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Common Reflection Angle Migration (CRAM) for improved input to reservoir description – An example from offshore India

Dean K. Clark, Maheswara Phani Babu, Paradigm; K.Neogi, Deepak Sareen, ONGC*

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 a 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 offshore India field and their examples. 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 one of the offshore fields of India. The reflection angle gathers are used as input to inversion and the results are calibrated with a well and compared to inversion results from conventional Kirchhoff pre-stack migration. Another example highlighting seismic-well reflectivity match is examined and the CRAM result is compared with that of Kirchhoff.

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 wave field 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,

Dean.Clark@pdgm.com
Paradigm, 7th Floor, C Wing, Eureka Towers, Mindspace, Link Road, Malad (W), Mumbai 400064, India

ensuring that all arrivals are taken into account while amplitudes and phases are preserved.

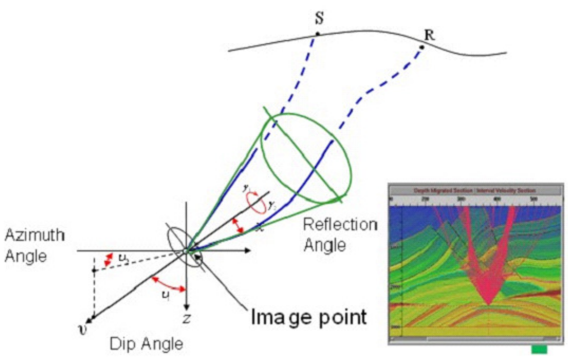

Figure 1: Local Angle Domain Imaging parameters; opening reflection angle γ1 and azimuth γ2, ; dip angle υ1 and azimuth υ2.

Example

The study area is from one of the offshore basins of India. The seismic data cover an area of 200 sq.km. and contain 300 inlines and 2000 crosslines. One single well composite log suite as well as VSP data were available for the study. Key horizons required for building the background model for inversion were also made available. The well was drilled to a depth of approximately 4.5km.

The objectives of the study were to compare the quality of CRAM CIG gathers and stacks with Kirchhoff gathers and stacks and evaluate the suitability of each type of data for extended reservoir characterization workflows including advanced velocity analysis, AVA and inversion. The results could be calibrated by matching with the available well data.

An initial velocity model supplied by the client was used for both the Kirchhoff and the Common Reflection Angle Migration. The input data to the study were unmigrated CMP gathers that had been processed through a conventional amplitude preserving processing sequence up to and including demultiple.

Figure 2 shows example Kirchhoff angle gathers and CRAM gathers at the same location. The event located at around 3.5km and highlighted in red, shows that for Kirchhoff, after conversion to angle domain, the useful data range is up to 28 degrees whereas for CRAM gathers at the same depth the angle coverage is up to 35 degrees. It may also be noted that the CRAM gathers contain events that appear less noisy and more continuous when compared with the Kirchhoff angle gathers. The higher angle coverage and improved continuity suggests that the CRAM gathers would be more suitable for use in AVA studies and other higher order reservoir characterization workflows.

Angle Gather Kirchhoff CRAM

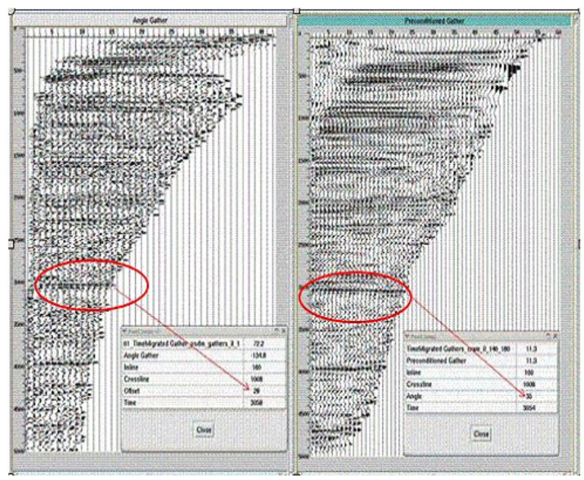

Figure 2: CRAM and PSDM Angle gathers at inline 160 and crossline 1524

Figure 3 shows the general workflow for the study. After preparation of well and VSP data, synthetic seismograms were created for matching with the Kirchhoff and CRAM stacked sections, after scaling to time. Residual moveout was carried out on the CRAM and Kirchhoff data independently and it was found that the residual moveout update was more stable with the CRAM data than the Kirchhoff data. Wavelets were estimated separately for both the Kirchhoff and CRAM data for full angle and two partial (near and far) angle stacks.

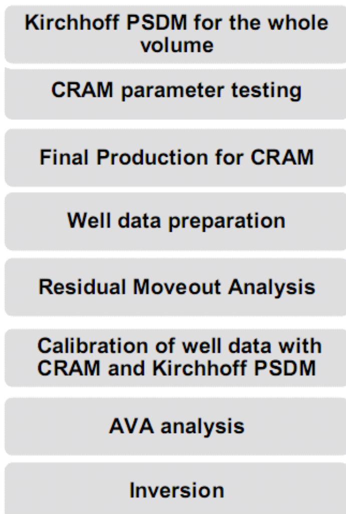

Figure 3. General Workflow for the Study

Figure 4 shows composite displays of seismic sections with synthetics for full angle stacks for both Kirchhoff and CRAM for crossline 1524. A better match is seen with the CRAM than Kirchhoff stack section, which was supported by the higher correlation values as shown in Fig 5

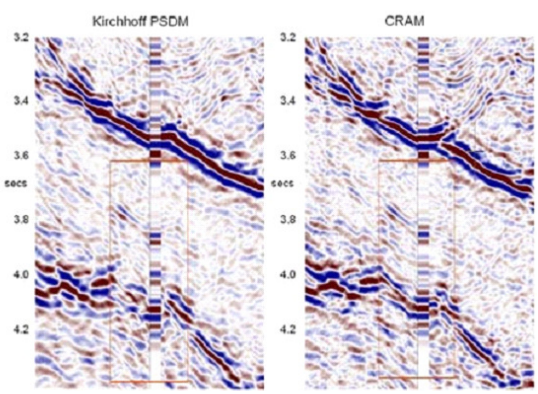

Figure 4: Syntheic match with Kirchhoff PSDM and CRAM

Consistently improved matches with CRAM were also obtained in the inline direction and for near and far angle stacks when compared with Kirchhoff. This observation also supports the improved suitability of CRAM data for AVA, inversion and higher order reservoir characterisation workflows.

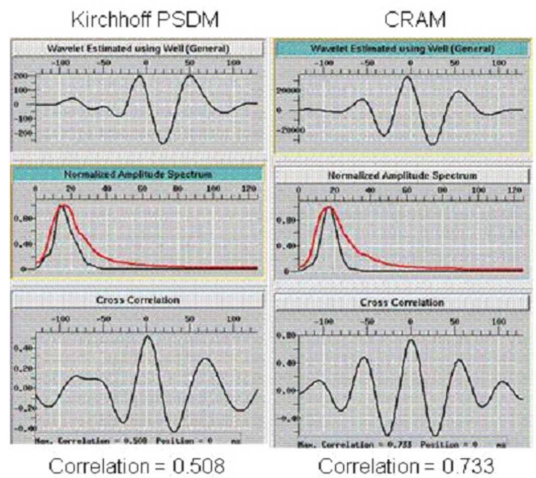

Figure 5: Crossline 1524. Wavelets, frequency spectrum and correlation values of Kirchhoff and CRAM.

The angle stacks were used to make a reconnaisance for potential AVA anomalies which were further investigated on the angle gathers. Figure 6 shows one example from around 2km depth, a probable shallow gas sand that exhibits a clear anomaly on the CRAM data.

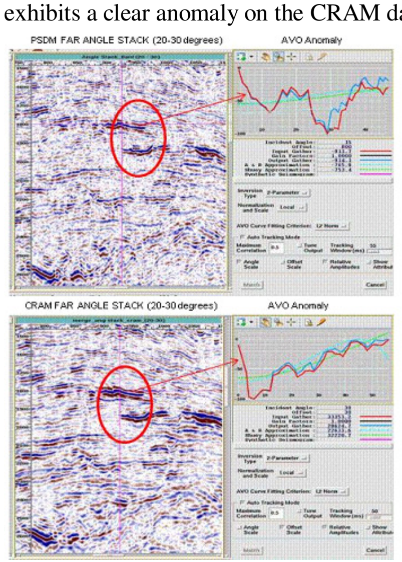

Figure 6: Far angle stacks (20-30 degree) and corresponding AVA anomaly of Kirchhoff and CRAM

The Kirchhoff PSDM data angle stack seen in Figure 5 is more noisey than the CRAM angle stack and the AVA response is ambiguous. Several anomalies and nonanomalies were investigated with similar results. The results suggest that CRAM data would be more suitable for reconnaissance AVA of exploration leads and prospects than conventional Kirchhoff pre-stack migrated data.

The migrated gathers were then used as input to pre-stack constrained simultaneous inversion. The principal objective of seismic inversion is to transform seismic reflection data into a quantitative rock property for the description of the reservoir.

The well data were used to correlate the formation boundaries with seismic marker events and to build the background model. The seismic data were inverted in a window around the area of interest between 3700 and 4500 msecs.

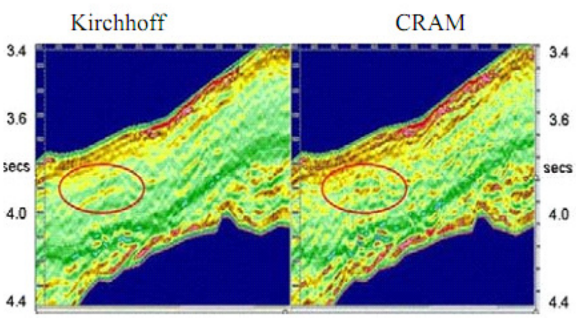

Figure 7: Initial P Impedance Inversion results of Kirchhoff and CRAM

The impedance outputs were matched with the impedance log from the well and the result from CRAM gave a better match than that from Kirchhoff pre-stack migration. In Figure 7 it can be seen that the CRAM inversion result is more detailed than that from Kirchhoff. The highlighted area shows a flat low impedance event not readily apparent on the Kirchhoff result. The event coincides with the reservoir interval and may be a fluid indicator.

Conclusions

An example of Common Reflection Angle Migration on a 3D data set offshore India 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 synthetic produced from the well.

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.

Analysis of suspected AVA anomalies and non-anomalies in the volumes suggest that CRAM data would be more suitable for reconnaissance AVA of exploration leads and prospects than conventional Kirchhoff pre-stack migrated data.

Results from inversion to impedance were examined and compared with the result from CRAM having a better match with the log data and appearing to show more interesting detail in the reservoir interval.

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

References

Zvi Koren, Sheng Xu and Dan Kosloff "Target Oriented Common Reflection Angle Migration" SEG International Exposition 72nd. Annual Meeting 2002

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