainly depends on the Seismic signal energy that reaches the exploration target layer after penetrating overlying formations and returning to the surface. The strong impedance interface of the overlying formations has a screening effect on the transmission of the wave field, thus weakening the reflection signal energy from the target reservoir. As a result, in such areas it becomes very difficult with very poor seismic imaging quality. To solve such problems, preservation of low-frequency signals in the acquisition as well as in the processing of seismic data is important as the low-frequency signal has a stronger capability against absorption and scattering. In normal processing sequence we use all frequencies during migration but if we restrict our frequencies during migration itself, the results are different. This paper deals with the analysis carried out by low frequency migrations on different prospects having different objectives. It is observed in case studies that with low frequency imaging, fractures are visible where as in normal imaging with all frequencies, fractures may not be visible.

Introduction:

Seismic imaging of target reservoirs in the areas overlain with large seismic impedance values, the conventional seismic exploration method faces stern challenges. The screening effect on the transmission of the wave field by strong impedance interface of the overlying formations weakens the reflection signal energy which resulted to poor seismic imaging quality. Oil and gas exploration in such areas becomes very complicated. It is necessary to get down to the basics, such as analyzing wave propagation in these regions and trying to find effective methods to boost the deeper-layer signal energy and lower the interfering wave energy, to solve these exploration problems. Apart from the effective methods for this purpose, such as converted wave exploration and wide-angle seismic surveys, attempts have been made to use the low frequency migration algorithms for imaging such reservoirs as the low-frequency signal has a stronger penetration with minimum absorption and scattering. Therefore, the preservation of low-frequency signals and subsequent migration of these low frequencies only helps precision for these target layers. Meanwhile, the low frequency signal contains additional weak reflection information which can be used to study the internal reflection characteristics of the reservoir such as oil. Also migration operator is frequency-selective across the migration aperture: it passes all temporal frequencies of the input traces in the innermost portion of the aperture (referring to the shallow dips), and gradually cuts out the higher frequencies as it approaches the outer portion of the aperture. Thus, while all frequencies of the input data contribute to the shallow-dip portion of the migrated image, only the permissible low frequencies of the input data contribute to imaging the steepest dips. The brief introduction of two migration algorithms is given below to compare the low frequency migration results with each other and with normal all frequency Kirchhoff's migration results. The case studies from different basins having different objectives are then discussed here separately along with encouraging results.

Kirchhoff Migration:

Kirchhoff migration has been a major tool over the past decade for pre-stack seismic imaging. It is efficient and can image steep dips with turning waves. While the imaging accuracy of single arrival Kirchhoff' pre-stack depth migration has been sufficient for all but the most challenging structural imaging problems, accuracy comparisons with many wave field extrapolation methods have often brought out its limitations. In complicated geology, where several arrivals are required to give a good image by its principle, choosing of single arrival Kirchhoff migration will produce a degraded image as it does not

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preserve the amplitudes as compare to other multi arrival migration algorithms viz Reverse Time Migration.

Reverse Time Migration:

Another migration algorithm based on extrapolation back in time while using the stacked section / gathers to be the boundary condition at z=0 is known as Reverse Time Migration. The algorithm can handle dips up to 90 degrees with the accuracy of phase-shift migration. The important consideration is that the extrapolation step Δt in Reverse Time Migration must be taken quite small, usually a fraction of the input temporal sampling interval. This then makes the algorithm computationally intensive. When velocity set up is complex then Reverse Time Migration images subsurface by running the WE for source forward in time and by running the WE for receiver back in time for each shot followed by their cross correlation and summing the partial image generated by each shot. Any diving wave or any up going wave field are therefore accounted. This is not a new concept for the industry but highly computational intensive and therefore costly too with superior results which accounts for all ray paths. It offers amplitude preservations and accounts for phase beneath the caustics handles high frequency variations of velocity field. It increases S/N due to lesser aliasing. Therefore integrity at steep dip > 70^0 and for complex velocity model is acceptable. Since it's computational requirement is very high and frequency dependent, therefore, it is being used at low frequencies like 17 Hz etc.

Case Study-I:

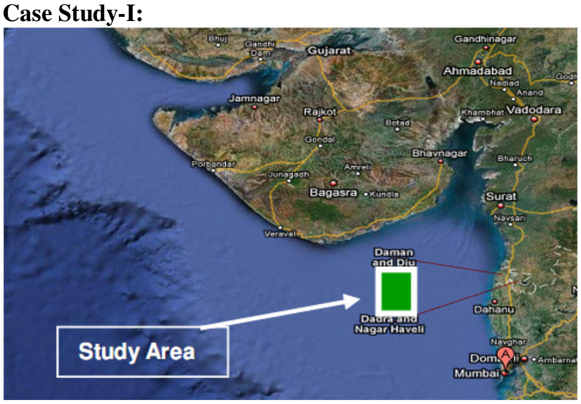

Fig-1: Location Map for Case study-I

This case study is from Western Coast of Indian basin **(Fig-1)** where the objective was below trap and Kirchhoff's 3D PSDM with all frequencies could not produce the desired results where as the same migration algorithm was restricted to low frequencies at 17 Hz and 20 Hz on a line where well was located. The low frequency Kirchhoff's migration shows some feature like fractures below H5(trap) at 2way time around 1500 to 1750 ms which was not visible in the normal depth / time migrated section **(Fig-2)**. Results of Common angle migration (CRAM) on the same dataset for the same line also show the features like fracture at low frequencies **(Fig-3).** It is generally not expected that a low frequency band pass filter on migrated data with all frequencies can produce the same results as the case for low frequency migration. The low pass band filter 5-10-18-22 Hz on the migrated section with all frequency did not produce the results which was achieved with low frequency migration (**Fig-4**).

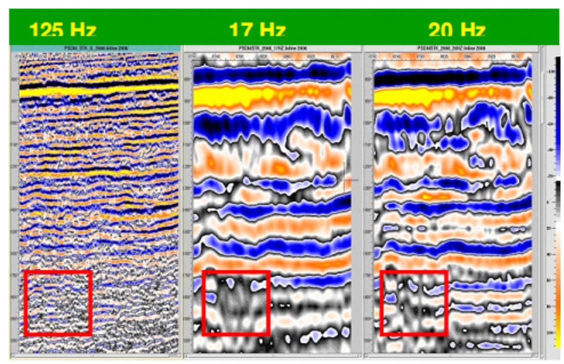

Fig-2: Comparison of PSDM at low frequency

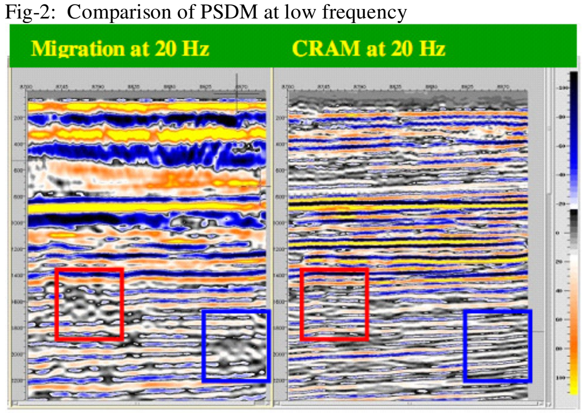

Fig-3: Comparison of PSDM at 20 Hz Kirchhoff's & CRAM

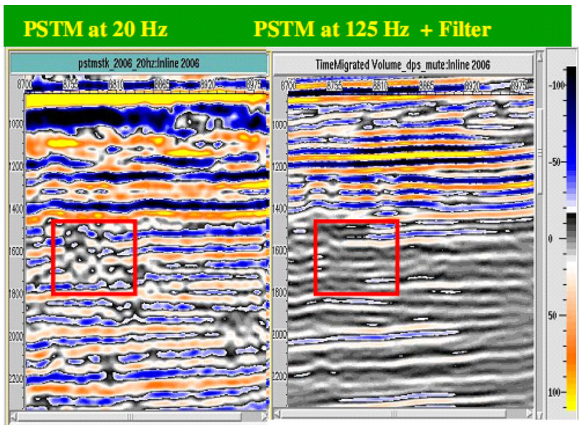

Fig-4: Comparison of PSTM at 20 Hz with PSTM at 125 Hz with band pass filter

Case Study-II:

This study has been carried out on a data set from Gulf of Kutch, India **(Fig-5)**. The primary objective was to improve the seismic imaging of Mesozoic basin sediments lying beneath the Deccan Trap where previous post-stack and pre-stack time migration volumes have been unable to bring out sufficient resolution of the structure. The dominant frequency beneath the basalt was about 17 - 20Hz, with maximum useful frequency about 30Hz.

Fig-5: Location Map for Case Study-II

Different depth migration algorithms were tested viz; Kirchhoff migration, Wave Equation migration, Beam Migration and Reverse Time migration on the same data set. Kirchhoff migration with all frequencies shows a noise with lesser strength signal at lower section in comparison to other Migration for the same interval velocity and aperture. Since RTM is directly related with the max frequency of migration output being the costly affair in the industry, the freq parameter was kept as low as 17Hz which has resulted in higher amplitude strength and a lower frequency from top to bottom in comparison to the other migrations tested. The results for Kirchhoff's migration (all frequencies) are compared with RTM output (at 17 Hz) to show the impact of low frequency output during migration when objective is below trap **(Fig-6)**. Here again a low frequency Kirchhoff's migration at 17 Hz was generated to match with RTM at 17 Hz output. The RTM imaging is still superior in terms of imaging, signal strength and fault resolution but the results of low freq Kirchhoff's migration are comparable **(Fig-7)**.At the same time, the results of low freq Kirchhoff's migration (at 17 Hz) are better in comparison of Kirchhoff's migration with all frequencies **(Fig-8)**, where trap and the sequences below are mappable.

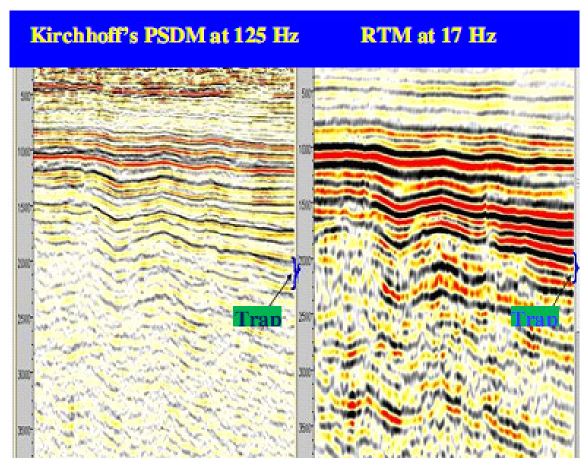

Fig-6: Comparison of PSDM at 125 Hz with 17 Hz

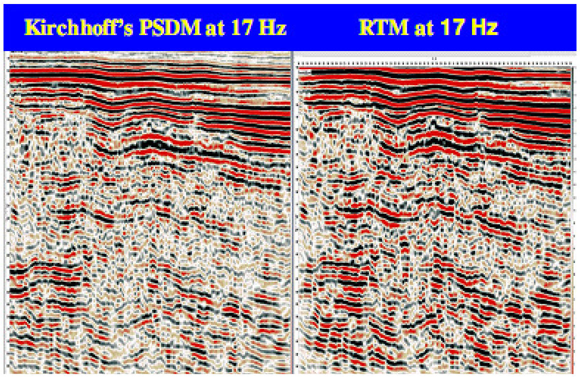

Fig-7: Comparison of low freq migration at 17 Hz

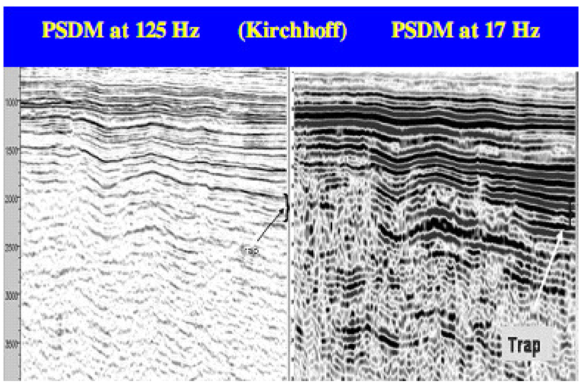

Fig-8: Comparison of PSDM at 125 Hz with 17 Hz

Case Study-III:

This case study is taken from Vietnam Offshore **(Fig-9)** with the objective to image the basement and basement related fractures for exploration of possible entrapment of hydrocarbons.

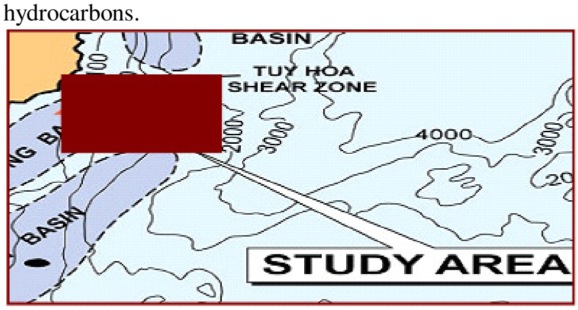

Fig-9: Location Map for Case Study-III

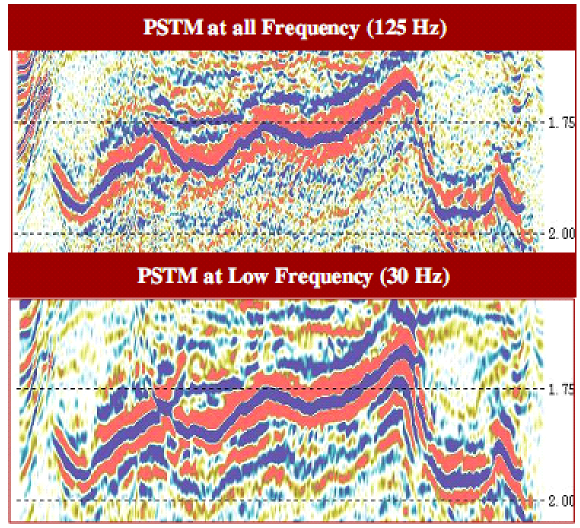

Fig-10: At low freq PSTM Basement fractures are visible

These fractures like features are found producing at the nearby block within the basin. The normal Kirchhoff's Time migration with all frequencies has been carried out. The basement and related fractures are seen on the section but when the migration at different frequencies was tested, the low frequency Kirchhoff's Time migration has shown the features of fracture basement in a better way **(Fig-10)**.

Case Study-IV:

The study area falls in Western offshore block of Indian Basin **(Fig-11)** along the western rising flank, over a half graben, close to the western horst block and followed by a basinal low to the eastern part. The low followed the same basinal NNW-SSE trend and continued till the end of Early Eocene. It became the main pathway for clastics input from north. This case study is with an objective to map detailed structural and strati-structural dispensation of the reservoir for hydrocarbon exploration and to image the fault boundary around the proposed well location. Here Kirchhoff's 3D pre stack time migrated image with all frequencies was generated where it was found difficult to put the proposed location based on other related studies. A low frequency Kirchhoff's PSTM results at 17 Hz and 20 Hz compare to full frequency migration could be suitable to put the faults correctly and proposed well location could be corrected (**Fig-12).**

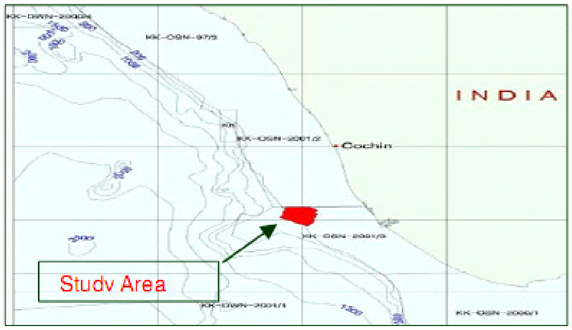

Fig-11: Location Map for Case Study-IV

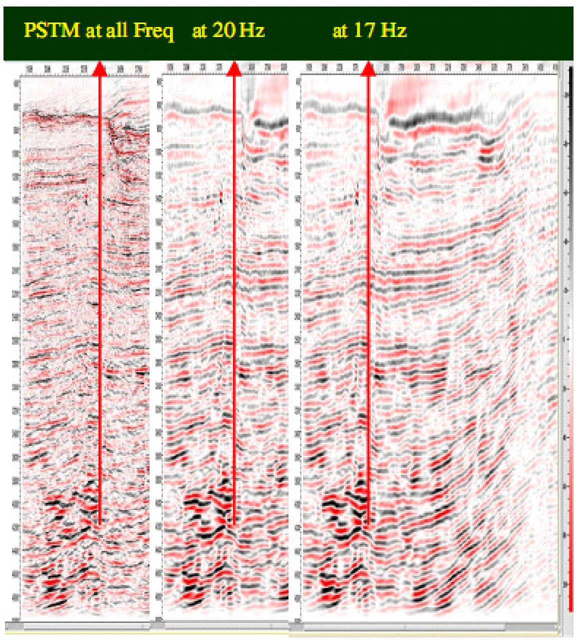

Fig-12: Imaging of Fault boundaries at low freq migration

Discussion:

Results from Case Study-I shows vide **Fig-2,3 & 4**, the fractures below trap can be imaged using any migration algorithm at low frequencies. Band pass filtering after imaging will not help in getting the desired results. Also **Fig-2, 3 & 4 (blocked portion)**, the features are related to Mumbai offshore basement where the fractured zones are mostly associated with poor continuity and poor quality of the reflectors with decreased seismic amplitude. Observed decrease in the spatial autocorrelation of seismic amplitudes, decreased frequency bandwidth and increased attenuation are inferred to be plausible evidence for the presence of fractures as these observations are consistent with expected fracture signatures. The blocked zones of the figures are highly discontinuous in nature and can be attributed to the seismic response of fracture in the present scenario. Case Study-II shows that though RTM at 17 Hz is giving the best imaging results but Kirchhoff's imaging at 17 Hz can also be used to get the quick and low cost object oriented results. Case Study-III results shows that the basement and basement related fractures can be mapped using low frequency migration. It is not necessary that always a 17 Hz or 20 Hz migration will produce the desired results. The actual frequency can be lower or higher than the 17 Hz as the case may be. Present imaging with 30 Hz has given the desired results. **Fig-10,** is related to Cuu Long Basin, offshore Vietnam. In this area, the fractured granite basement forms an excellent reservoir rock, and is the main target of exploration and development activities. For an evidence sake, the **Fig-13** given below is from a case study to image the top of the basement and the fractures inside the basement. However in Fig**-10** of our study, the fractures are very small. Similarly, the low frequency imaging in Case Study-IV has proved to be effective to put the faults correctly which interns helped in placing the well at correct location.

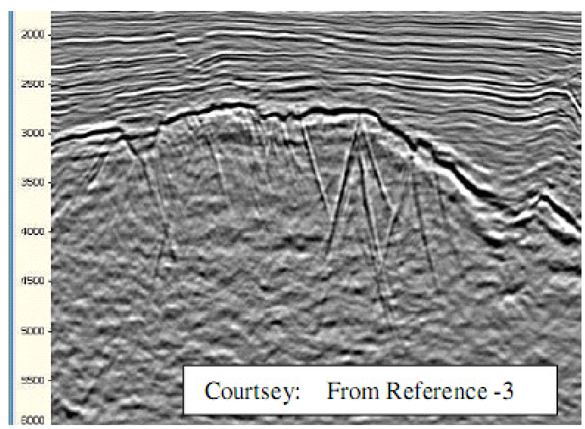

Fig-13: Imaging of Fault fractures inside the basement

Conclusion:

- The preliminary study suggests about the frequency dependency of seismic imaging at low frequencies.
- The low frequency imaging technique is not only for the identifying the fractures, faults, sub basalt imaging but also a effective low cost tool.
- This technique can be used in target oriented sense as it produces the over all low frequency output as the case for RTM.
- Band pass filtering after imaging will not produce the desired results.
- Any migration algorithm will work in low frequency imaging.

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Don Pham etal, "Imaging of Fractures and Faults Inside Granite Basement using Controlled Beam Migration" published in *SPG2008*