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Common Reflection Angle Migration (CRAM) for improved input to reservoir description – an example from Mumbai High Field

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Summary

A new seismic subsurface imaging technology is presented for generating high-resolution, amplitude preserved, angle dependent reflectivity gathers in the local angle domain. Such local angle domain common image gathers (CIG) can be obtained from a multi arrival, ray based Common Reflection Angle Migration (CRAM) creating an uniform illumination at the subsurface image points from all directions. The Common Reflection Angle gathers are ideal input for Amplitude versus Angle (AVA) and pre-stack inversion studies since they are amplitude and phase preserved. We take a look at the results of using such CIG data as input to reservoir characterization workflows on Mumbai High field. Comparisons are made with conventional Kirchhoff migration results.

Introduction

Amplitude preserving seismic processing workflows incorporating Kirchhoff pre-stack migration, have been used in the industry since the mid 1990s with the resulting migrated gathers being used as input to AVO/AVA and reservoir characterization workflows. Today, there is an ever increasing demand for advanced velocity modeling and imaging techniques to provide an improved knowledge of subsurface structures in geologically complex areas as well as more accurate and quantifiable description of reservoir properties.

CRAM is specifically designed for detailed velocity model determination; target-oriented, high-resolution reservoir imaging; accurate AVA and reservoir property extraction; and imaging data recorded in areas of complex structure and velocity. The migration supports isotropic and anisotropic models, and can be performed using all types of marine and land datasets, including OBC/OBS.

The CRAM algorithm is extremely versatile; thus it can be adapted to any exploration objective. It can be used for fullvolume imaging with full-apertures. It can also be run over small target areas of interest with background dip-azimuth information, leading to a model-driven aperture for achieving fast turnaround, high-quality and high-resolution performance.

We present an example of carrying out CRAM on a subset of data from Mumbai High field. The CIGs are used as input to inversion and the results are calibrated with a well and compared to inversion results from conventional Kirchhoff PSDM.

Theory

In order to overcome the possible kinematic and dynamic artifacts on common image gathers generated by common offset and common shot Kirchhoff depth migrations that may adversely affect determination of accurate reservoir properties, a reconstruction of common image angle gathers are needed (Xu at al. (2001), Koren et al (2007). CRAM (Koren et al, 2002 and Koren et al, 2008) is a multi-arrival, ray-based migration that uses the whole wavefield within a controlled aperture. Unlike conventional ray-based imaging methods working in depth-offset domain, the ray tracing is performed from image points up to the surface, forming a system for mapping the recorded surface seismic data into the Local Angle Domain at the image points. CRAM's imaging process combines a number of ray pairs representing the incident and reflected/diffracted rays from the subsurface. The procedure is based on a uniform illumination at the image points from all directions, ensuring that all arrivals are taken into account while amplitudes and phases are preserved.

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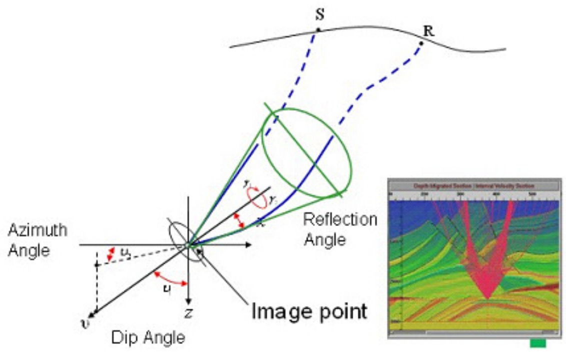

Figure 1: Local Angle Domain Imaging parameters; opening reflection angle $\gamma 1$ and azimuth $\gamma 2$, ; dip angle $\upsilon 1$ and azimuth $\upsilon 2$.

Mumbai High Example

The Mumbai High field is located off the western coast of India, in the Arabian Sea about 160 kilometers north-west of Mumbai. The dimension of the field is roughly 70 kilo meters long and 25 kilometers wide. The field is doubly anticline bounded to the east by a NNW –SSE trending fault. The field is split into northern and southern blocks by an east-west trending graben which acts as a permeability barrier. The water depth ranges from 40-90 meters and average water depth is about 70 meters.

Mumbai High is the largest producing oil field of India which was discovered in 1964 with the first exploratory well being drilled in 1974. Production from the field started in 1976 and since that time the field has been developed extensively.

The most important oil and gas reservoir in this field are Miocene carbonates but results have also been found in Paleocene basal clastics, Cretaceous basalt, and Achaean metamorphic rocks.

In October 1997 PGS acquired an ocean bottom cable 3D seismic survey over the Mumbai High field. It was then processed and interpreted by PGS at SPIC, Panvel, Mumbai.

In 2005, Paradigm reprocessed the ocean bottom cable 3D seismic data over the entire 1750 sq km seismic data of bin size 12.5m x 12.5m for Pre-Stack Time Migration (PSTM) and Pre-Stack Depth Migration (PSDM) on the bin size of 12.5m x 12.5m in order to resolve the reservoir heterogeneity and predict the depth of the reservoir with accuracy of 2m. Although the detailed velocity modeling and depth migration largely achieved the objective of providing a much more accurate mapping of the reservoirs in depth, the output pre-stack depth migrated gathers were found to be problematic in their suitability for mapping reservoir properties with confirmation.

In order to assess whether CRAM could provide more accurate reservoir properties to the updated reservoir models, a small feasibility study was carried out at ONGC's SPIC at Panvel. The feasibility study was carried out on 7.5 sq.km output data around well N11/5 delivering angle dependent reflectivity gathers which are well corrected for amplitude and phase distortions and fit for subsequent reservoir description studies. The Common Reflection Angle Migration gathers were inverted for Pwave and S-wave impedance, tied to well logs and compared to results from conventional Kirchhoff PSDM.

The existing velocity model derived in 2005 through Kirchhoff PSDM modeling was used for the study in a workflow described in Figure 2.

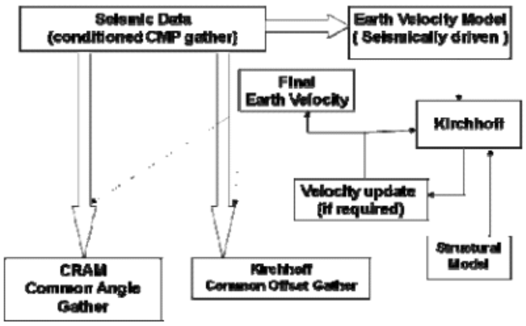

Figure 2. CRAM Imaging Workflow

The Initial model is shown in section through inline 2706 in Figure 3.

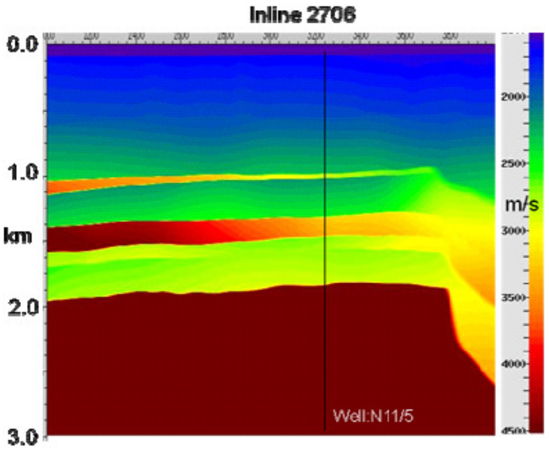

Figure 3. Interval Velocity Model through inline 2706

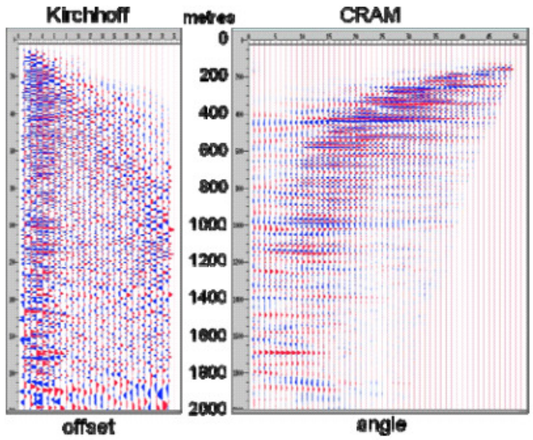

Figure 4. Comparison CIGs from inline 2706 and crossline 3210 near well N11/5

Comparison of the image gathers in Figure 4 shows that the CRAM data are less noisy, with reflection events appearing more continuous than the Kirchhoff data, particularly near the reservoir zones below 1000 metres. The CRAM data also contain less phase and amplitude distortions.

In the case of Mumbai High, it has been suggested by the sub-surface team that the reservoir zone of LIII is contaminated by short period multiples that have been generated from LII and the water bottom or near water layer inter-bed type multiple. This effect is shown below in Figure 5 where the dotted lines represent the short period multiple interference that passes through the LIII reservoir zone.

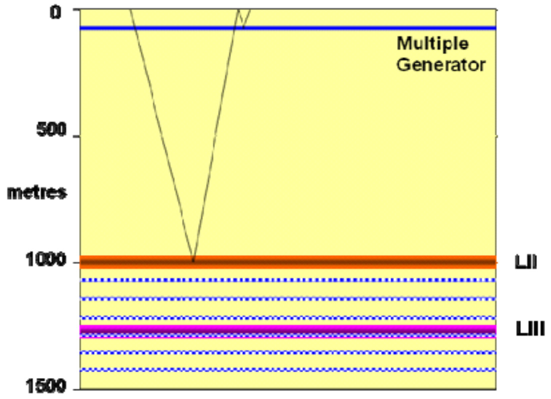

Figure 5: A schematic of multiple generating model for Mumbai High

Attempts at removing the short-period multiple in previous processing were not very successful, particularly since there is no velocity discrimination between primary and multiple events, meaning that methods such as radon demultiple do not work.

CRAM has the potential to internally "kill" multiples by performing a tapered local slant stack in the imaging condition. In addition to shot-receiver locations and traveltimes, each seismic event is now associated with a specific direction on the surface. This additional condition significantly reduces the probability for imaging multiples. The unique advantage within the CRAM is that the local slant stack operator is performed individually for each event (to be migrated), having access to accurate ray parameters (directivity) and accurate estimation for the size of the local slant stack operator (Fresnel zone for each ray).

When we examine the data in Figure 4 more closely, the Kirchhoff CIG does appear to be contaminated by shortperiod multiple energy. This is proven by matching the sets of seismic data with the well. The reflectivity match with CRAM is higher than with Kirchhoff. A composite display of CRAM with VSP corridor stack from well N11/5 is shown in Figure 6. The match with the data ahead of the drill bit was found to be extremely good.

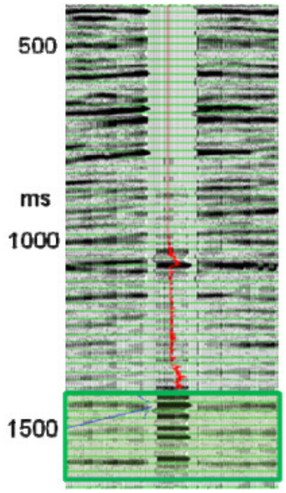

Figure 6. VSP Corridor stack from well N11/5 with CRAM seismic composite display. The shaded zone highlights image ahead of the drill bit.

The fact that the CRAM data are less contaminated by short-period multiple in the reservoir zones also implies that the CRAM data are better suited for pre-stack inversion.

Three angle stacks of angle bands 0-15, 15-30 and 30-45 degrees were generated for input to pre-stack inversion. The extracted wavelets are very consistent across angle bands and are shown in Figure 7.

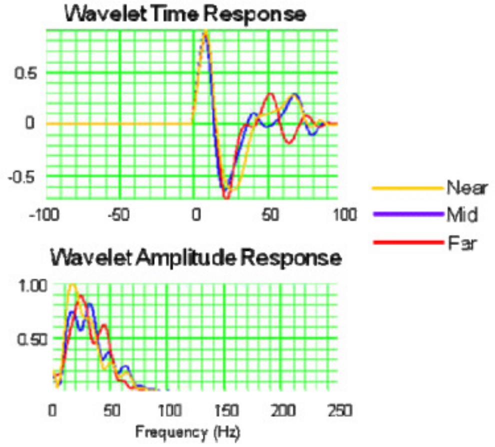

Figure 7. CRAM angle dependant wavelet extractions.

The data were inverted for P and S impedance using the same background models. The impedance results from CRAM matched the impedance logs from well N11/5 almost perfectly and were much improved when compared to impedance results from Kirchhoff data, revealing more detail and consistency for stratigraphic interpretation. The P impedance output along inline 2706 is shown in Figure 8 with the P impedance curve from the well inserted.

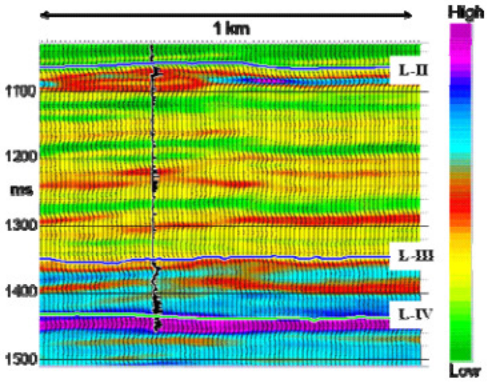

Figure 8. P-Impedance derived from CRAM data with P impedance log from well N11/5 inserted.

Conclusions

An example of Common Reflection Angle Migration carried out on a small area of Mumbai High field has been presented and the results compared to Kirchhoff PSDM.

In this example, the imaging quality of CRAM is superior to Kirchhoff and is proven by the improved match with the VSP corridor stack from well N11/5.

Short-period multiples, which contaminate the reservoir intervals making higher order reservoir studies problematic, appear to be reduced by the CRAM process.

The extracted wavelets on full and angle stacks are more consistent on the CRAM data than the Kirchhoff data suggesting that the CRAM data are more suitable for AVA, inversion and higher order reservoir characterisation workflows.

Results from pre-stack inversion to impedance were examined and compared, with the result from CRAM having an extremely good match with the log data and appearing to show more interesting detail in the reservoir interval. As an extension, reservoir properties derived from CRAM data should be more reliable when used to populate updated reservoir models.

The output driven feature of CRAM means that target oriented migrations can be used to investigate reservoir zones of interest very efficiently.

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