



Common Reflection Angle Migration for basement fracture identification- A case study

V P SINGH*, SURENDRA KUMAR, ANILKUMAR, ARJEESH GUPTA, TR MURLI MOHAN

Email: singh_vp1@ongc.co.in

Abstract

Imaging of basement and identification of fractures, connectivity and their distribution is a challenge particularly in OBC data. Fractured basement has played an important role for hydrocarbon discoveries. Ray based, multi arrival, Common Reflection Angle Migration (CRAM) depth imaging technology may provide the solution for generating high resolution, amplitude preserved, angle-dependent reflectivity gathers in local angle domain (LAD) by uniform illumination at the subsurface image point from all directions. We have used this advance depth imaging technology on a huge volume of OBC data pertaining to Mumbai High Field.

Introduction

Accurate reservoir properties are adversely affected by common offset single arrival Kirchhoff's depth migration. CRAM is a multi arrival migration that uses the whole wave field within a controlled aperture, forming a system for mapping the recorded surface seismic data into the local angle domain (LAD) at the image point. The output of CRAM consists of reflection angle gathers that account for all azimuths. The CRAM angle gathers provide optimal data for amplitude verses angle and very useful for target oriented reservoir imaging, property extraction and accurate AVA analysis.

Study Area

The area under study (Fig-1) falls in the western part of India and it is 160 km north-west of Mumbai. The field is anticline and on both sides bounded by NNW-SSE trending faults, Bombay high field is divided in north and south fields by east trending graben which acts as a permeability barrier.



Fig.-1: Area of study

The average water depth is about 70 m. Bombay high field has been developed extensively and largest producer of hydrocarbon in India. In October 1997, an ocean bottom cable 3D seismic data had been acquired over the Mumbai High field, processed and interpreted.

In 2005, Pre-Stack Time Migration (PSTM) and Pre-Stack Depth Migration (PSDM) of whole volume was carried out in order to resolve the reservoir. The output pre-stack depth migrated gathers were found to be problematic in their suitability for mapping reservoir properties with confirmation. The main acquisition parameters of 3D data acquired in the study area are given below.

Acquisition Parameters

- Survey geometry** : parallel End ON
- Spread Layout : OBC (two lines)
- Receiver Line Interval : 400mts
- Group Interval : 25mts
- Source Line Interval : 50mts
- Bin size : 12.5x25
- Fold : 50
- Near offset : 25mts
- Far offset : 3500mts
- Sail Line Interval : 100mts
- Pop Interval : 25m flip-flop

Recording Parameters

- Recording System : Syntrek 480
- No of Channels : 720
- Sampling Interval : 2ms
- Record Length : 4 Sec
- Recording Format : SEGD rev8058/8036

Source Parameter

- Source Type : Bolt Airgun
- Configuration : Dual Source flip-flop
- No of Guns/Array Length : 48/15mts
- Sub array Separation : 8mts

Receiver Group Parameters

- Sensor Type : MP-25
- Natural Frequency : 10Hz
- Hydrophone Group : 2
- Group Array : Linear
- Phone Per Sensor : 2
- Receiver Line/Swath : 2
- Cable Type : TESCROP
- Cable Separation : 400mts

The input data used for CRAM processing is OBC-summed CMP gathers. Fold map (Fig-2) of whole volume of data (1700 sq. km) is generated for quality control. The Input Data was noisy and noise attenuation was done on whole volume of data and stack was generated for QC purposes (Fig-3&4). Velocity picking on input data was carried out at close grid and initial velocity volume from velocity picks was generated for Pre Stack Time migration.

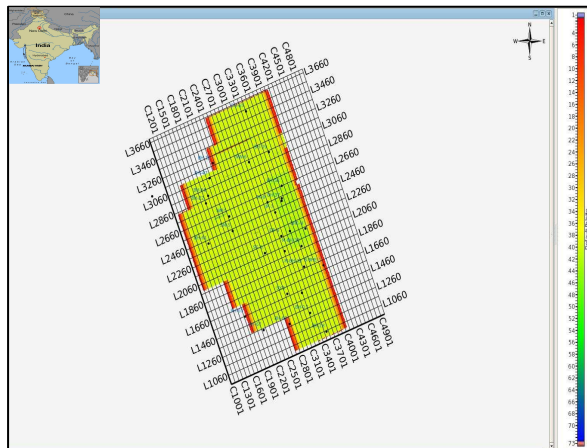


Fig-2: Fold map of full volume of data

Target Line PSTM was carried out for RMS velocity refinement. Second pass velocity picking was done to see the flatness of gathers. RMS Velocity volume of second pass was created. Initial Interval Velocity Volume was created though Constrained Velocity Inversion Method (CVI) from RMS velocity volume. CVI application enables us to create a smoothed and

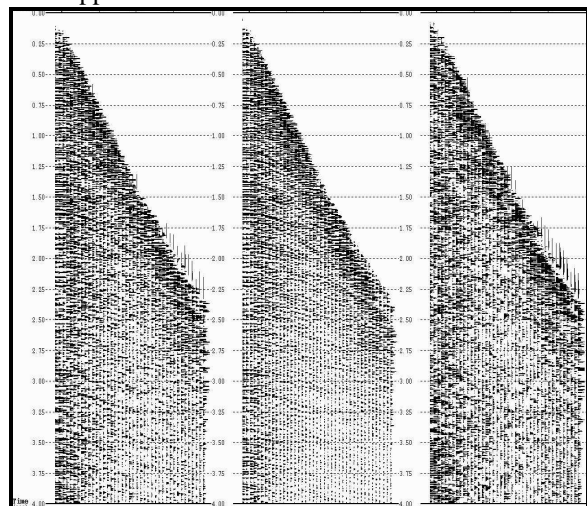


Fig-3: Gather conditioning, Input (left), conditioned (middle) and difference (right)

Flattened gathers indicate velocity model building is satisfactory. Conditioned CMP gathers and final updated interval velocity volume are the basic input for CRAM

physically credible velocity volume/section or update an existing velocity volume/section. The input can be vertical functions that were sampled irregularly and sparsely (laterally/vertically) at a picked points. Target line Kirchhoff's PSDM was carried out by using interval velocity volume. Study of flattened PSDM gathers of whole volume of data enables us to obtain residual depth move out picking. The residuals are picked on whole volume of data and residual volume is created in depth domain. There are several ways to correct the interval velocity volume using the residual velocity volume. The interval velocity volume was updated using CVI method and final interval velocity modelling was performed. Finally with updated interval velocity Kirchhoff PSDM was carried out to see the quality of flattened PSDM gathers.

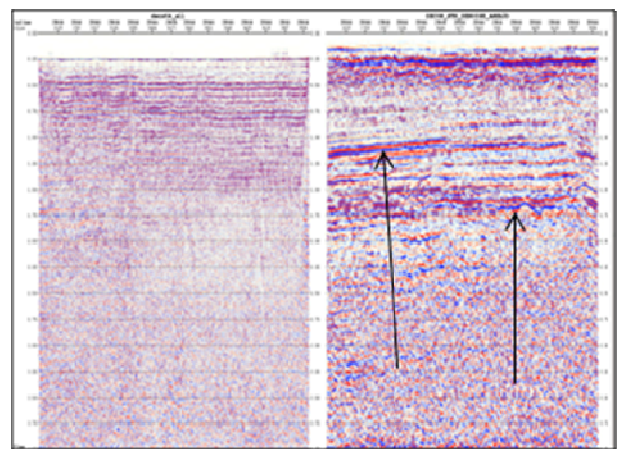


Fig-4: Stack after denoising, input (left), denoised stack (right)

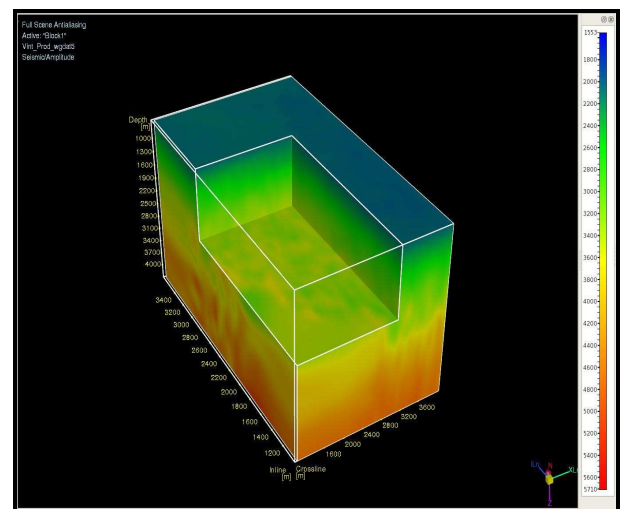
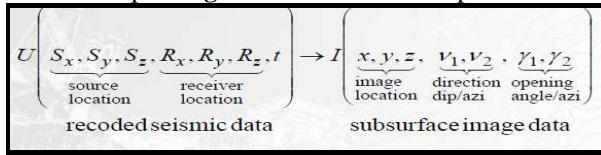


Fig-5: Interval Velocity Volume

execution. Velocity volume is shown in Fig-5. CRAM is an advanced imaging system that first maps the full recorded seismic data into surface grid points and then

decomposes data into local angel domain bins (LAD). It is based on specially designed diffraction operators using ray tracing from the sub-surface as shown in **Fig-6**. Seismic data mapping /binning can be understood with the help of **Fig-7**. This can also be explained as



where U is surface data, I is subsurface data and M is Image point. S is source location, R is receiver location, v_1 is dip and v_2 is dip azimuth which output is directional Gathers. γ_1 is half opening angle and γ_2 is opening azimuth which outputs Reflection angle gathers (CRAM) shown in **Fig-8**. There are several main CRAM parameters which are very critical and are decided based upon the ray tracing application using final interval velocity model. CRAM parameters are Max frequency, target depth, Inline/Cross-line apertures and opening angle, dip angle, pencil distance etc. CRAM parameters decided in the study area are opening angle is 60° top/ 40° bottom, dip angle 40° top/ 60° bottom, target depth is 6000 m ,max frequency is 90 Hz, pencil distance is 100 m . The output of CRAM is Reflection angle gather $\{I\gamma(M, \gamma_1)\}$:half opening angle **Fig-8**

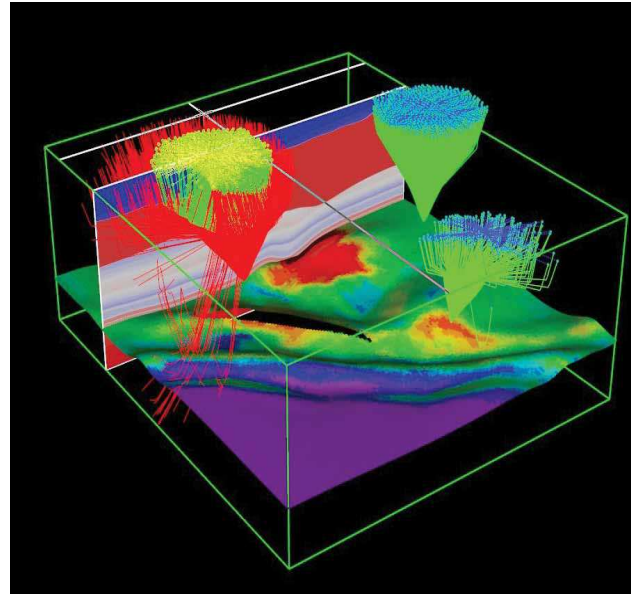


Fig6: The ray shooting (half opening angle + maximum dip). Ray tracing at three different locations red color shows number of unsuccessful rays and blue color shows the successful rays and is critical in CRAM parameters optimization.

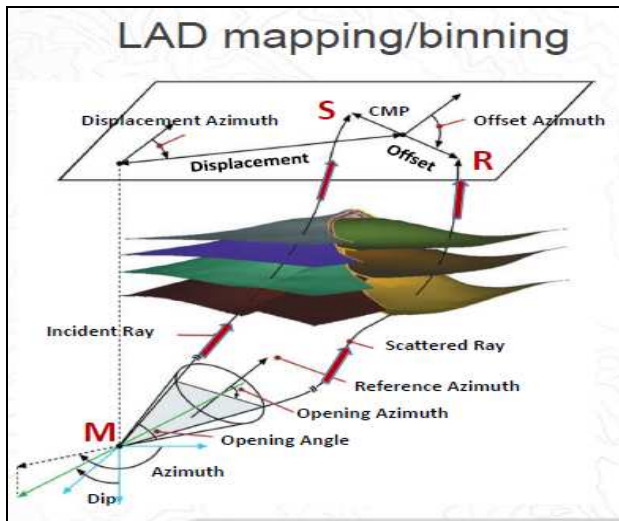


Fig7: Subsurface to Surface and Surface to Subsurface ray based mapping. Each ray pairs map a specific seismic data event recorded on the acquisition surface, into four-dimensional local angle domain space in the subsurface-dip and azimuth of the ray pair normal, opening angle and opening azimuth. (Zvi Koren, *et. al.*)

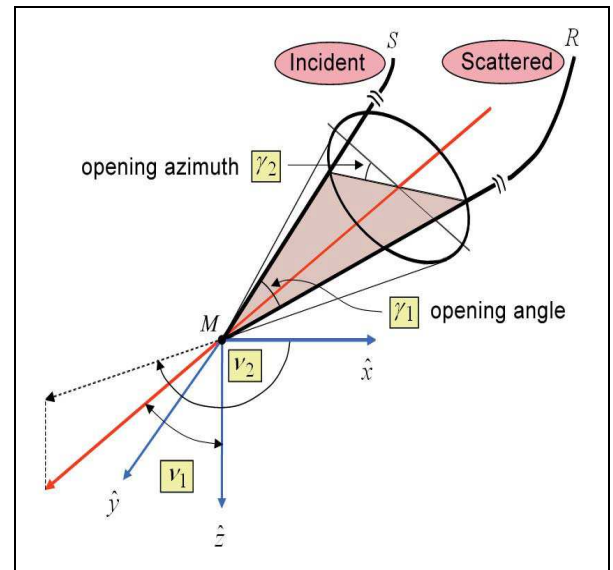


Fig-8: Selected ray pair (incident and scattered) at a given subsurface point M and the four angles associated with the LAD: dip v_1 and azimuth v_2 of the ray pair normal, opening angle γ_1 and opening azimuth γ_2 . Four angles describing the direction of the incident and reflection rays may be related to four LAD angles and vice-versa. (Zvi Koren, *et. al.*)

The CRAM output gives clean image of the sub surface. Gathers are in angle domain which is generally free from noise and multiples. CRAM is advance technology even then some signatures of the noisy components and

different orders of multiples remain within the processed data. Moreover any attempt to attenuate these unwanted signal results in attenuating actual primary reflecting events. A snapshot of conditioned CRAM gather is shown below (**Fig-9**).

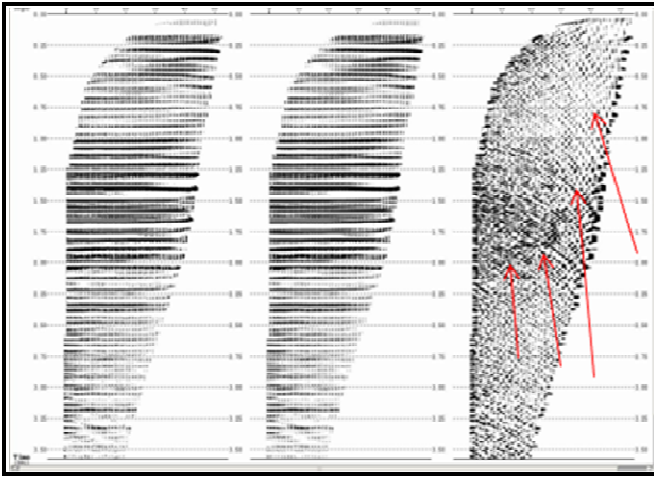


Fig-9: Denoised CRAM Gather

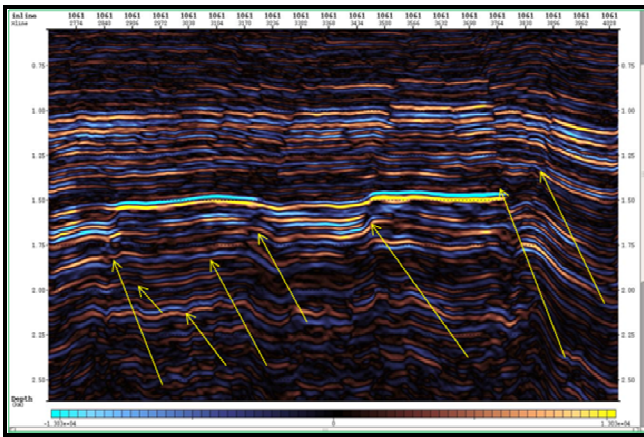


Fig-10: CRAM angle stack 3-15 degree IL 1061

The CRAM gathers are scaled to time migrated domain and stacking and post processing is done in angle domain. After conditioning, the scaled CRAM gathers and stack is again scaled back to Depth domain.

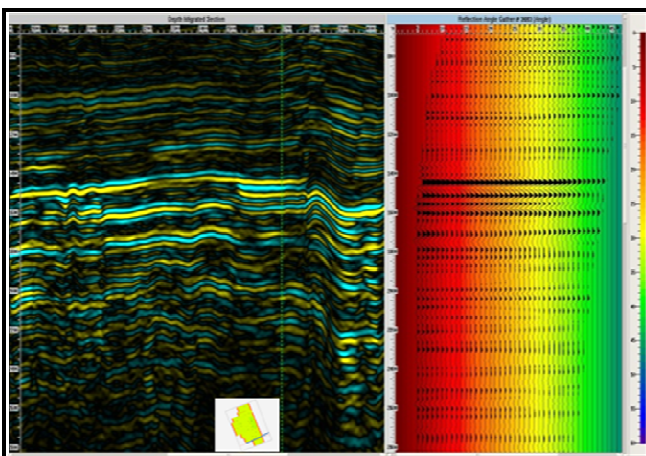


Fig-11: CRAM gather superimposed with angle at IL1650/XL3651

Multiples are removed from CRAM gathers as shown by red arrows (**Fig-9**). In CRAM angle stack (3-15 °) faults are clearly seen as shown by yellow arrows (**Fig-10**). Quality of CRAM gather at IL1650/XL3651 and angle is superimposed on CRAM gather is shown in (**Fig-11**). A comparison of depth slice at 1800 m from vintage data is shown in **Fig-12** clearly shows the output of CRAM (**Fig-13**) is clear and fault patterns are very distinctively demarcated.

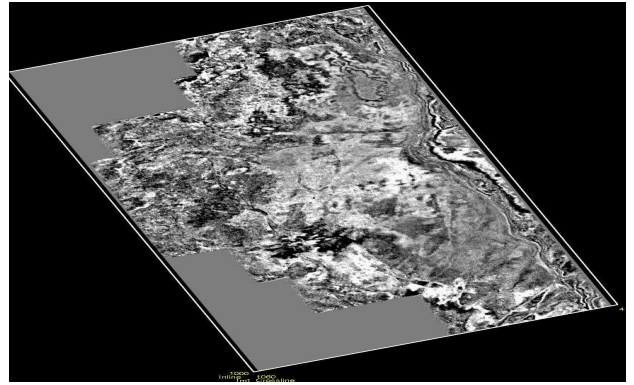


Fig-12: Depth slice at 1800m (vintage data)

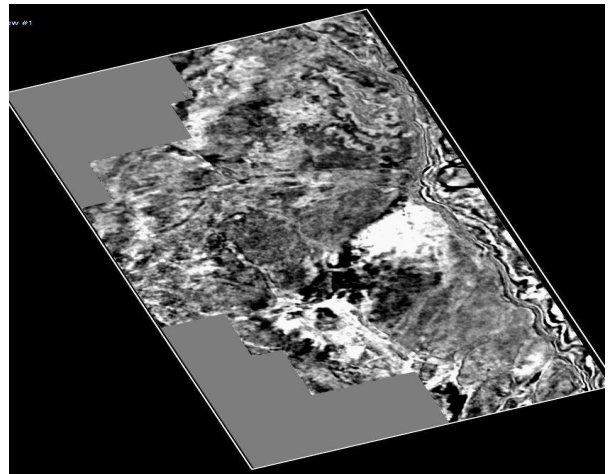


Fig-13: Depth slice at 1800 m

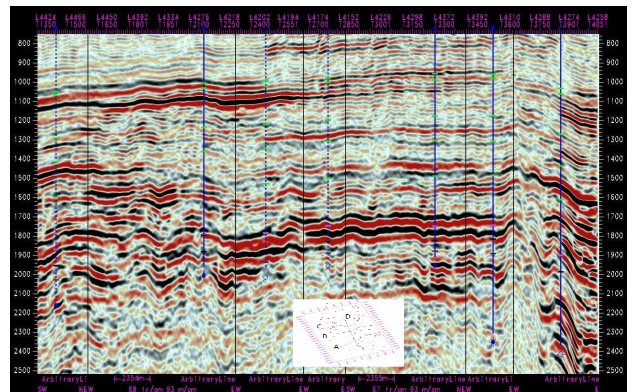


Fig-14: RC Line "B" connecting wells

The interpretation team has divided whole volume of data in four parts as marked by A,B, C, D and generated the RC lines passing through different wells from east to west (RC lines A,B,C) and north to south (RC line D) in Mumbai oil field and matched the markers with the wells

falling in the area (Fig-14). Seismic-to-Well misties were examined and found that the depth are well matching at L1,L2,S5,L5 and L6 levels and depth error is less than 1% in the wells falling on RC lines A,B,C,D

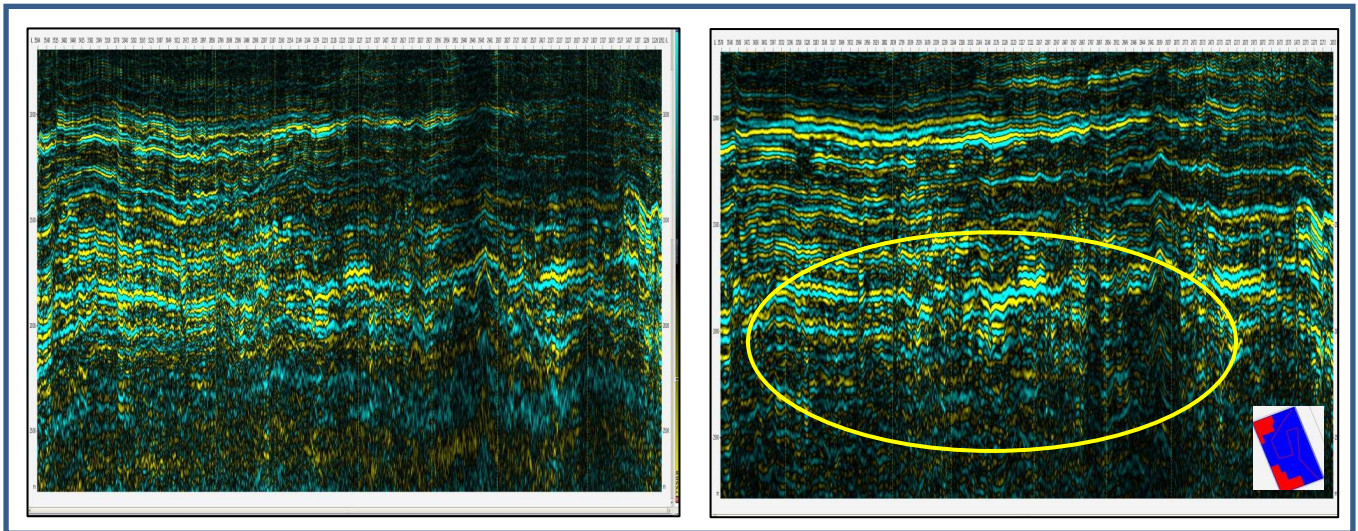


Fig-15: Comparison of KPSDM vintages data and rightmost CRAM output along the RC line passing through whole volume of data. Yellow circle define the faulting below the basement.

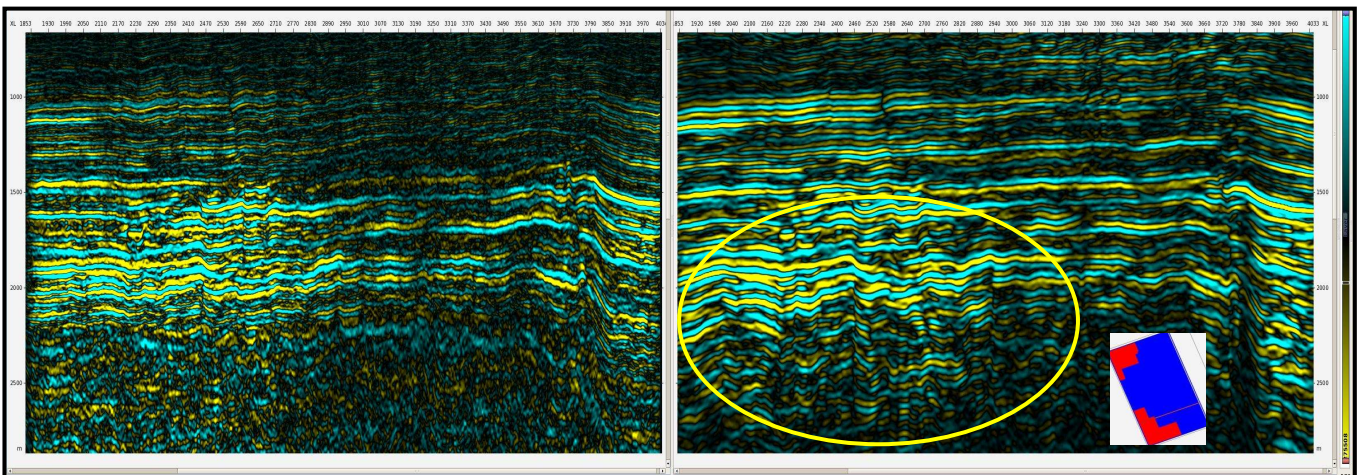


Fig-16: Comparison KPSDM vintages data and CRAM output across IL1632. Yellow circle define the faulting below the basement.

From Fig-15 and 16 it is clear that the identification of fault is clearly brought out in CRAM output. A fault represents the release of a lot of stress, and that release can cause sympathetic fractures to form near fault lines so it is not uncommon to find a lot of Fracture joints in region where faulting occurs. A fracture is a break in the rock and a break does not require movement and a lot of stresses have been applied on the rock that were sufficient to cause the break . Fracture can provide permeability for fluid movement such as hydrocarbons. Highly fractured rocks can make good aquifers or hydrocarbon reservoirs because of significant permeability and fractured porosity. There are number of wells drilled in basement and producing good amount of hydrocarbons in our study area. Fractures

are usually difficult to resolve from seismic amplitude data due to the seismic frequency content which limits seismic resolution. Curvature attributes have been found to be useful in delineating faults and predicting fracture orientation and distribution (Roberts, 2001; Hakami et al., 2004).Curvature attributes for predicting fractures (positive and negative) 50 mts below the basement have been carried out. Fig-16 shows Positive curvature attributes derived from CRAM data. The value of curvature is high in both the cases (positive and negative curvature). The positive value is positively high means deformation has been taken place. From the well data it was found that fracturing has been occurred below the basement.

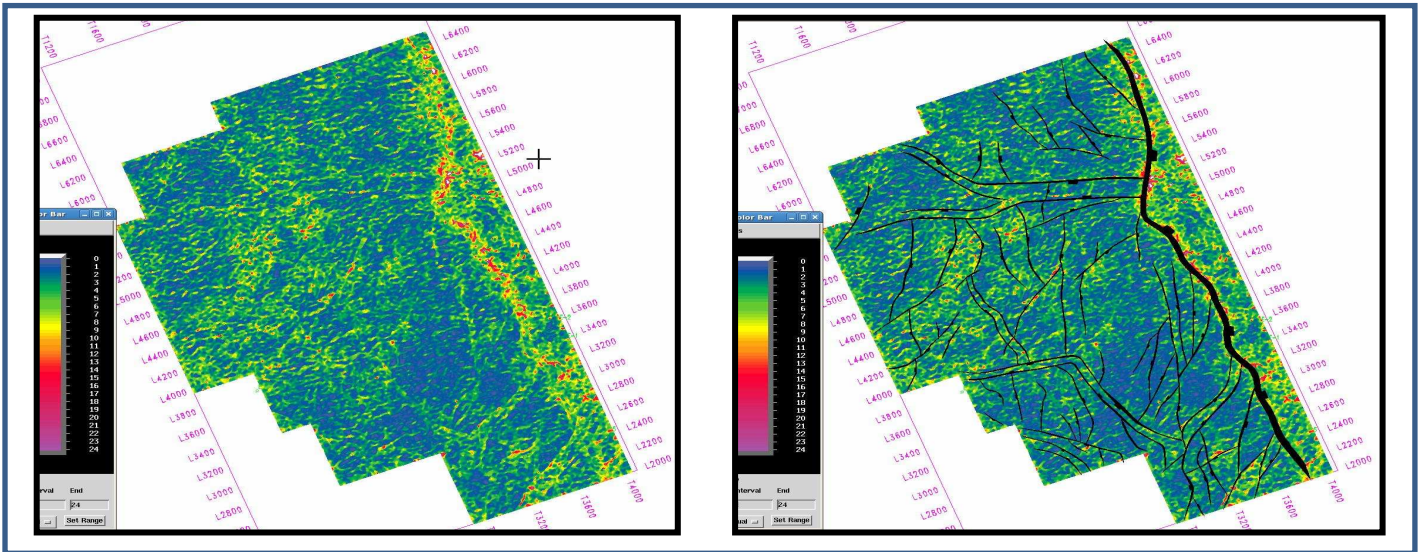


Fig-16: Positive curvature attributes for Fracture study from 3D CRAM data

Conclusions

Common Reflection Angle Migration carried out on a full area of Mumbai High field has been processed. The output of CRAM data is matching with well markers at every level with a confidence around 1% depth error. The CRAM data shows that short-period multiples appear to be reduced. The extracted wavelets on full and angle stacks are more consistent and suitable for AVA, inversion. The output driven feature of CRAM means that target oriented migrations can be used to investigate reservoir zones for reservoir characterization. 3D curvature attributes (positive) generated from CRAM data may be helpful for identification of fractures in the basement.

Acknowledgements

The authors would like to thank their colleagues at ONGC GEOPIC for their help and cooperation. We would also like to thank ONGC for their kind permission to publish

The views expressed in the above article are entirely of the authors and not the organization.

this paper. The authors are also thankful to N P Singh, WOFF, interpretation group, and software/hardware group GEOPIC for extending their help to complete this study.

References

1. Aleksander Inozemtsev, Zvi Koren and Alexander Galkin, Noise Suppression and multiple-attenuation using full –azimuth angle domain imaging: case study.
2. Chopra, S. and Marfurt, K. [2007] Curvature attribute applications to 3D surface seismic data. *The Leading Edge*, **26**(4).
3. Sharma P.K., Kutty A., Rautela P.S., Shrivastava R. K., Depositional model of the L-III horizon in a sector of – Exposition 72nd Annual Meeting 2002. Bombay High south field and its bearing on the reservoir characterization SPE India oil and gas conference: New Delhi, 7-9 April 1998.
4. Zvi Koren, Sheng Xu and Dan Kosloff, Target Oriented Common Reflection Angle Migration SEG International exposition 72nd.Annual Meeting 2002.