Borehole Image Log Interpretation in Fractured Basement of Contai Area, Bengal Basin, India for Hydrocarbon Exploration

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Abstract: Fractured basement reservoirs are not being explored fully despite of their proven commercial success globally. Basement reservoirs consist of rocks such as granite, granodiorite, gneiss, basalt etc. All basement is not fractured. Fractures finding in basement rock through conventional petrophysical tools is not possible. Borehole image logging tools such as Formation micro resistivity image (FMI) and Circumferential borehole acoustic image log (CBIL) are most important tools in petroleum industry to find the fractures, dip magnitude and its direction of fractures, in-situ horizontal stress direction (S_H), bedding plane and lithological boundaries etc. Fractures in conductive nature can be identified by both micro resistivity and acoustic image tools. Resolution of resistive image tool for identifying conductive fractures is much better than acoustic tool. But the demerit of resistivity image tool is that it cannot detect whether conductive fractures are either open or close. Acoustic tool can identify open or close fracture through amplitude and travel time. For open fracture, both amplitude and travel time of acoustic image tool will show low amplitude sinusoidal nature. Amplitude of acoustic tool has been reduced in open fracture due to mud entry in open fracture as a result dissipation of acoustic energy against open fractures occur and so amplitude is reduced. For closed fracture there is no mud entry within fractures, so amplitude of acoustic tool would be strong but travel time will not show any sinusoidal because of no dissipation of energy in travel time. When fractures are mineralized by minerals, they are called closed fractures and certainly those close fractures are devoid of hydrocarbon. Both FMI & CBIL tools were lowered in well R of 'Oil & Natural Gas Corporation Ltd' for finding fractures in basement of Contai block, Bengal basin, India. Well R was drilled up to the depth of 3950 m. Basement top is at a depth of 3606m and bottom depth was 3950m. Huge number of fractures in the depth interval 3606m – 3950m in basement of Bengal basin were identified by both tools of FMI and CBIL. Most of them are closed due to mineralization by conductive minerals. We may conclude that basement of area of Contai, Bengal basin, India is having fractures which are closed and therefore, this basement is devoid of hydrocarbon.

Key words :Fracture basement, Conductive fracture, Open and close fracture, Sub vertical fracture, In-situ horizontal stress direction

1. Introduction

Commercial production of hydrocarbon has begun from fractured crystalline basement across the globe since decades. Several oil discoveries are found in the basement of North Sea and the West of Shetlands [1, 2]. The examples of producing fractured reservoirs are belonging to the Cuulong Basin, Vietnam and Southern Sumatra Basin, Indonesia along with other significant basins in Yemen, China, and India [3, 4, 5]. The petroleum system components of basement reservoirs are no different from those of conventional clastic reservoirs. The basement reservoir typically comprises of lithologies such as granite, granodiorite and gneiss with secondary lithologies including dolerite and basalt. The permeability of this reservoir is provided by fractures ranging in scale from faults detectable from seismic data to those fractures that can be detected and quantified from the evaluation of core [6, 7]. Basement reservoirs may tend to have complex geological histories with fracture properties resulting from a combination of tectonic, hydrothermal and epithermal processes. Drilling of production wells is usually to be perpendicular to the dominant fracture system. Wells are to be deviated rather than vertical in order to optimally intersect the dominant fracture systems. Borehole image logs will provide information of the fractures with sufficient accuracy at well location [4, 8]. Many seismic techniques have been developed recently for providing fracture information

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between wells or exploring fractured basement before drilling a well [7]. Our study area is Contai block. Contai block is located in the continental shelf area in the southern part of Onland Bengal basin with an aerial extent of 610 sq.km (Figure1). From 2D seismic section of Contai block, Gondwana formation shows as a good reflector as well as basement also indicated presence of possible fractures. Therefore, Directorate General of Hydrocarbon (DGH), India had assigned ONGCL to drill 4 wells in Contai area for exploration of hydrocarbon in Gondwana formation and fractured basement. Initially three wells C, G and H were drilled up to Gondwana and drilling could not be completed in these 3 wells up to basement due to difficulties faced while drilling further below Gondwana formation.

Finally, a well R was drilled by 'Oil & Natural Gas Corporation Ltd" (ONGCL) for the purpose of finding fractures in Contai area, Bengal basin, India. FMI and CBIL tools were lowered with conventional tools. Fractures in basement were identified by both image logs. Most of the fractures are closed as they were mineralized. Therefore, basement in Contai area is devoid of hydrocarbon.

2. Geology of Bengal Basin

Bengal basin is a foreland basin with a succession of mainly deltaic sediments derived from the erosion of the Himalaya and Indo-Burmese ranges. The Bengal basin developed into isolated graben-controlled basin in basement during the breakup of Gondwana land. The Bengal Basin is one of the major sedimentary basins in Indian Sub-continent. The Indian part of the basin encompasses an area of approximately 57000 sq. km. in onland and 33,700 sq. km. in offshore part. The area is bounded by Indian Shield to the northwest, Surma Basin to the east, deeper part of Bay of Bengal to the south-southeast and Mahanadi Basin to the southwest [9, 10]. The Ganga-Brahmaputra rivers and their tributary/distributary system transport sediments from the Himalayas and surrounding Indian cratonic part to pour into the basin, forming one of the biggest modern delta systems of the World [11]. Contai block was given to 'Oil & Natural Gas Corporation' by Directorate General of Hydrocarbon, India for finding hydrocarbon. Tectonically Contai block is located in the stable shelf area in the southern part of onland Bengal Basin with an aerial extent of 610 sq. km. (Figure 1).

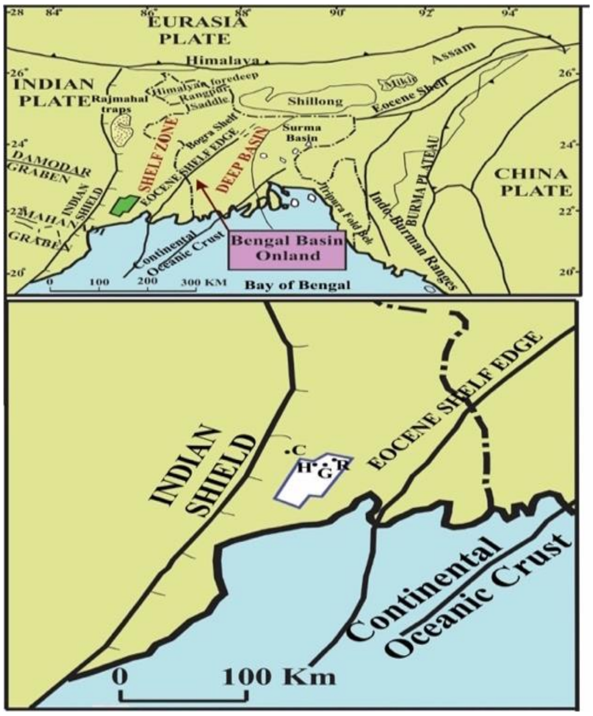


Fig 1: Tectonic Map of Bengal basin showing Contai block (White polygon) with wells [12].

In Contai area, four wells, namely; C, G, H and R have been drilled by ONGC. The well C was drilled in the year 1989-90 to explore possible hydrocarbon accumulation in Paleocene-Cretaceous sequence and stratigraphic information and hydrocarbon potential of upper part of Gondwana sequence. The well was drilled down to 3862 m and was terminated within Lower Gondwana (Talchir Formation). The stratigraphic correlation between these four wells is shown in Table 1. Based on the hydrocarbon show and Log data in Paleocene (Jalangi Formation), six objects within Paleocene were tested by means of open hole / cased hole testing methods. One object (3102-3096 m) was although identified within Gondwana but could not be tested due to non-availability of packer. All the zones tested, produced formation water with minor inflammable dissolved gas.

Table 1: Showing the stratigraphic correlation between four wells, Contai area.

<table>
<tr><th>AGE</th><th colspan="2">FORMATION</th><th>Well R
K.B: 9.93m</th><th>Well H
K.B. 10.21 m</th><th>Well G
KB: 9.37m</th><th>Well C
KB: 11.6m</th></tr>
<tr><td>Plio-Pleiostocene to Recent</td><td colspan="2">Bengal Alluvium &Debagram Formation</td><td>0 - 1512</td><td>0 – 1453</td><td>0 – 1490</td><td>0 – 978</td></tr>
<tr><td>Miocene</td><td colspan="2">Pandua</td><td>1512 - 2007</td><td>1453 – 1952</td><td>1490 – 2015</td><td>978-1427</td></tr>
<tr><td rowspan="2">Oligocene</td><td colspan="2">Memari</td><td>2007 - 2030</td><td>1952 – 1969</td><td>2015 – 2035</td><td>1427 – 1452</td></tr>
<tr><td colspan="2">Burdwan</td><td>2030 - 2363</td><td>1969 – 2261</td><td>2035 – 2333</td><td>1452 – 1820</td></tr>
<tr><td rowspan="2">Eocene</td><td colspan="2">Hooghly</td><td>2363 - 2416</td><td>2261 – 2324</td><td>2333 – 2395</td><td>1820 - 1827</td></tr>
<tr><td colspan="2">Kalighat</td><td>2416.5 - 2796</td><td>2324 – 2736</td><td>2395 – 2771</td><td>1827- 2047</td></tr>
<tr><td>Paleocene</td><td colspan="2">Jalangi</td><td>2796 - 2911</td><td>2736 – 3051</td><td>2771 – 2994</td><td>2047 – 2294</td></tr>
<tr><td rowspan="2">Late Cretaceous</td><td colspan="2">Ghatal</td><td>2911 - 2940</td><td>3051 - 3087</td><td>2994 – 3031</td><td>2294- 2355</td></tr>
<tr><td colspan="2">Bolpur</td><td>2940 - 3124</td><td>3087 – 3147.5</td><td>3031 – 3095</td><td>2355 – 2412</td></tr>
<tr><td>Lower to Upper Cretaceous</td><td colspan="2">Rajmahal Trap</td><td>3124 - 3252</td><td>3147.5-3557</td><td>3095 – 3244</td><td>2412 – 2500</td></tr>
<tr><td rowspan="4">Permian to Lower Triassic</td><td rowspan="4">Gondwana</td><td>Panchet</td><td>3252 - 3320</td><td>3557-3665</td><td>3244 – 3330</td><td>2500 – 2732</td></tr>
<tr><td>Raniganj</td><td>3320 - 3400</td><td>3665 - 4318</td><td>Not drilled</td><td>2732 – 3340</td></tr>
<tr><td>Barakar</td><td>3400 - 3532</td><td>4318 - 4491</td><td rowspan="3">Not drilled</td><td>3340 – 3640</td></tr>
<tr><td>Talchir</td><td>3532 – 3606</td><td>4491 – 4590</td><td>3640 – 3862</td></tr>
<tr><td>Archaean</td><td colspan="2">Basement</td><td>3606 – 3947</td><td>Not drilled</td><td>Not drilled</td></tr>
</table>

The well G was drilled down to 3330 m and bottomed within Upper Gondwana sequence. Electrolog correlation with well C indicates that the well G is structurally down by 746m, 778m and 572m at Gondwana, Paleocene and Eocene level w.r.t to well C located 20km away towards NW in up dip. Three objects were tested in Paleocene-Cretaceous section. The depth intervals: 2863-2857.5 m and 2854.5-2850.5 m, belonging to the Middle Jalangi, gave encouraging lead in the form of continuous flow (for about a month) of mainly dry methane gas (about 98% methane) @ 60 m^3/day and water @ 18 m^3/day. This drilled well has thus proved both generation and presence of hydrocarbon in this part of the basin. The wells C, G and H were not drilled in basement. Only well R was drilled to basement covering 300m interval within basement. Our study area is basement only for fracture findings.

3. Analysis of Image Log in Study area

The well R was the well where drilling is completed to the depth of 3950m. Basement interval in this well R is 3650 m to 3950m= 300m.Conventional tools such as Dual Latero tools, Litho Density-Neutron porosity tools, Sonic and natural Gamma ray tools were lowered and log data were obtained from bottom depth 3950m to 1000m for formation evaluation. Borehole image logging tools such as formation micro resistivity imager (FMI) and Circumferential borehole acoustic image (CBIL) logging tools were lowered and image log data recorded only in basement interval 3650 – 3950m in the well R for finding and study fractures in basement for hydrocarbon exploration in basement. Main objectives are to characterize the fractures from the image logs and to integrate micro resistivity and acoustic image log for estimation of maximum horizontal stress (S_H) direction, dip of the fracture, type of fractures, bedding plane and lithological boundaries etc. The tadpole plot shows dip of fractures, bedding and lithological boundary following the symbols of classification of dip:

Classification

Induced fracture

Fracture_Conductive

Breakout

Fracture_Low Amplitude

Bedding_Deformed

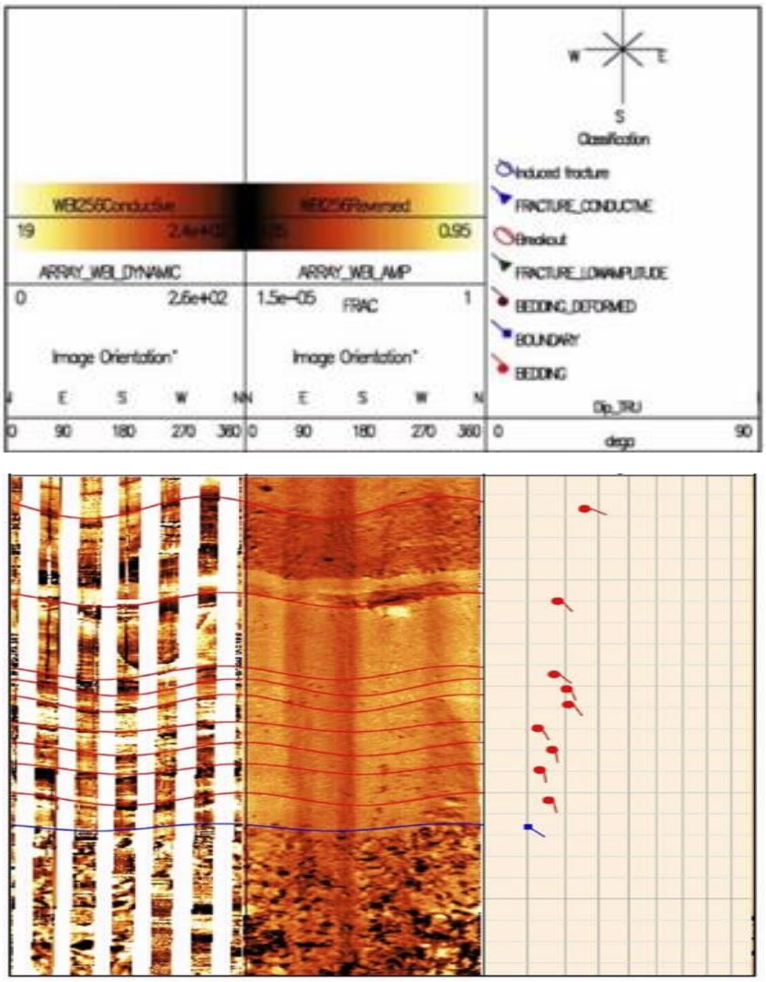
Boundary

Bedding

Figure 2 to Figure 9 is the processed output of Borehole Image log data of micro resistivity and Circumferential borehole acoustic image data in the interval of 3650 -3950m of basement of Bengal basin. Data is processed by author after using Electro log Analysis software.

3.1 Bedding Plane Identification in the Interval 3650-3655 m

This depth interval 3650-3655m displays FMI and CBIL logs to identify bedding planes and its orientation. Bedding planes are marked in Figure 2. Resistive image log (FMI) is much more resolved vertically than acoustic image log (CBIL) for delineation of bed boundary (Figure 2). Tadpole plot shows the dip amount and azimuth of the bedding plane. Figure 3 shows the Rosette (Rose) diagram of bedding plane within basement striking NE-SW direction for depth interval 3650-3950m (Figure 3)



3650 m

Fig 2: Showing the bedding plane of FMI and CBIL log in the interval 3650- 3655m of well R of Contai area

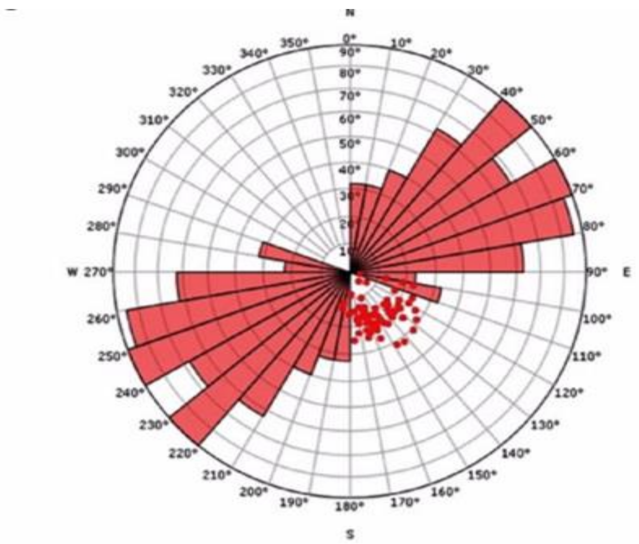


Figure 3: Showing the strike direction of bedding plane in the interval 3650m-3950m of well R of Contai area

3.2 Conductive Fractures

The low amplitudes fractures are identified from 3650 to 3950m of basement of Contai area. Figure 4 typically shows few low amplitude conductive fractures in both resistive and acoustic images**.** The acoustic amplitude and micro resistivity image logs indicate sinusoidal shaped fractures but acoustic travel time image log does not indicate any such types of features. Since these fractures are mineralized, there is no dissipation of acoustic energy. Travel Time image does not show any sinusoidal features due to the mineralized fractures. Micro resistivity image shows dark colored sinusoidal features due to presence of low resistive/ conductive mineral in the fractures. The closed fractures in basement are devoid of hydrocarbon. Therefore, the depth interval of 300m in basement from 3650-3950 m is devoid hydrocarbon. Figure 5 indicates the mean strike direction of N45ºE of mineralized fractures for 300m depth interval. The strike direction shows the paleo stress direction of the basement fractures.

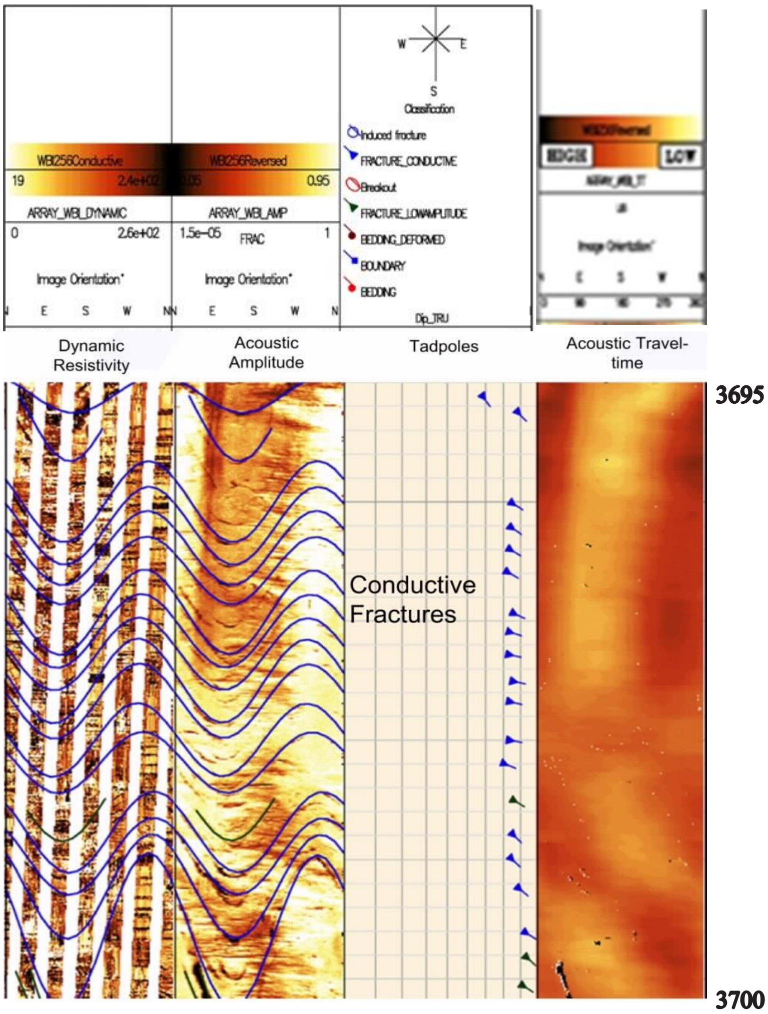


Fig 4: Showing conductive fractures (mineralized) in depth 3695-3700m of well R

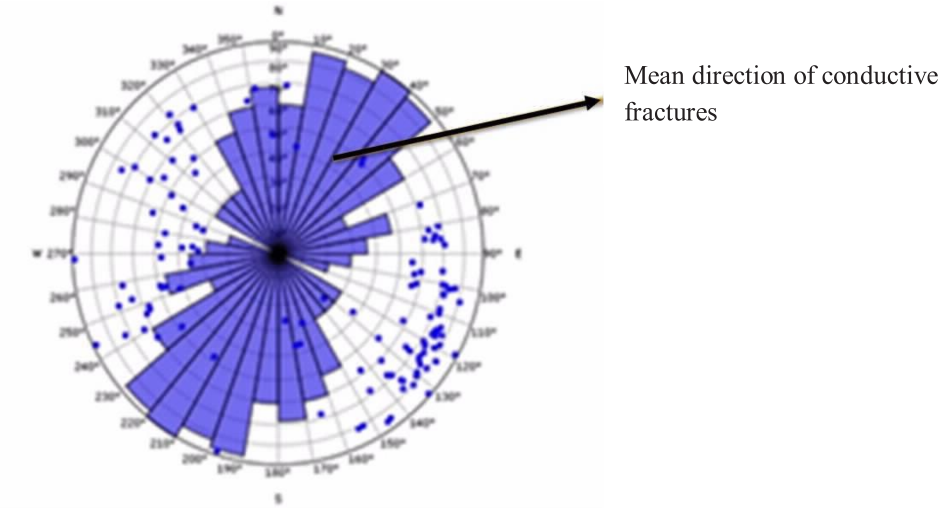


Fig 5: Strike of conductive fractures in the interval 3650-3950 m of well R

3.3 Drilling Induced Tensile Fracture in the Depth Interval 3746-3750 m

Figure 6 represents the drillings induced fractures (DIF) which are observed very distinctly in acoustic borehole image log in the interval 3746-3750 m in basement. The orientation of DIF is aligned with the orientation of maximum horizontal stress (S_H). Strike direction of DIFs is NE-SW indicating that the orientation of S_H is NE-SW (Figure 7)

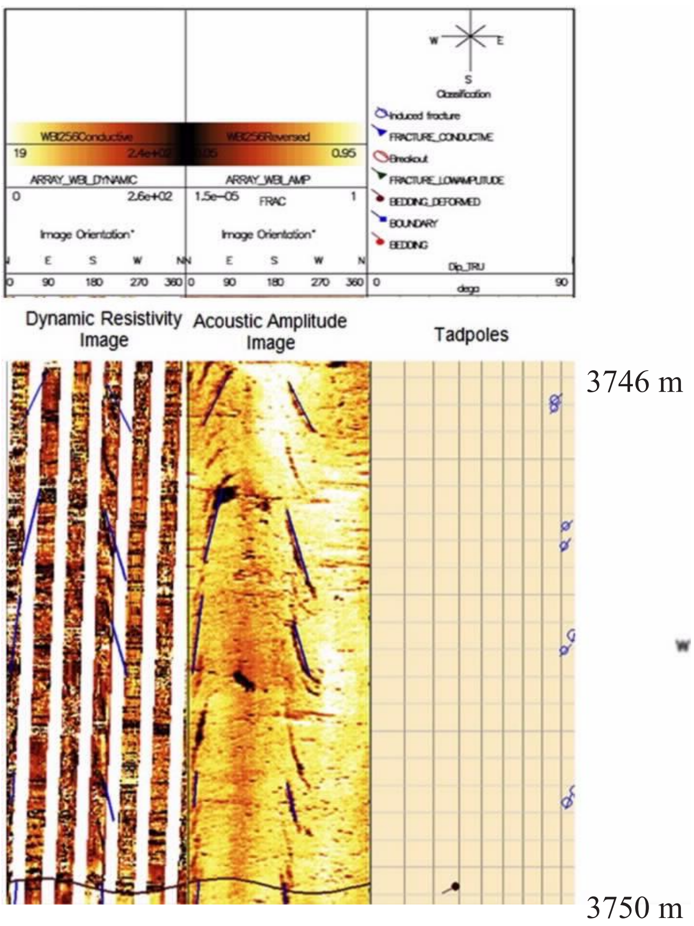


Fig 6: Showing drilling induced fracture in the interval 3746 m to 3750 m in basement

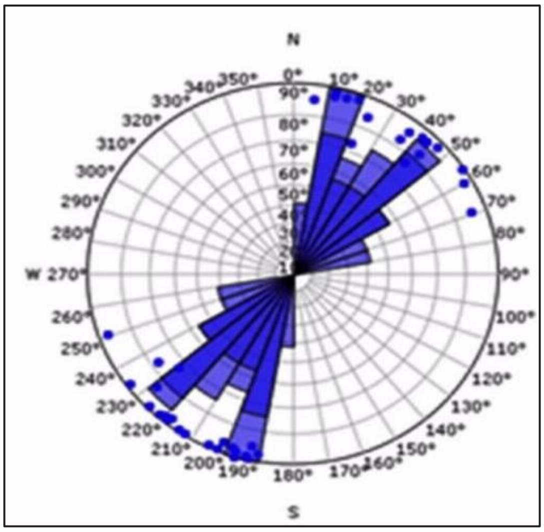


Figure 7: showing azimuth direction of Drilling induced tensile fracture and this direction also the In-situ Maximum Horizontal Stress (S_H) direction of well R

3.4 Open Fractures in the Depth Interval 3710 – 3713 m

The fracture observed in acoustic image log in the interval 3710-3713m (Figure 8) is low amplitude open fracture. Acoustic travel time (TT) image characterizes total loss of energy indicating black sinusoidal features and striking parallel to S_H direction.

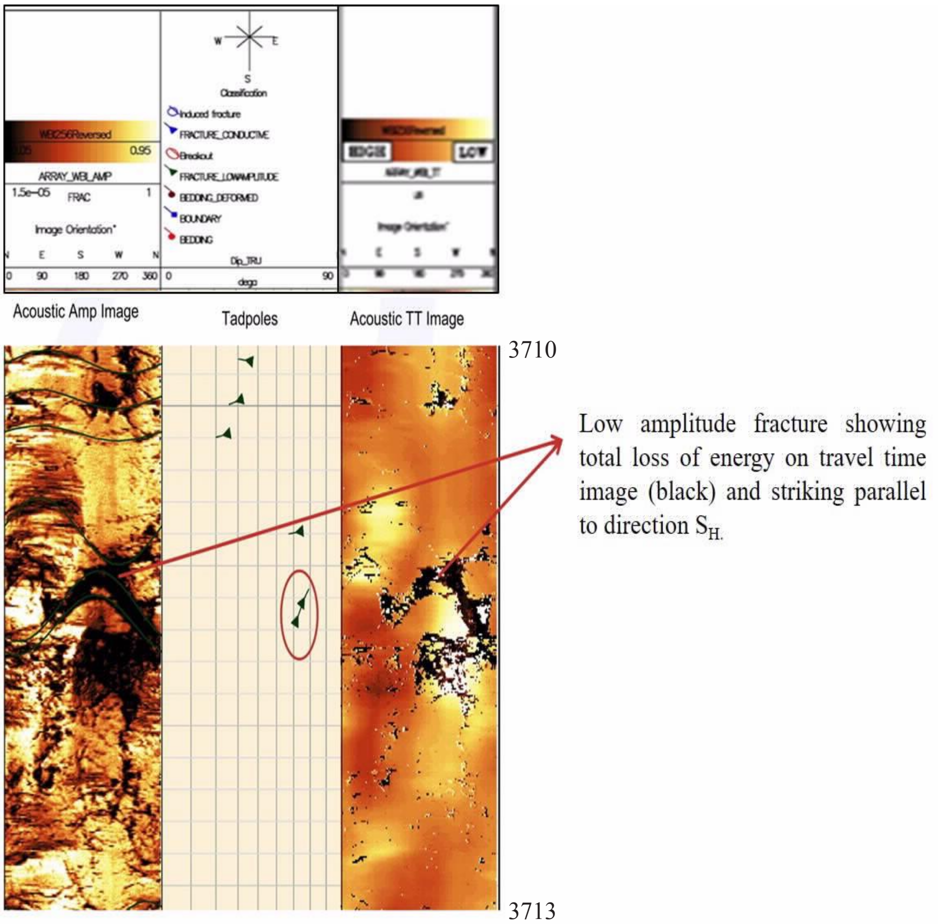


Figure 8: Shows the open fracture in interval 3710 -3713 m of CBIL tool of well R

3.5 Sub-vertical Open Fracture at the Depth Interval of 3924 to 3932 m in the Basement

Figure 9 elaborates features indicating low amplitude sub-vertical fracture terminated against the fracture right above it. Total energy loss on travel time image (dark) indicates that it is open in nature. Striking direction is parallel to the orientation of SH.

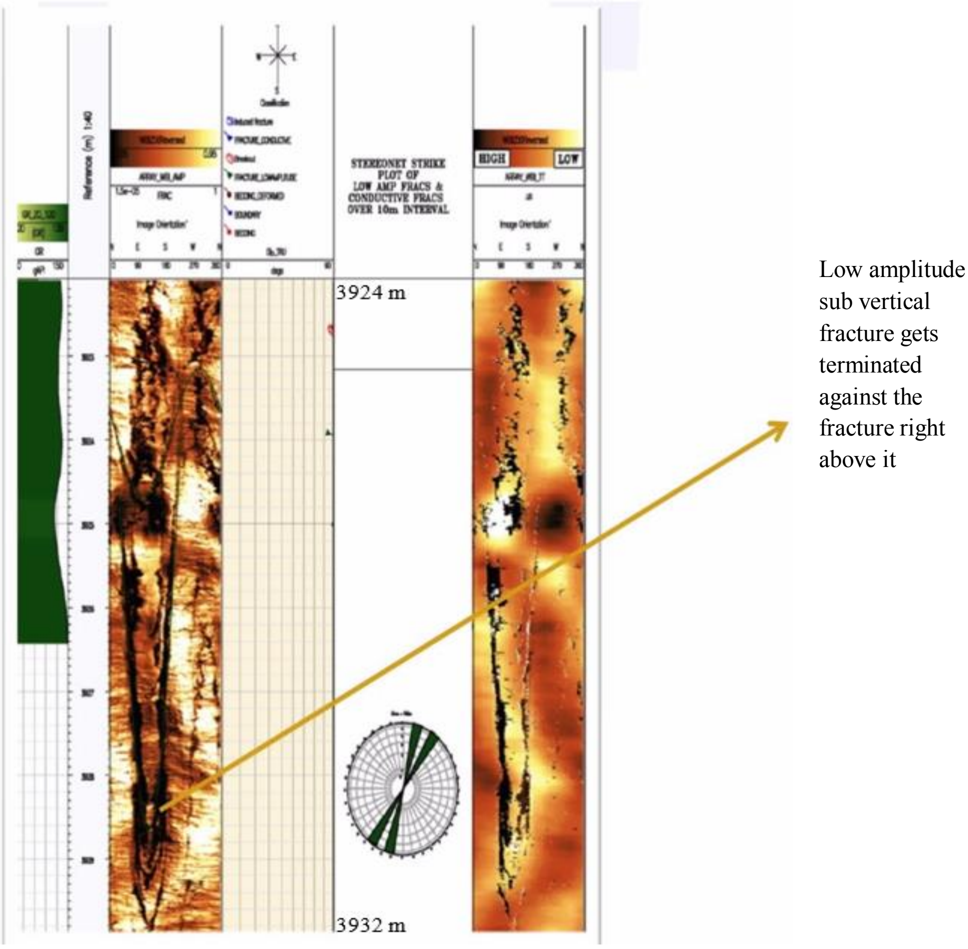


Fig 9 Shows sub vertical open fracture in the interval 3924 – 3932m of acoustic tool of well R

4. Results

Fractured basement of Bengal basin of one well is studied through micro resistivity and circumferential borehole acoustic image logs. From the above image log studies, it is inferred thar few natural fractures in the basement are open and they are oriented parallel to the maximum horizontal stress direction. Acoustic travel time image in the basement shows that most of the fractures are mineralized and closed. This closed mineralized fracture characterizes with strong amplitude acoustic information along due to presence of energy on travel time image. Very few fractures observed in acoustic image log are open. Sub vertical open fracture exists in the depth interval 3924-3932m striking parallel to the maximum horizontal stress (S_H) direction. Fracture basement of Bengal basin is devoid of hydrocarbon as most of the fractures in basement are mineralized and as a result they are closed observed from image tool. Low amplitude open fracture is showing total loss of energy on travel time.

5. Discussion

There is a great interest and value in fracture detection and evaluation of fractured basement reservoirs in Bengal basin. The procedure for identification and evaluation of natural as well as induced fractures in basaltic basement of the Cambay basin has already been presented previously [13]. The Deccan trap basaltic basement in Tarapur-Cambay block has potential for holding commercial hydrocarbon due to presence of fractures and weathered basement. Electrical and ultrasonic borehole images along with conventional sonic logs have been used to characterize fracture system. Electrical image logs assume that all conductive fractures are open and can transmit fluid. In reality the majority of the fractured reservoirs flow hydrocarbon from only a few isolated fractures or from a specific fracture set or system. A combination of image logs and acoustic logs characterize fractures and other form of high permeability geological flow conduits [14]. The combination of these measurements allows a detailed analysis of fracture type (open, closed and plugged), fracture orientation, and most importantly the ability of individual open fractures and fracture sets to flow fluid. Image logs identify three types of fracture including open (Conductive), partially open and closed(resistive) fractures of which open and partially open fractures are important for hydrocarbon accumulation. Finding of this discussion is to utilize acoustic and resistivity image logs for identification of low amplitude fractures, open and mineralized fractures as well S_H direction. Dip of the fractures in the Contai area ranges from 10 to 80 degrees. Image logs identify conductive and mineralized fractured zones. Subvertical fractures are delineated. The strike direction of open fractures for a well in Contai area ranges from $N20^0E$ to $N40^0E$. The S_H orientation is varying from N20 to 40^0E in the basement of Contai area. Fractured basement of Bengal basin is devoid of hydrocarbon as most of the fractures in basement are mineralized and as a result, they are closed identified from CBIL tool.

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