Improved imaging and subtle faults and fracture characterization using full azimuth angle domain imaging: A case study from Cambay basin, India

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Abstract

Wide azimuth 3D seismic data contains a lot of information which can be used in many advanced imaging techniques such as full azimuth angle domain imaging. It utilizes the azimuth rich information in local angle domain (LAD) and decomposes the data in two complementary, full-azimuth, common image angle gather system viz Directional and Reflection gather. The directional angle gather system can be further decomposed into specular and diffraction gathers. Information of continuous surfaces can be derived from specular gather whereas the diffraction gather is used to derive information about discontinuity viz faults and small-scale fractures (Masako Robb et al. 2013; Zvi Koren et al. 2010). The reflection angle gathers display the reflectivity as a function of the opening angle and opening azimuth. The reflection angle gathers are used for picking of angle domain Residual Move outs (RMO) which, together with the information derived from directional gather can be used as an input for anisotropy study. In this work, full azimuth angle domain depth imaging technique is used to improve imaging in the deeper part and map subtle faults in the study area (Dabka-Matar). For fracture characterization, core data and image logs (FMI) are essential. In this work, an attempt has also been made to predict the fracture intensity and orientation using diffraction volume.

Introduction

Over the time, Seismic imaging has changed a lot. As most of the easy oil has already been discovered, hunt for hydrocarbon in geologically complex area is not a choice but compulsion. Because of this, maximum useful information from seismic data needs to be extracted. Starting from 2D imaging, efforts are continuously being made to utilize all recorded information from seismic data. Full azimuth angle domain imaging is a step in this direction and this technique uses the complete recorded wave field to provide a highly accurate and detailed description of the subsurface. The system has proven successful in extracting unprecedented value from all modern and legacy seismic data acquisitions, especially those with wide and rich azimuth. In the study area, such data was available over which, this study has been carried out. The objective of the study was to improve imaging in the deeper part of the area and bring out subtle subsurface features clearly. This study describes a comprehensive approach to utilize full azimuth angle domain imaging and analyses the results obtained from it.

General Geology of the area

Study area falls in the Jambusar-Broach block of Cambay basin. Cambay Basin is a narrow-elongated rift basin situated in north western part of Indian Peninsula in the state of Gujarat and part of Rajasthan, between Latitudes 21oN and 25o N and Longitudes 71o 15'E and 75o15' E. Length and maximum width of the basin are 425km and 138km respectively, covering an area of 59,000sq.km. There are of several intra basinal uplifted blocks limited by Radhanpur-Barmer arch (which separates Cambay basin from the Kutch basin), Saurashtra Craton on the west, Aravalli hills in the northeast and Deccan Craton to the southeast. It extends from north of Sanchor to the south in Cambay Gulf and ultimately open into the Arabian Sea. On the west and east, it is bounded by enechelon faults (Basin margin faults) paralleling the Dharwar trend and cuts across the Aravalli and Satpura trends. The Basin has Deccan Trap volcanic rocks as technical basement over which 8 kms (+) thick Cenozoic sediments were deposited. Sediment thickness deposited in different parts of basin.

Study area lies between Mahisagar and Narmada rivers. Lineaments in this block also trend in N-S direction. Inversion along the normal faults has led to the evolution Gandhar and Jambusar structures. Gandhar ,a major field in Cambay basin lies in this block, followed by minor producing fields in Jambusar,Dahej,Pakhajan, Dabka, Gajera, Kural, North Sarbhan, Mattar ,Palej towards north ,northeast and east of Gandhar ,Nada and Single well pool of South Malpur lies west of Gandhar field. The major reservoir rocks are sands of Hazad member, with marginal production from the overlying Ardol member sands in Mattar area. Broach low is the main kitchen for south Cambay Basin. Two deep wells Jambusar-P-1 and Gandhar-36, were drilled in Broach-Tankari depression down to a depth of 5486m and 4500m respectively, of which Jambusar-P-1 encountered basement, thickness of Olpad Formation and Cambay Shale encountered being 1720m and 1420m respectively. In Gandhar-36, the Olpad Formation was penetrated partially and thickness of Cambay Shale was 1050m. The total sedimentary thickness in Tankari-Broach low has been estimated to be around 8 Km in the deepest part.

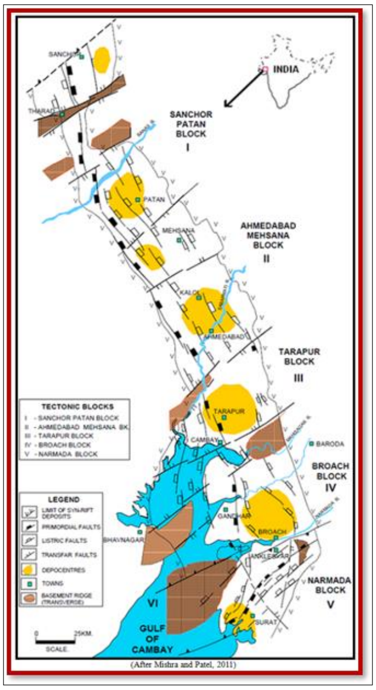

Figure 1: Location of Cambay basin (Right) and study area within Cambay basin.

Methodology

The major steps of the study are as follows:

Preparation of an effective velocity model by incorporating information from well data, interpreted horizons and faults

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Pre-stack depth imaging in local angle domain, generation of reflection and directional angle gather

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Separation of specular and diffracted energy by applying suitable filter, using the directional angle gather

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Application of automatic fault extraction (AFE) procedure to enhance diffraction image data

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Validation of seismically imaged fractures with FMI log data at well locations

Velocity Model Building

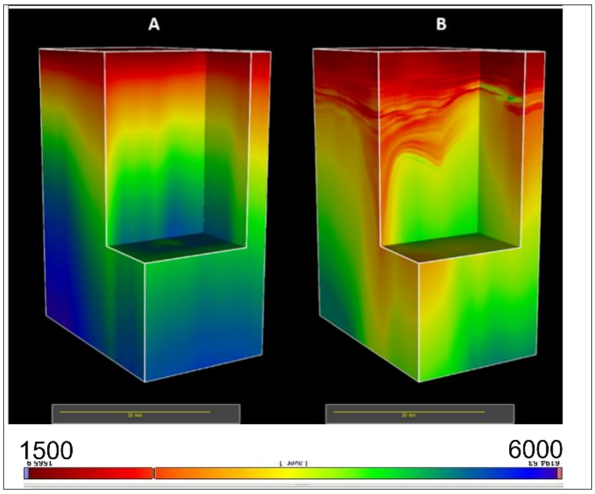

Figure 2: (a) Initial Velocity model derived from RMS velocity using dix method. (b) Final velocity model after tomography by incorporating wells, horizons and fault information.

In this study, Velocity model was prepared using “subsurface knowledge unified approach”, commonly known as SKUA modelling. In conventional approach, Initial velocity model is derived through RMS velocity using Dix conversion. However, in the current approach, geological information as Faults, Horizons and well data is used to build initial velocity model. The position of faults and horizons is considered simultaneously, and a stratigraphic column, which describes the chronological order of the horizons and their stratigraphic role, is used as input in the horizon modeling algorithms. The resulting models are not only geologically consistent but are also perfectly sealed. This velocity is further updated using tomography to obtain final updated velocity. Initial and final velocity models have been shown in figure 2.

Depth migration in local angle domain

Pre-stack depth migration was done in local angle domain (LAD). Seismic data on surface can be considered as a function of source coordinates, receiver coordinates and time. The full-azimuth angle domain decomposition involves a combination of ray pairs indicating incident and reflected/ diffracted rays. Each ray pair maps a specific seismic data event recorded on the acquisition surface, into a four-dimensional local angle domain space in the subsurface - dip and azimuth of the ray pair normal, Opening angle and opening azimuth. After this, Reflection and directional angle gathers are obtained. A representative gather is shown in figure 3.

Generation of specular and diffraction volume

Directional gather contains both specular and diffraction energy. The direction which has maximum energy is known as specular direction. This direction represents actual reflector dip at that image point. Specular direction mainly contains reflection energy and this energy is termed as specular energy. The remaining part of the energy (Non specular) is attributed as diffraction energy, which contains information mainly from discontinuities like faults and fractures (Abhinandan Ghosh,2019; V P Singh et al,2020). Specular stack volume is obtained using specular enhancement. To apply specular enhancement in the full-azimuth decomposition and imaging system, a specular weighted filter is applied on the full-azimuth directional gathers. In Figure 4(a) and 4(b) a comparison between vintage conventionally imaged reflection stack section with the equivalent specular stack section is made

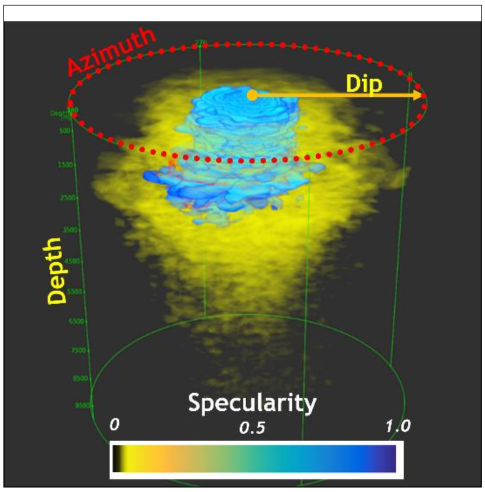

Figure 3: 3D view of full-azimuth directional gather showing specular directions at different subsurface depth points.

Prominent sub-trap reflection that is visible in the specular stack data. In Figure 4(c) and 4(d) fault likelihood attribute derived from same vintage reflection stack section is compared with the current equivalent reflection stack section. Improvement in fault mapping can be seen. Using the similar approach as in specular stack, Diffraction stack volume is obtained. The diffraction volume shows enhanced imaging of spatially consistent geological discontinuities and higher resolution fault definition. Figure 5a shows a diffraction depth slice at 1740m depth.

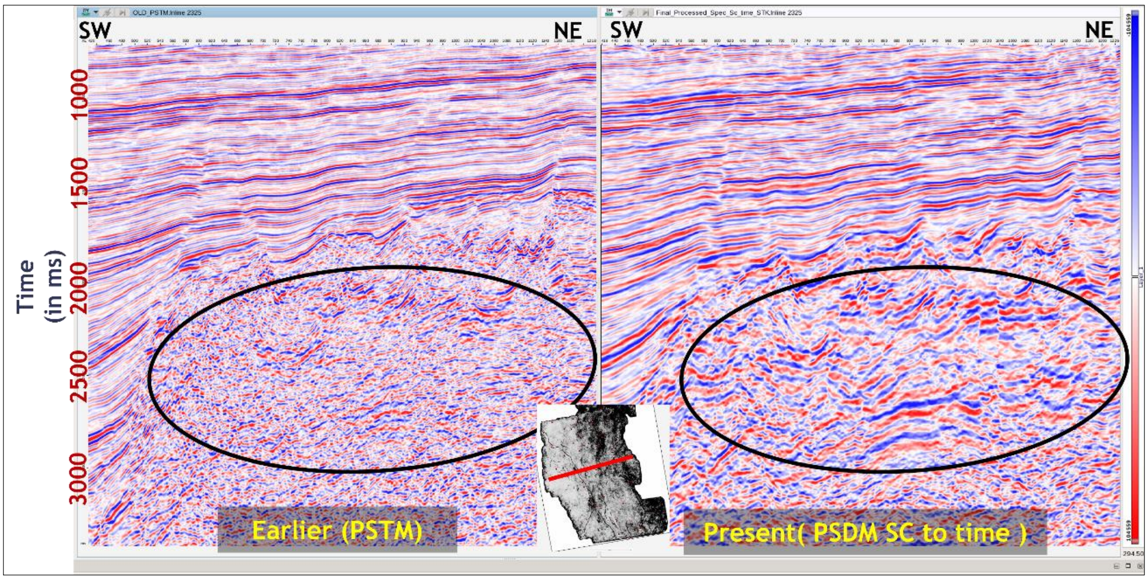

Figure 4: (a) Vintage reflection stack (Left). (b) Specular stack showing well-imaged deeper events (Right).

Automatic fault extraction

The AFE technique was applied to the diffraction volume to extract and enhance linear and planar fault-related features. Figure 5b shows the same depth slice as in Figure 5a, after application of AFE. Here, faults have been separated from other discontinuity features in the diffraction stack data, and they are now sharply defined. Fracture intensity map can also be derived using AFE output. It is shown in figure 5c. In the study area, two established field A & B with different fracture intensity exists. AFE derived fracture intensity map suggests that field A has a greater fracture intensity as compared to field B, which is consistence with existing geological model.

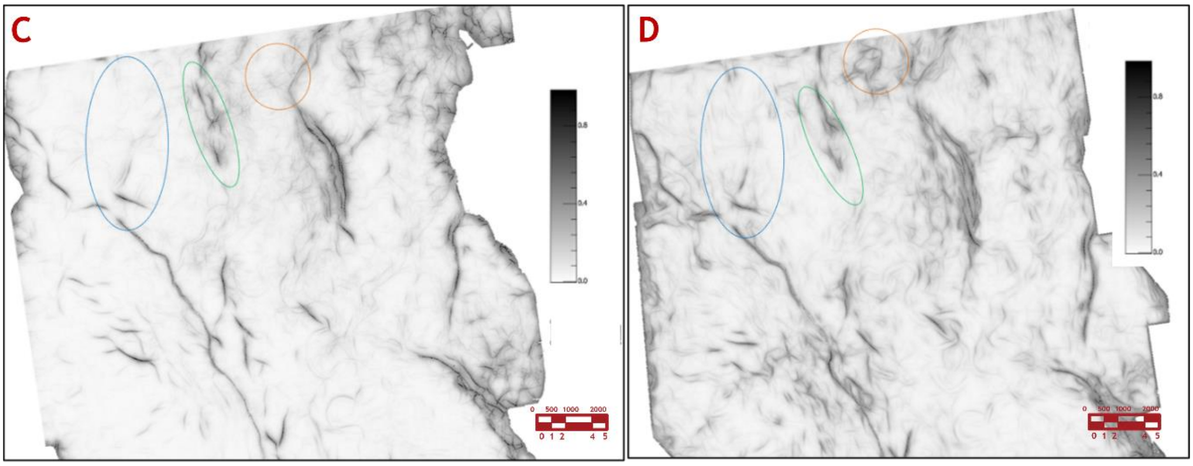

Figure 4: (c) Fault likelihood attribute obtained from Vintage reflection stack. (d) Fault likelihood attribute obtained from present reflection stack (Image courtesy: Interpretation team, Block 1, WON Basin)

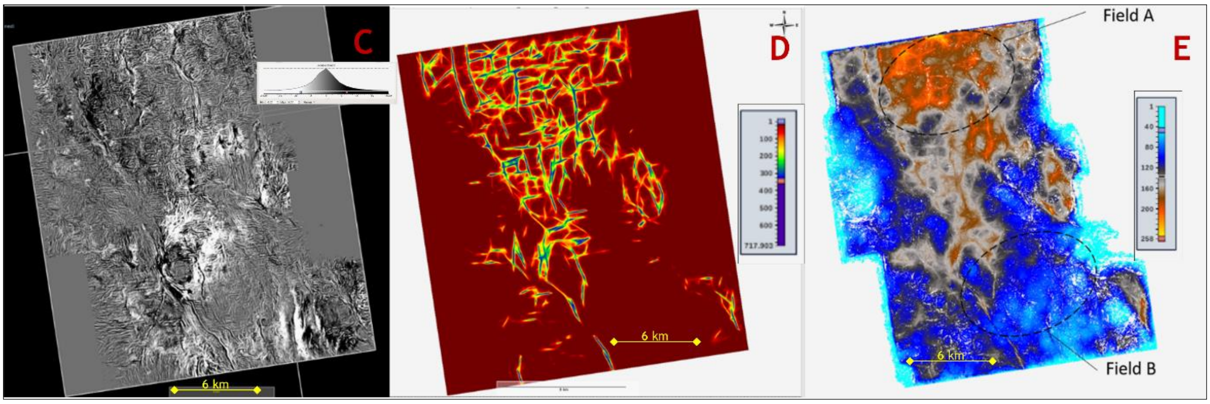

Figure5: (a) Depth slice at 1740 m from diffraction stack showing detail information. (b) Same depth slice after application of AFE showing enhanced definition of faults. (c) Fracture intensity map showing relative variation of fracture over the study area.

Validation of results

Seismic fault/fracture plane extraction compared with data from FMI logs. Fault/fracture plane interpretations made from AFE analysis match well with fracture data from FMI logs. Figure 6 compares fracture orientation derived from rose diagram. Figure 6b represents AFE derives rose diagram and figure 6c represents rose diagram obtained from FMI log.

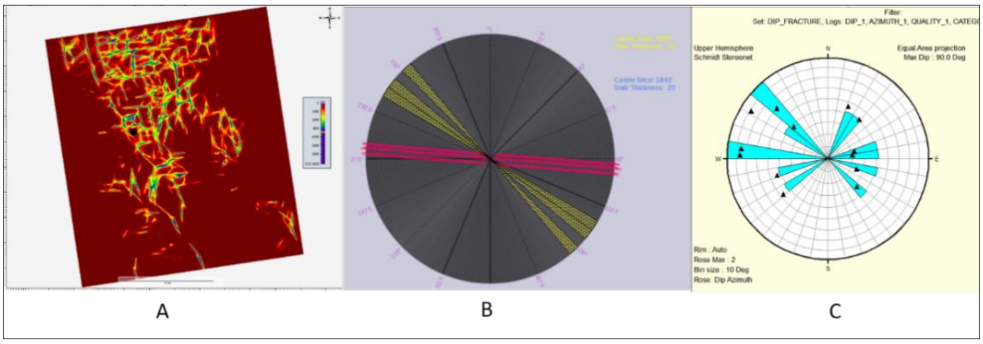

Figure 6: Fracture orientation from (a) AFE vector azimuth (b) Diffraction rose diagram (c) FMI rose diagram

Conclusions

Full azimuth angle domain imaging provides an alternate way to map the events in structurally complex area. This technique has shown significant improved imaging of seismic events and mapping of the subtle faults and fractures in the deeper part carried out in area between Mahisagar and Narmada rivers. Significantly improved subsurface imaged volume is available for interpreter to carry out his job. Specular and diffraction imaging successfully separated out reflection and diffraction energy. Enhancement in deeper events on specular stack can be seen as compared to the vintage data. The diffraction stack properly delineates major-minor faults and fractures. Automatic fault extraction technique provides additional attribute like fracture intensity and orientation, fault enhanced etc. from diffraction stack. Besides, the fracture orientation and intensity mapped from seismic data is shown to match with that from FMI log data. New outputs will help in identifying hydrocarbon prospect in this area.

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