Basement Fracture Imaging & attribute analysis on Full azimuth sub-surface angle domain Directional Gather decomposed from OBN data - a case study in Mumbai High Field

A. Ghosh, S. Basu, K V. Krishnan.*
Seis Data Processing and Interpretation Centre, ONGC, Mumbai, India
ghosh_a1@ongc.co.in

Keywords

Local angle domain, wave-field decomposition, full azimuth directional angle gather, specular enhancement, attribute analysis, Automatic Fault Extraction

Summary

Mumbai High is a proven field, having hydrocarbons in fractured basement also. Proper imaging of Basement fracture is a challenging task for basement exploitation. In this paper we discuss how an innovative strategy was designed to map the fractured zone more efficiently than the conventional processes. Our attempt consists of,

(i) Full azimuth sub-surface angle domain Directional Gather decomposition from full azimuth OBN data
(ii) Specular Amplitude Enhancement in the sub-surface / Local Angle Domain (LAD)
(iii) Automatic Fault Extraction

LAD is a system of four angles defining the interaction between incident & reflected waves at a specific image point.

Introduction

In geology, basement is defined as any rock below sedimentary rocks that are metamorphic or igneous in origin. Basement rocks are hard & brittle with very low matrix porosity & permeability. When the basement structures moved through tectonic action, millions of cracks have been created within the basement rocks e.g. basalts and granite, resulting seismic scale faults & highly connected fracture networks, mostly of below seismic resolution. Under right conditions, significant volume of oil accumulate not in the basement rocks but in the cracks between the rocks. Fractured & weathered basement reservoirs emerge as a potential play worldwide. In India, following five Petroliferous basins viz, A&AA, Mumbai High, KG, Caubery, Cambay (all by ONGC), and Mangala field in Rajasthan (by Cairns) & Dholka area of Cambay (by GSPC) are on commercial basement hydrocarbon production.

Depending on the depth of burial, seismic reflection from the basement can be very weak and masked by several types of noises & multiples. Enhancing the signal from basement is therefore an element for its imaging. Here we have tried novel "**diffraction imaging**" system, which aims to attenuate the reflectors, leaving behind any focussed diffraction events generated by faults, unconformities and depositional discontinuities. The ability to decompose the specular & diffraction energy from the total scattered field obtained within the full azimuth directional gather is the core component of diffraction imaging system. It uses point diffractor ray tracing which ensures maximum illumination of image points from both (a) all subsurface directions & (b) all surface source-receiver locations, accommodating all arrivals. Managing multi-pathing in wave-propagation produces better images in complex geology than Kirchhoff's migration which assumes single arrival. Moreover LAD PSDM performs a special beam migration as the imaging is applied to local beams formed by local tapered slant stack events from the input data traces using optimal computed parameters, viz. Surface slowness vectors & estimated Fresnel zones of both shot & receiver.

A natural fracture is a macroscopic planar discontinuity that results from stresses that exceed the rupture strength of a rock and lead to a loss of cohesion. Fractures are not easily visible in a standard seismic display (Singhal at al, 2010). Often it is difficult to map subtle faults and other trace to trace discontinuities hidden in a 3D seismic data. They may appear as minor changes in the seismic waveform which are not easily discernible using conventional interpretation of seismic cross-sections.

Seismic attributes based on continuity and/or discontinuity principle provide useful tools to characterize fault and fractures (Chopra & Marfurt, 2007; Basir et al, 2013). We have computed seismic attributes & finally extracted 3D surfaces of small faults & fractures in the target reservoir.

Theory / Method with Examples :

Work Flow :

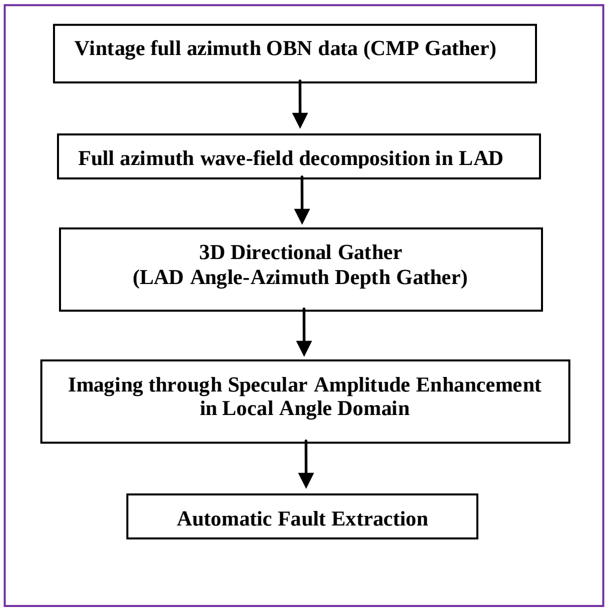


Fig. 1. Work Flow chart.

(i) LAD PSDM :

$$U\left(\underbrace{S_x,S_y,S_z}_{\text{source loc}},\underbrace{R_x,R_y,R_z}_{\text{receiver loc}},t\right)$$
$$\Downarrow$$
$$I\left(M,\underbrace{p_{in}}_{\substack{\text{incident}\\ \text{slowness}}},\underbrace{p_{sc}}_{\substack{\text{scattered}\\ \text{slowness}}}\right)$$

Imaging systems involve the interaction of two wave-fields at the image points : Incident & Scattered(Reflected/Diffracted). Each wave-field can be decomposed into local plane waves or rays.

Each ray pair maps the seismic data recorded on the acquisition surface into four dimensional LAD space : dip (ν_1) & azimuth (ν_2) of the ray-pair normal, opening angle (Υ_1) & opening azimuth (Υ_2). [Fig.2]

$$U\left(\underbrace{S_x,S_y,S_z}_{\text{source loc}},\underbrace{R_x,R_y,R_z}_{\text{receiver loc}},t\right)\rightarrow I\left(\underbrace{x,y,z}_{\text{image loc}},\underbrace{\nu_1,\nu_2}_{\text{dir ang}},\underbrace{\gamma_1,\gamma_2}_{\text{refl ang}}\right)$$

The seismic recorded data decomposed to directional image gathers. For each direction, seismic data events corresponding to ray pairs with the same orientation of reflection surface but different opening angles are accounted for in weighted summation form. The directional gathers contain directivity-dependent information about both specular & diffraction energy.

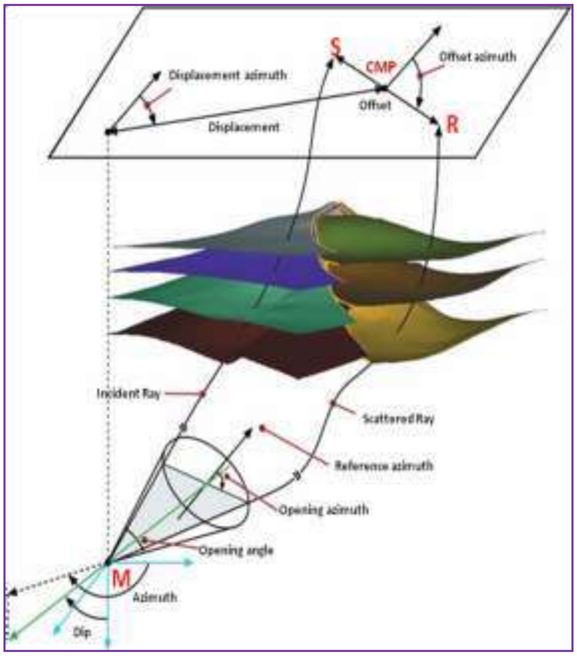


Fig. 2. Full Wave-field decomposition in LAD.

Input seismic of PSDM consists of OBN CMP Gather (maximum fold : 241, maximum offset : 3000m) having 360˚ source – receiver azimuthal distribution [Fig.3], ideal for full azimuth sub-surface angle decomposition. Interval velocity vertical function shows a very good matching with VSP (green line) at well-A as shown in Fig.4

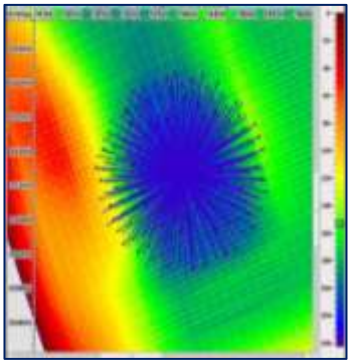
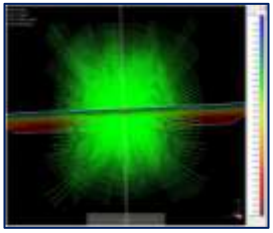


Fig. 3. Azimuthal Distribution

Fig.4. Int Vel Well-A

Ray tracing using interval velocity model at basement level image point using migration aperture (6km X 6km) is shown below :
Total Ray : 3598, Successful Ray : 2290 (63.64%)
Maximum take-off angle : 110 degree.



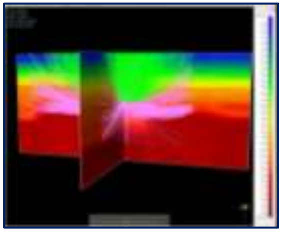


Fig.5.Ray Tracing:Top View Fig.6.Ray Tr.: Side View

Following migration parameters are adopted :

Area : 71 SKM, Bin Size : 12.5m X 12.5m
Migration Aperture : 6km X 6km, Max Freq. : 90hz
Depth range:0 – 3000m @ 5m, Shot Bin Size : 25.0m
Half opening angle range at top : 0 – 60 degree
Half opening angle range at bottom : 0 – 30 degree
Dip angle range at top & bottom : 0 – 80 degree
Distance between ray tracing pencils : 100m
Increment in depth samples
between ray tracing points : 4
LAD table switch : 0
LAD table resolution reduction level : 2
No. of Rays : 26,000
Ray Pairs Reduction : 30%
Reflection Fold : 500, Diffraction Fold : 1000

LAD PSDM reflection output is shown below. Reflection Gather [Fig.7] at Well-A is segregated in six reciprocal azimuth sectors : (0-30), (30-60), (60-90), (90-120), (120-150), (150-180) having opening angle (0-30) at bottom & (0-60) at top. Clearly azimuth sectors are different from each other. Reflectors at a particular depth, showing different moveout & angle range in different azimuth sectors. Azimuthally-dependant analysis of seismic data at well–A is also shown below, in both horizontal & vertical directions. [Disk depth : 2500m]

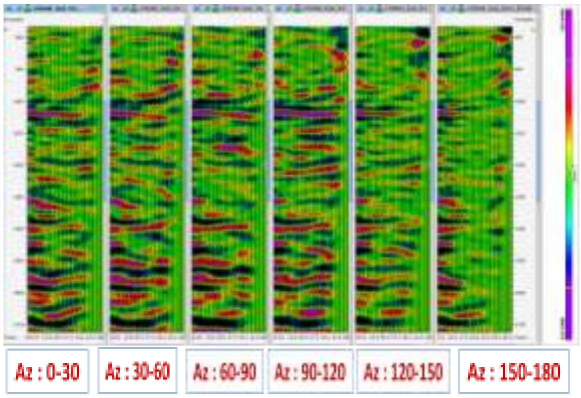


Fig. 7. Azimuth Sectoring of 360˚ Reflection Gather.

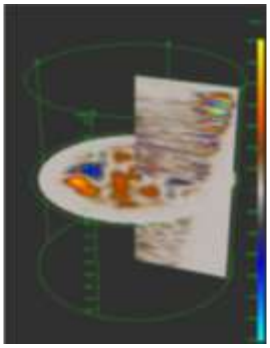


Fig. 8. Azimuth : 0˚

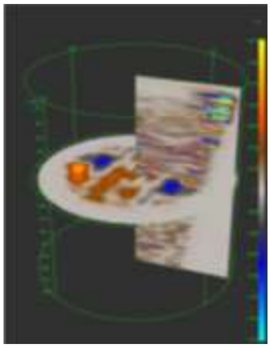


Fig. 9. Azimuth : 30˚

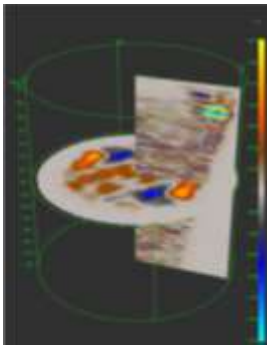


Fig. 10. Azimuth : 60˚

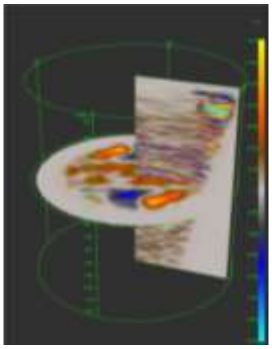


Fig. 11. Azimuth : 90˚

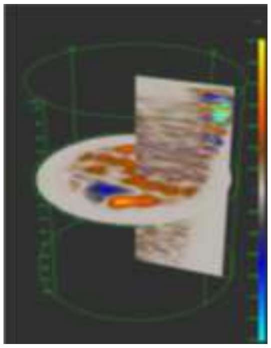


Fig. 12. Azimuth : 120˚

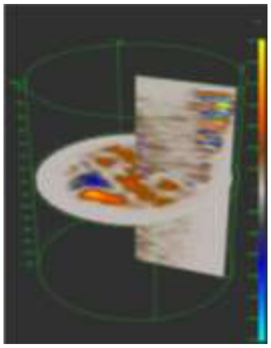


Fig. 13. Azimuth : 150˚

Azimuthal variation of seismic amplitude at depth 1500m is clearly visible in Fig.14.

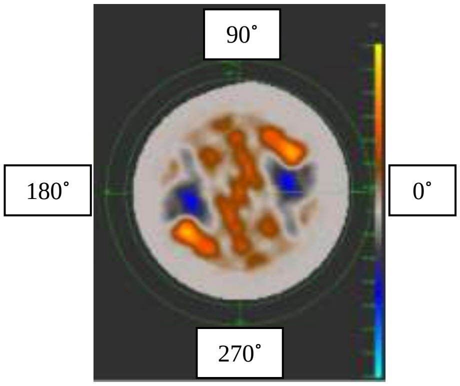


Fig. 14. Depth : 1500m, Azimuth : 0˚-360˚

(ii) Specular Amplitude Enhancement in LAD :

The capability of full azimuth direction gathers to contain directivity dependent information at each subsurface point, allows the creation of enhanced feature images by applying a different specular / diffraction weighted filter to create a specular (continuous structural surface) / diffraction (discontinuous objects like small-scale fractures, faults) stack [Koren & Ravve (2011) and Ravve & Koren (2011)]. The high energy values associated with the specular directions can be used to obtain more detailed high resolution sharpened images.

Specular Stack [Fig.15] of IL passing through well-A is shown below. For comparison KPSDM stack processed in conventional way, using same input [Fig.16] is also shown.

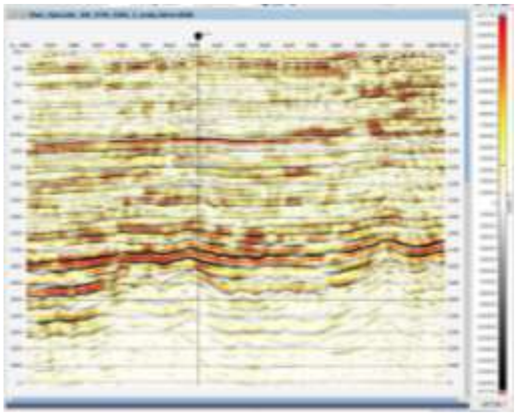


Fig. 15. Specular Stack.

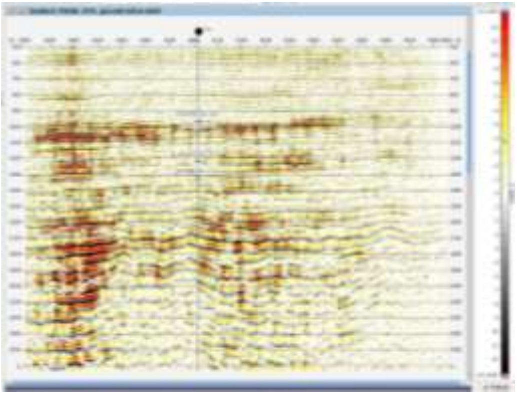


Fig. 16. KPSDM Stack using same input.

(iii) Automatic Fault Extraction (AFE) :

Local waveform similarity of LAD PSDM generated diffraction stack is measured within a specific aperture defined in space & time, utilizing dip & azimuth calculations outputting Coherency cube, which provides accurate maps of the spatial change in the seismic waveform. AFE automatically interprets fault surfaces from 3D Coherency volume. It first reduces the horizontal striping generated due to acquisition footprint from the coherency volume & then enhances the linear events. In the next step, a slab of horizontal slices is processed to enhance planar feature within the slab. In the final step, digitized vectors are edited within a range of azimuths, overlapped & closely parallel vectors are removed and short co-linear vectors are linked to longer vectors giving final AFE output.

AFE results are superimposed on specular image both in vertical [Fig.17] & horizontal [Fig.18 & Fig.19] directions. AFE faults match very well with specular stack fault patterns.

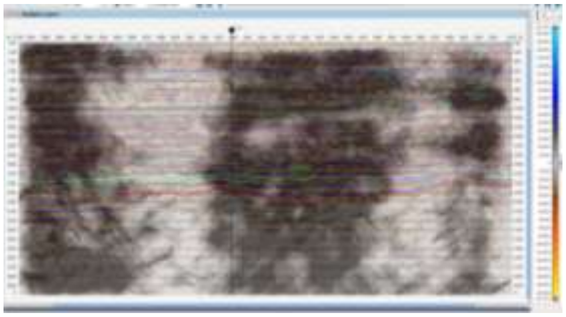


Fig. 17. AFE superimposed on Specular stk : IL 6066.

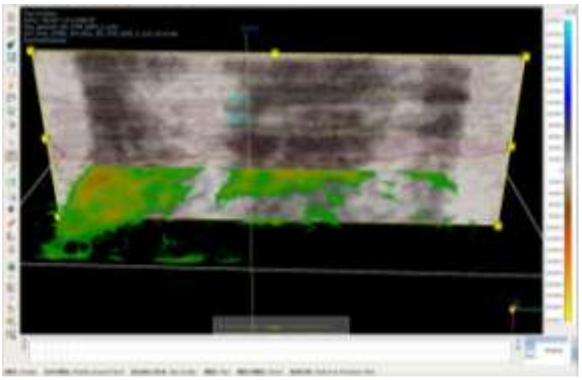


Fig. 18. AFE superimposed on Specular stk : IL 6066 & Depth Slice 2100m

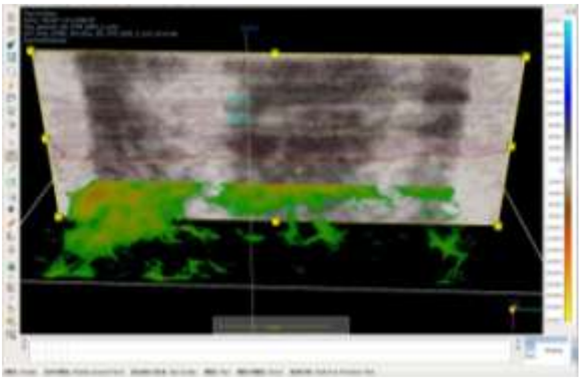


Fig. 19. AFE superimposed on Specular stk : IL 6066 & Depth Slice 2400m

Some highly dense fault of short vector length is prominently imaged in AFE depth slices [Fig.20] on the northern part. Well-A is placed on moderate vector length fault zone.

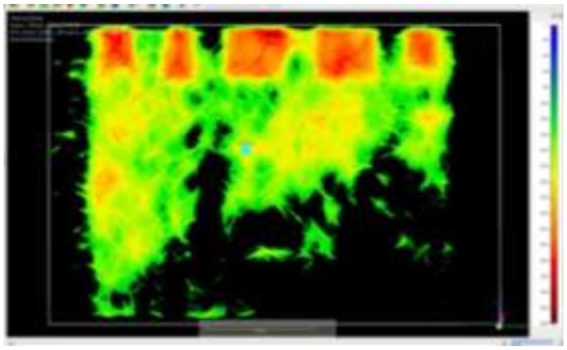


Fig. 20. AFE Depth Slice : 2100m

Conclusion:

Thus, by decomposing surface seismic data into full azimuth sub-surface angle domain data, simultaneous imaging of specular & diffracted energy can be done in a more efficient way than conventional KPSDM, which finally opens a new vision in Basement Fracture Imaging. Specular image reveals higher image quality in terms of the seismic horizon continuity, an increase in traceability level and reflection detail specially from the basement. Reduced migration noise imaged more accurate basement boundary. Azimuthally dependent seismic data opens the path of azimuthal anisotropy analysis. Initially LAD PSDM outputs are considered best for imaging purposes only due to its specular enhancement quality. But here after enhancement of diffraction part of LAD imaging, suitable work-flow is adopted to generate required attribute on which AFE is performed for fracture imaging. LAD PSDM generated AFE results have shown its better capability of fracture imaging. The study is an innovative step towards future basement exploration.

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