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IMAGING FRACTURES FOR BASEMENT EXPLORATION

– a Case Study in Padra Field

Abstract :

Fracture plays an important role in unconventional reservoir like Basement. Basement reservoirs are found in metamorphic and igneous rock where faulting and tectonic upliftment has led to creation of fracture network, underlying a sedimentary basin. Fractures enhances permeability. Optimum well placement and trajectory of well bore on basis of Fracture network is most important parameter deciding production and subsequent recovery efficiency of the reservoir.

Synergy between seismic and non seismic methods of Fracture detection is most important. Fracture measurement from Core or Formation Micro Imaging (FMI) log of drilled well has to be validated with fractures identified from seismic.

Various attributes like coherency, curvature and ant track derived from Reflection seismic has been so far being used for detecting faults and fractures. In this paper, Fractures are detected from Diffraction seismic volume using Automatic Fault Extraction (AFE) technique. In Padra field, South Cambay basin, the Basaltic Deccan trap forms the basements which is a proven hydrocarbon producer. Diffraction Imaging system is being tried here on Full Azimuth acquired 3D-3C seismic data with bin size (10mx10m). Using wave field decomposition in Sub-surface Angle Domain, separate Reflection & Diffraction volumes are produced. Fractures are extracted from Diffraction volume using AFE technique, which agrees well with fracture detected from FMI log.

Work Plan :

Padra field, located in eastern margin of South Cambay basin, is famous for oil and gas production from unconventional fractured Deccan trap reservoir. More than 100 wells are drilled in the field, and oil gas production is contributed from Trap, Olpad and Ankleshwar Formations. It is well established fact that the reservoir porosity, permeability and hydrodynamic behaviour in Trap are attributed to natural fractures present in it. Proper imaging of Basement fracture is a challenging task for basement exploitation. In this paper we discuss how an appropriate strategy was designed to image new deeper reflector well below the Trap Top & to map the fractured basement zone more efficiently than the conventional processes. Our attempt consists of,

(i) Building up of an effective velocity model using (a) Sonic Log of Fifty (50) wells up to Trap Top, (b) Velocity scanning & Tomography within the Trap, which can illuminate deeper reflector well below the Trap top.

(ii) Full azimuth sub-surface angle domain Directional Gather decomposition from full azimuth land data,

(iii) Specular Amplitude Enhancement in the sub-surface / Local Angle Domain (LAD) to image new deeper reflector within Trap,

(iv) Enhanced diffraction imaging using appropriate diffraction filter on Directional Gather

(v) Automatic Fault Extraction (AFE) from enhanced diffraction image.

(vi) Validation of imaged fracture with FMI log at several well locations.

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. Conventional imaging procedures remain biased towards high energy events defined by continuous reflectors or major discontinuities like large faults. This energy is referred to as "**specular"** energy and typically dominates the seismic data volume. But a significant amount of energy associated with high-resolution features, e.g. small faults, stratigraphic edges, reservoir heteroginities, is also recorded in the form of **"diffraction"** energy. This high-resolution and low energy details are masked by dominant specular energy and irretrievably lost through integration & stacking processes employed in standard seismic processing & imaging procedures. Information encoded in diffraction energy can help explain reservoir compartmentalization, permeability and performance.

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.

Geological Setting & Stratigraphy :

Padra structure lies in the north eastern rising flank of the late Tertiary Broach depression (Fig.1&2). In our survey area (Fig.3),the structure shows a series of NNW-SSE tending normal faults almost parallel to one another forming successive horsts and grabens and thus resulting in series of fault blocks and many fault closure within it. In general, wells lying on the horsts are oil bearing while those falling in grabens are dry in the basement.

Stratigraphically, the area is covered by Tertiary and Quaternary sediments of about 600-700m overlying Decan Trap unconformably. The Olpad Formation belonging to Paleocene age are the first sediments deposited on Trap. They consist of trap conglomerate with red and variegated claystone, Trap wash and in lower part predominantly sand. Cambay shale Formation is very thin to almost absent in the area. Ankleshwar Formation deposited in an upper deltaic environment, directly overlies the Olpad Formation and it cannot be differentiated into Members in the area. In the north eastern part of the field Post Dadhar sediments directly overlie the Trap and the entire aleogene section is pinching out in this direction. Cambay Basin has Decan Trap as basement. These are basalts laid down by multiple lava flows during Paleocene to Upper Cretaceous time. Different lava flows are recognizable on logs. Individual lava flows have a layered structure. The bottom of each flow is massive basalt which grades into amygdaloidal and weathered basalt towards the top.

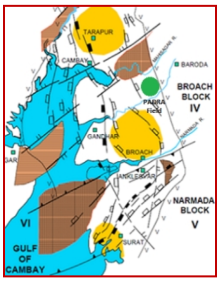


Fig.1 Tectonic Map Study area:Padra, South Cambay Basin

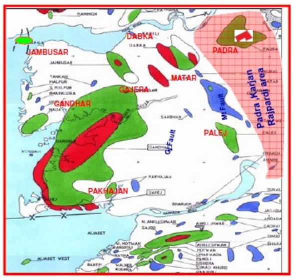


Fig.2 Prospect Map Study area:Padra

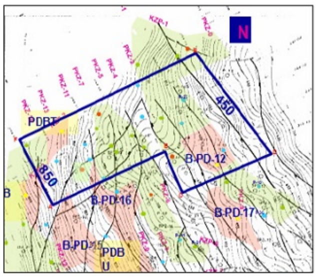


Fig.3 Survey area polygon overlying on Time Map near the top of Decan Trap, Padra

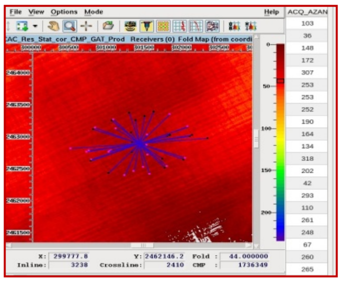


Fig.4 Azimuthal Distribution of I/P CMP Gather

Objective of Present Study :

1. Detection of Fault/fracture within basement of Padra Phase-I multicomponent data.
2. To decipher the basement architecture.

So far, conventional seismic reflection images mapped up to Top of Decan Trap only which is the technical basement of the Cambay Basin and the deeper zone below Trap Top cannot be properly illuminated (Fig.12). Fault / Fracture Maps (Ant-Track), generated by conventional method of using reflection seismic volume are not so sharp enough (Fig.14). Input seismic provided is the same CMP gather used for earlier imaging, generated with the following **Acquisition Parameters :**

Area : 50 SKM, Bin Size:10m X 10m, Year :2009-10, Swath Geometry: Orthogonal, Symmetric Split Spread, Total active channel : 2240 (140 X 16), GI : 20m, Receiver Line Interval : 140m, Shot Line Interval : 140m,Shot Interval : 20m, Spread Length : 1390m, Near Offset : 14m,Maximum Far Offset : 1925m, RL:6s, SI:2ms,Foldage : 80 (10 X 8), Low Cut Filter : Out, High Cut Filter : 187 Hz

Input seismic consists of Land CMP Gather having 360˚ source – receiver azimuthal distribution (Fig.4), ideal for full azimuth sub-surface angle decomposition.

Work Flow :

Vintage full azimuth Land data, Residual Static Correction & Noise Attenuation in Three (Shot, Receiver & CMP) domain → Velocity Model Building : Illumination within Trap → Full Azimuth Wave-Field Decomposition in LAD → 3D Directional (Angle-Azimuth) Gather → Specular Amplitude Enhancement → Diffraction Filtering in LAD : Diffraction Volume → Automatic Fault Extraction : Basement Fracture Mapping → Validation of Fracture with FMI

(i) Data Conditioning in Omega Software :

Noise attenuation is done successively in Shot, Receiver & CMP domain. Surface Consistent Amplitude Correction is applied to correct the amplitude variation generated by complex near surface & inhomogeneity at the surface. Residual Static Correction is done in shot domain following an optimised methodology resulting better alignment of shallow reflectors.

(ii) Velocity Model Building in Paradigm S/W:

Using fifty suitably filtered sonic logs around the area (Fig.8), Geostatistical Velocity Model was built up from zero to 500 m below the Trap Top (Fig.5).

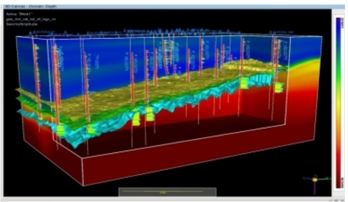


Fig.5 Velocity Model building using fifty sonic log

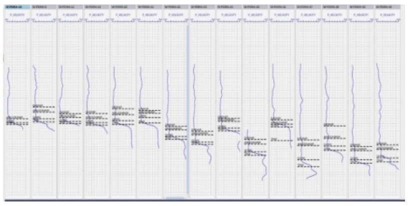


Fig.6 High sonic velocity observed from Trap Top

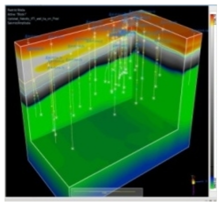


Fig.7 Final Velocity Model

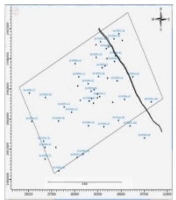


Fig.8 Location of fifty wells

We do not have any deeper well information, but every sonic log shows a very high trend of sonic interval velocity from Olpad / Trap Top formation (Fig.6). So we attempted velocity scanning with an aim to illuminate deeper zones below Trap Top and reached to a very high interval velocity. Lastly velocity models of two zones are bridged up and through Tomography Final Velocity Model was built up (Fig.7).

(iii) LAD PSDM :

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

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

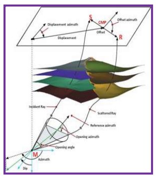
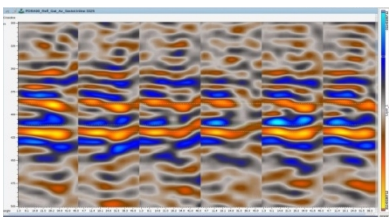
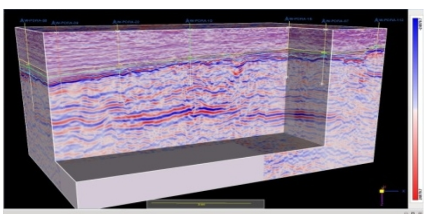


Fig.9 Full Wave-field decomposition in Local Angle Domain (LAD)

Imaging systems (Fig.9) 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 (v1) & azimuth (v2) of the ray-pair normal, opening angle (ϒ1) & opening azimuth (ϒ2). 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. LAD PSDM reflection output is shown below. Reflection Gather (Fig.10) at Well-A is segregated in six azimuth sector of 30deg each, [0-30] [30-60] [60-90] [90-120] [120-150] [150-180], showing distinct azimuthal anisotropy.





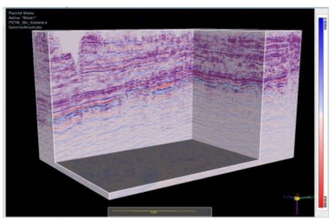


Fig.10 Azimuth sectoring of 360˚ Reflection Gather

Fig.11 Specular Stack showing deeper reflector below Trap Top

Fig.12 Vintage Reflection Stack, no illumination below Trap Top

(iv) 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)]. Here we had used the weighted filter on LAD generated directional gather in two different fashion :

- **(a) Specular Filtering** : Enhancement of specular energy only, discarding all kind of diffraction energy & noises, generating specular stack. The high energy values associated with the specular directions can be used to obtain more detailed high resolution sharpened images. Specular Stack (Fig.11) shows prominent deeper reflector below Trap Top. For the first time seismic image able to illuminate basement architecture of Padra Area.
- **(b) Diffraction Filtering :** Firstly muting of specular energy at a specified angular aperture & then searching for a diffraction pattern and finally enhancing remaining diffraction energy, generating diffracted stack of enhanced imaging of spatially consistent geological discontinuities and higher resolution fault definition. In Fig.13, diffraction depth slice shows a sharpen clear fault pattern, signature difference of lower & upper part of Trap Top (shown by green line). Major NNW-SSE fault pattern is distinctly visible.

Faults are subsequently extracted using this diffracted stack (discontinuity vol.) using AFE.

(v) Automatic Fault Extraction (AFE) : Attribute analysis of Spectral Decomposition in the Octave Increment mode is made using this Diffraction volume. AFE first reduces the horizontal striping generated due to acquisition footprint from the discontinuity 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.

Let us first look at the vintage Ant Track Depth Slice at 725m (Fig.14), generated from conventional reflection seismic (continuity) volume. Then the Depth Slice at 725m of AFE seed vector azimuth (Fig.15). Finally, horizontal seed vector & vertical slice vectors are linked together to form AFE Vector Plane. The later is displayed within a corendered volume of Specular & Diffraction seismic (Fig.16).

Fig.13 Diffraction Stack Depth Slice : 725m

Fig.14 Ant Track Depth Slice : 725m

Fig.15 AFE Seed Vector azimuth, Depth : 725m

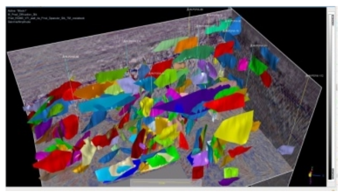


Fig.16 AFE Vector plane co-viewed in seismic

(vi) Validation of Fault Plane with FMI log:

Fault/Fracture plane derived from AFE matches considerably well with FMI logs. Here we compared,(a) AFE Vector Azimuth at well location only

(b) Rose Diagram derived from Diffraction depth slice (~1SKM) surrounding the well

(c) FMI Rose Diagram at well location only

For well # PDRA-XX :

AFE vector at well location is shown at 149˚ at Depth of 610m.(Fig.17)

Diffraction seismic shows Azimuth Range :147˚-158˚ for a depth range 610-615m. (Fig.18)

FMI log shows Azimuth range : 146˚-152˚ for depth range 612-613m. (Fig.19)

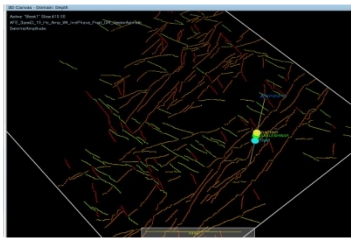
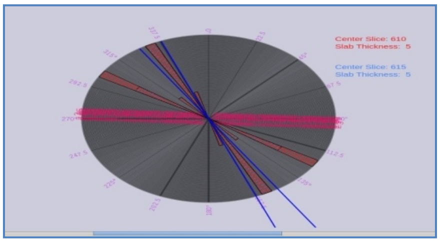
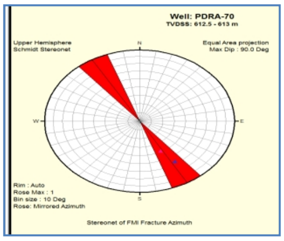




Fig.17 AFE Vector Azimuth   Fig.18 Diffraction Rose Diagram   Fig.19 FMI Rose Diagram

For well # PDRA-YY :
AFE vector at well location is shown at 145˚ at Depth of 665m.(Fig.20)
Diffraction seismic shows Azimuth Range :144.5˚-157.5˚ for a depth range 665m. (Fig.21)
FMI log shows Azimuth range : 131˚-152˚ for depth range 665-666m. (Fig.22)

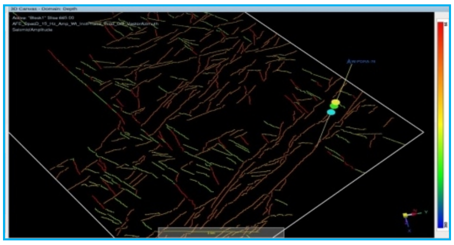
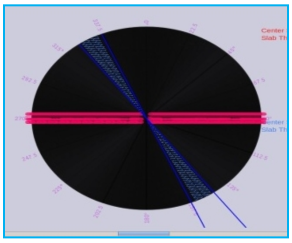
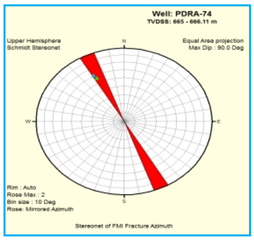




Fig.20 AFE Vector Azimuth   Fig.21 Diffraction Rose Diagram   Fig.22 FMI Rose Diagram

Conclusion:

Full azimuth (FAZ) data acquisition with wave field decomposition processing in Local Angle Domain (LAD) and velocity model building generates enhanced specular reflection amplitude volume, which well illuminates reflectors within Trap and Diffraction volume for detection of fractures. Attributes like coherency, curvature and ant track were extensively used so far for fracture detection in 3D seismic reflection amplitude volume. Here Diffraction volume is used for fracture detection through AFE, which agrees well with fracture detected from FMI LOG.

Diffraction volume as an attribute performs better as compared to coherency, curvature and ant track for fracture detection. The above workflow from FAZ data acquisition to wave field decomposition processing and fracture detection from Diffraction volume through AFE technique will be the future of Fracture Basement exploration. Fracture density map will help in placing suitable no of wells for exploitation of reservoir and well trajectory can be optimized for tapping more number of fractures for higher production.

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