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Carbonate Basement Fracture Identification from Conventional Data: Well log, Drilling Parameter, and Petrography- A study case from "X-1" well, North Palembang Sub-Basin, South Sumatra, Indonesia.

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Abstract

Most of the times, recognition of fracture evidences requires bundles of advance well data set that are costly and sometimes are not operationally practical to collect. This paper describes an approach to identify fractures evidence through more common data acquisition in a drilling. The data subject to wireline data, drilling data (drilling parameter and mudlog data) and petrography analyses from the cutting samples.

The "X-1" well was drilled with main objectives in shallower sandstone reservoir of Telisa Fm and secondary objectives in Talang Akar Fm. This well penetrated 75 m of carbonate basement as tertiary objective. Previous operator has not really explored the carbonate basement potential after the drilling completed as they regarded the interval as 'tight' and 'non pay' zone. Recent discovery of giant gas fractured reservoir in Sakakemang Block, around 100 km to the north west of the X-1 well has triggered the current operator to research the potentiality of basement reservoir in the study area.

The carbonate basement interval in "X" structure was characterized by an erratic and spiky resistivity and porosity log (density, neutron and sonic log) pattern. The lithology is mainly crystalline carbonate with average bulk density close to 2.7 gr/cc and sonic log reading 40-60 ms/ft indicating a very small amount of porosity.

Even so, some anomalies are recorded by the porosity logs in this interval when sonic porosity is less than density-neutron porosity. These facts indicate that the secondary porosity was developed in the rock matrix. From the petrophysical evaluation, it can be estimated that the secondary porosity is ranging from 2% to 19%. As what encountered in the logs, secondary porosity in the dominantly tight basement interval are also demonstrated from the drilling break event. Where secondary porosity exists, one can notice an increase of ROP (rate of penetration) from average 19-20 minutes/meters to 5-8 minutes/ meters. Hydrocarbon indication emerges from notable increase in Tgas, C1 (methane) and C2 (ethane) on basement interval. Another indication comes from a well control situation when penetrating the basement interval with secondary porosity. During pulling out BHA after penetrating top of basement, the well was flowing and the flow was flared. To cope with the flow from the borehole, the mud weight was increased from average 1.08 ppg to 1.1 ppg.

Beside the well and drilling data, a petrography analysis from cutting samples in the interval with secondary porosity was carried out to figure out the existence of secondary porosity and what exactly the type of secondary porosity is in the rock matrix. The petrography analysis is showing 98% of type III/IV twinning-calcite, indicating a hot paleotemperature, with intensive microfracture. The fractures were mainly open with partial micaceous mineral and quartz overgrowth filling.

From the study, it is shown that the usage of common primary data such as wireline log, drilling parameter, and even cutting petrographic analysis, can be optimalized to investigate natural fracture occurrence in the basement.

Keywords: Basement Fracture, Carbonate, Secondary Porosities, South Sumatra Basin

Introduction

The "X-1" well was drilled as a delineated well in an" X" field on 2009, after the gas discovery made by previous operator through a wildcat drilling a couple of years before. The gas was encountered in Telisa sand and Talang Akar sand with gas flow rate ranging from 0.8-4.8 MMSCFD. The gas was composed by 94% methane with less than 2% of CO_2. These two pay zone thicknesses are relatively thin, 6 meters and 3 meters thick in Telisa and TAF respectively. The wells in "X" structures have penetrated the carbonate basement interval. According to the wireline log data, drilling data, and seismic data, the latter interval shows some interesting anomalies which can elevate the prospectivity of previously sided as tight and non pay interval to become a 'mispay' zone which worth to test in the next drilling campaign. Recent success story in basement exploration from the neighboring fields triggers the current operator to conduct a detail study to investigate the potentiality of the basement fractures in the study area. One of the key factors to have basement as a successful reservoir is the presence of massive secondary porosities in its marix. Fracture, as a product of geologic process (tectonic), is among the secondary porosity types which can provide quite large amount of space for hydrocarbon to be accumulated.

Evidence of a fracture in one interval usually demands a complete and advance well data set for a geoscientist in order to identify it. Source of complexity in fracture identification comes from the fracture dimension which is quite usually below the tools' reading resolution. Recent development in wireline technologies has enabled the fracture identification being possible. Among all the wireline data, the borehole imaging log and core data maybe the most effective and direct method for detecting fractures. Due to the high cost, the distribution of borehole imaging log data is considerably limited or sometimes even not available in one field. In well "X-1", only conventional log data are available. Meanwhile, neither borehole imaging nor core data were acquired from the well.

This study will elaborate an approach to maximizing the usage of conventional log data, drilling parameter, and petrography analyses for fracture and hydrocarbon presence identification.

Geological Settings

The study area is located in North Palembang sub-basin, South Sumatra Basin, Indonesia (Figure 1). South Sumatra Basin has undergone three major tectonic events (Suhendan, 1984), which consist of:

1) Extension during late Paleocene to early Miocene forming north-trending grabens that were filled with Eocene to early Miocene deposits (40-29 Ma);

2) Relative quiescence with late normal faulting from early Miocene to early Pliocene (29-5 Ma); and

3) Basement-involved compression, basin inversion, and reversal of normal faults in the Pliocene to Recent forming the anticlines (5 Ma-Recent) that form major traps in the area.

Sedimentation history in the South Sumatra basin began with the deposition of continental sediments derived from local erosion of Lemat Formation in the Eocene (Cole and Crittenden, 1997; Courteney et al., 1990). As the rifting phase weakened during late Oligocene time, transgression occurred as a result of thermal sag and eustatic gain (Netherwood, 2000; Barber et al., 2005). This transgression event was then followed by sedimentation of Talang Akar Formation in several rifted grabens. The sediments of Talang Akar Formation were deposited in various depositional settings, from fluvial to deltaic and drives mixed sediment strata consisting of interbedded sandstones, shales, and coals. In the earliest Miocene, as the transgression continued, the depositional settings of Talang Akar Formation changed gradually from fluvial to more deltaic and then marginally deep marine.

During the Early Miocene, deposition of Baturaja Formation flourished on structural highs as carbonate buildups on some local inter-graben highs and basin margins or as carbonate mud-dominated in the low energy banks (Situmeang et al.,1992; Longman et al., 1992). In the deeper part of the basin, a shale-dominated-strata with thinly bedded sandstone and limestone intercalation, Gumai Formation, was deposited. During the Middle Miocene's maximum transgression, the Gumai shale seal across the region creating the most widespread regional seal (De Coster, 1974).

In the Middle Miocene, development of the Barisan Mountains and possible volcanic islands to the south and southeast, further decreased and then cut off and overwhelmed marine influences and added new clastic and volcaniclastic sources from those directions (De Coster, 1974; Cole and Crittenden, 1997; Hamilton, 1979).

Deposition during the Middle Miocene-Pliocene compressional regimes started with shallow marine – deltaic Air Benakat and Muara Enim Formations. Air Benakat Formation consists mainly of sandstone and fine-grained siliciclastic rocks, while coal bed intercalations occur in the Muara Enim Formation.

In the Pliocene, the sedimentation was driven mainly from the west and northwest of the basin which marked the Kasai Formation deposition. This formation overlies the Muara Enim Formation unconformably and consists of conglomerates, tuffaceous sandstone, and tuffs with lignite and silicified wood. Regional stratigraphic column is shwon in Figure 2.

Data and Method

The data and method used is from wireline log data, drilling parameter, gas reading and cutting analyses from "X-1" well. Petrophysical analysis was carried on at the first place to determine the possible fracture zones based on the log. Secondly, the intervals where fractures are identified from petrophysical analysis were calibrated with drilling parameter, gas reading and cutting petrographic analyses.

Result and Discussion

Petrophysical Analysis

The carbonate basement interval in Rahmat structure was characterized by an erratic and spiky resistivity and porosity log (density, neutron and sonic log) pattern. This pattern may indicate the high-density variation inside the interval. According to the cutting description, the basement lithology predominantly consists of off-white chalky limestone, wackestone-packstone, microcrystalline, moderately hard-hard.

As from the log, typically, the carbonate limestone is tight with bulk density near to 2.7 gm/cc. This tight lithology is also shown by the abrupt change in resistivity from 1-12 ohm.m-1 in the TAF (Talang Akar formation) to more than 1000 ohm.m-1 in the basement and also increase in travel time (sonic) from average 90-110 ms/ft to 40-60 ms/ft (Figure 5).

The evidence of porous interval in this carbonate basement can be recognized by discrepancies in density and sonic log derived porosity, where density porosity is higher than sonic porosity. Such porosity evidence is commonly referred as secondary porosity. Secondary porosity refers to the opening created after the rock was formed (e.g. fractures, solution channel). The secondary porosity can be calculated with following equation:

$\varphi f \cong \varphi d - \varphi s$ .... (Eq.1)

where

φf : secondary porosity

φd : density porosity

φs : sonic porosity

Since the sonic speed is higher for the solid rock's fabric or matrix, the compressive sonic pulse or wave is mostly transmitted through the matrix. However, the bulk density log and its derived density porosity curve, measures all the porosity spaces. That is why the difference $\varphi d - \varphi s$ is an estimator to the secondary porosity and fracture porosity. Figure 3 gives simple illustration showing how the sonic waves natural behavior affecting estimated porosity from the logs. Figure 4 shows crossplot between density porosity and sonic porosity in basement interval of “X-1”well. From the crossplot, it is clear that the porosity in the basement interval is mostly secondary. Zones showing the secondary porosity evidence can be recognized at depth 419-452 mMD and 467-484 mMD on well “X-1”well (blue highlight in Figure 5).

Drilling Parameter

Indication of porous layer in carbonate basement of Rahmat can be clearly seen as well from the drilling parameters. One can expect to have a sudden change in the drilling parameters when hitting a porous interval, a naturally fractured zone, or a poorly consolidated zone. This sudden change is commonly known as a drilling break. Among the common drilling parameters as indicators of drilling break are rate of penetration (ROP) and weight on bit (WOB). As drilling bit hits a boundary between less and more porous zone, the rate of penetration will increase and the weight on bit will decrease. Aforementioned break usually become a precaution/warning sign of a kick or worse a loss to happen. During the drilling operation, the potential kick or loss is closely monitored by performing flow check. If there is an excess of formation pressure (formation pressure > borehole pressure) which will trigger a flow from the borehole, a well control situation shall be performed by increasing the mud weight, and deploying a blowout preventer to control the rush of fluid to the surface and prevent a potential catastrophe.

Figure 6 demonstrates the wireline log and drilling parameters (ROP and WOB) of “X-1”well. One can notice that in the intervals with secondary porosity anomaly, there is significant increase of ROP (faster ROP highlighted in red in Figure 6) and followed by drop of WOB (highlighted in brown in Figure 6). The average ROP in the upper carbonate basement (419-452 mMD) is 19-20 minute/ meters. At least six (6) zones signal the drilling break events with ROP less than 5-8 minute/meters. These zones will be the well testing target on “X-1”well well. The proposed testing zone in the basement interval are summarized in Table 1.

Beside the drilling break and log evidences, some well control situations were also reported when penetrating basement interval in “X-1”well. The first flow from the bottom hole fluid happened after pulling out the BHA from 422-199 mMD, the well control situation was applied by increasing the mud weight from 1.08 to 1.09 (SICP=250 psi) and flaring the bottom hole fluid (gas). The second gas flow occured when pulling out the BHA to 177 m, the same well control situation was repeated as in the first occassion. The mud weight was increased to 1.1 to kill the flow (SICP=241 psi) and the gas was flowed to flare.

The most suspicious well flowing probably corresponded to the presence of basement gas was the last well flowing control. The well was flowing when waiting for the cement to dry after setting casing to 345 mMD. The mud weight was dropped down from 1.12 to 1.09 before the cementing job. The cement was flowing from the annulus 90 minutes after the cement job. The anullar BOP was shut, SICP dropped from 320 psi to 268 psi after 10 hours waiting for cement to dry. The well was killed by injecting 10 bbls cement through the annulus.

Petrographic Analysis on Cutting Samples

The result of petrography is showing a very interesting result. The lithology of the Rahmat carbonate is showing a recrystallized limestone or marble. This recrystallized limestone is composed by mostly a deformed twinning calcite. This limestone is heavily fractured, and some fractures are filled by secondary mineral, such as muscovite, indicating an alteration by hot temperature was occurred. Figure 7 shows a petrography analysis from “X-1” well.

Conclusions

This study has demonstrated the integration of conventional wireline log data, drilling and gas reading parameter, and petrographic analysis in order to identify fractures zone and identify hydrocarbon potentiality of the fractures zone. Through a simple approach, early detection of fractures can be performed which in case of borehole imaging data and core data absence, could help geoscientist to make decision the fractures zones target in a driliing campaign.

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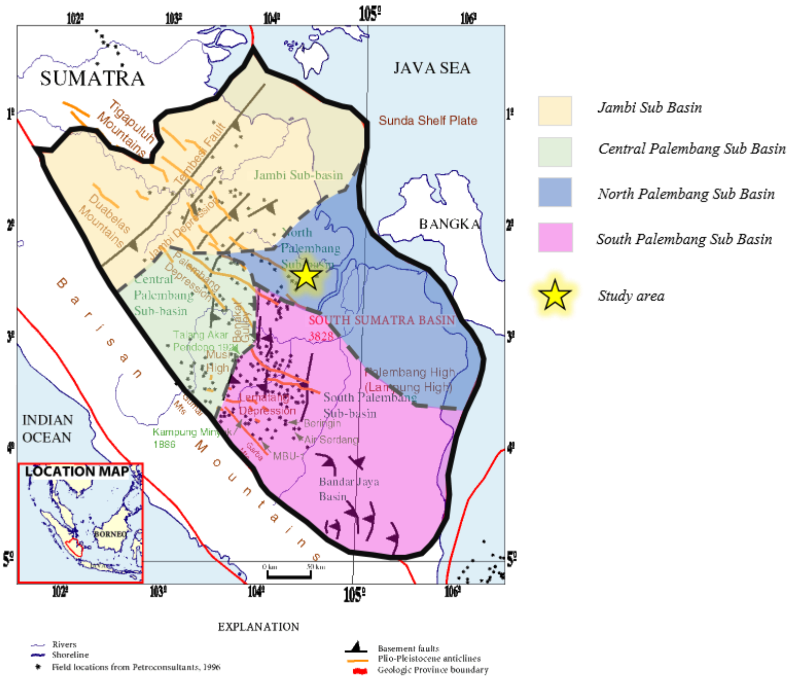

Figure 1. Index map of the South Sumatra Basin Province, showing major structural features. The structures were assembled from Hutchinson (1996); Williams et al. (1995); Moulds (1989); van Bemmelen (1949) [after Bishop, 2001]. Highlighted in yellow is location of the current study.

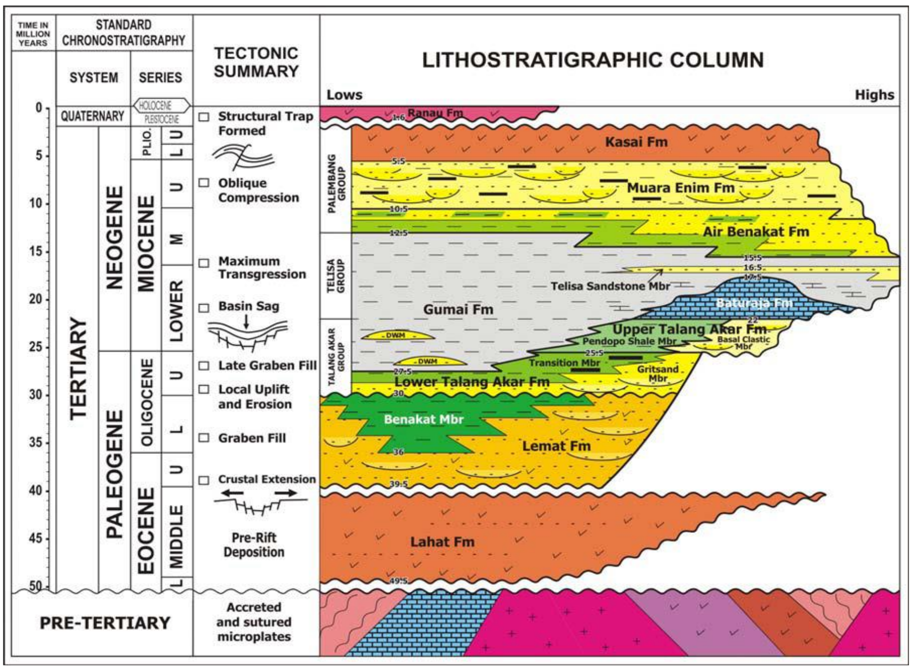

Figure 2. Stratigraphic column of South Sumatra Basin (Argakoesoemah and Kamal, 2005)

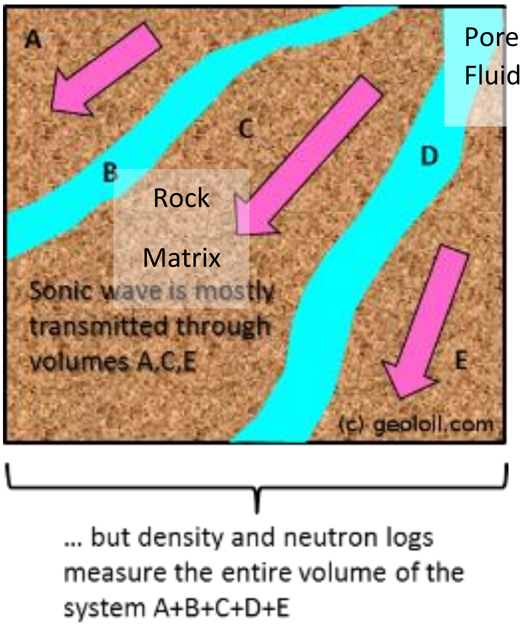

Figure 3. Illustration of how the sonic wave transmitted in the rock. The sonic wave will tend to 'choose' propagating in the dense medium such as through matrix where the transit time is faster. Therefore, it will cause the porosity estimated from the sonic to be lower than the 'true' porosity. (source: https://geoloil.com/fracturePorosity.php)

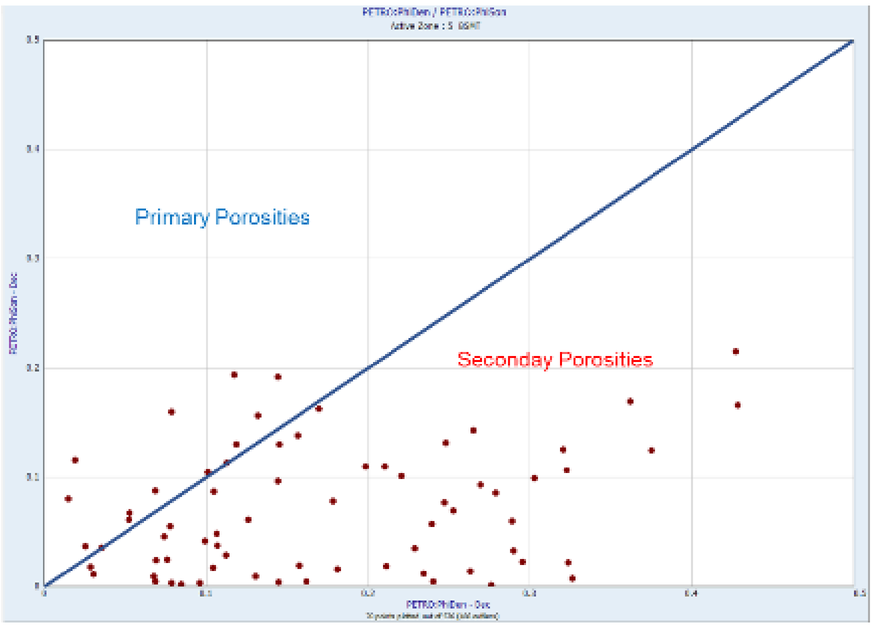

Figure 4. Cross plot between sonic porosity (y axis) and density porosity (x axis) in the "X-1" well carbonate basement interval. The dashed line represents an intersection when sonic porosity equals to density porosity. The area below and above the blue diagonal line possesses the interval with secondary porosity (density porosity > sonic porosity) and the intergranular porosity (density porosity < sonic porosity) respectively. Notice that most of the porosity plot from basement interval are within the secondary porosity area.

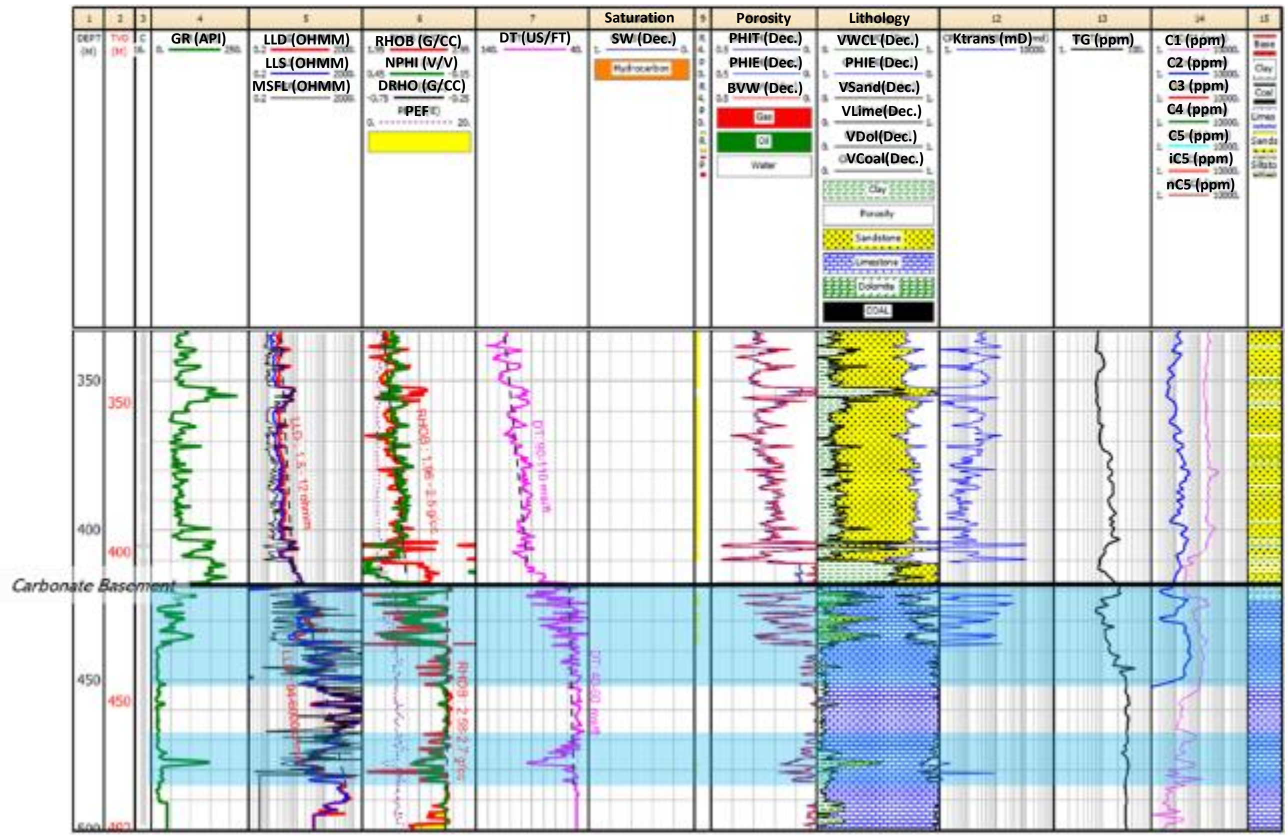

Figure 5. "X-1" well basement interval log characters. Carbonate basement was penetrated at 418 mMD (410.6 mSS). The blue highlights show the intervals with secondary porosity as the main testing interval in carbonate basement. Track 1: Depth (MD), Track 2: Depth (TVDSS), Track 3: Caliper, Track 4: GR (green), SP (dashed-gray), Track 5: resisitivity (deep-red, medium-blue, flushed-black), track 6: RHOB (red), NPHI (green), track 7: sonic-DT , track 8: Sw, track 9 : reservoir and pay flag, track 10: porosity, track 11: mineralogy, track 12: KTransform, track 13: total gas reading (TGAS), track 14 : gas chromatograph reading, track 15 : cuttings lithology.

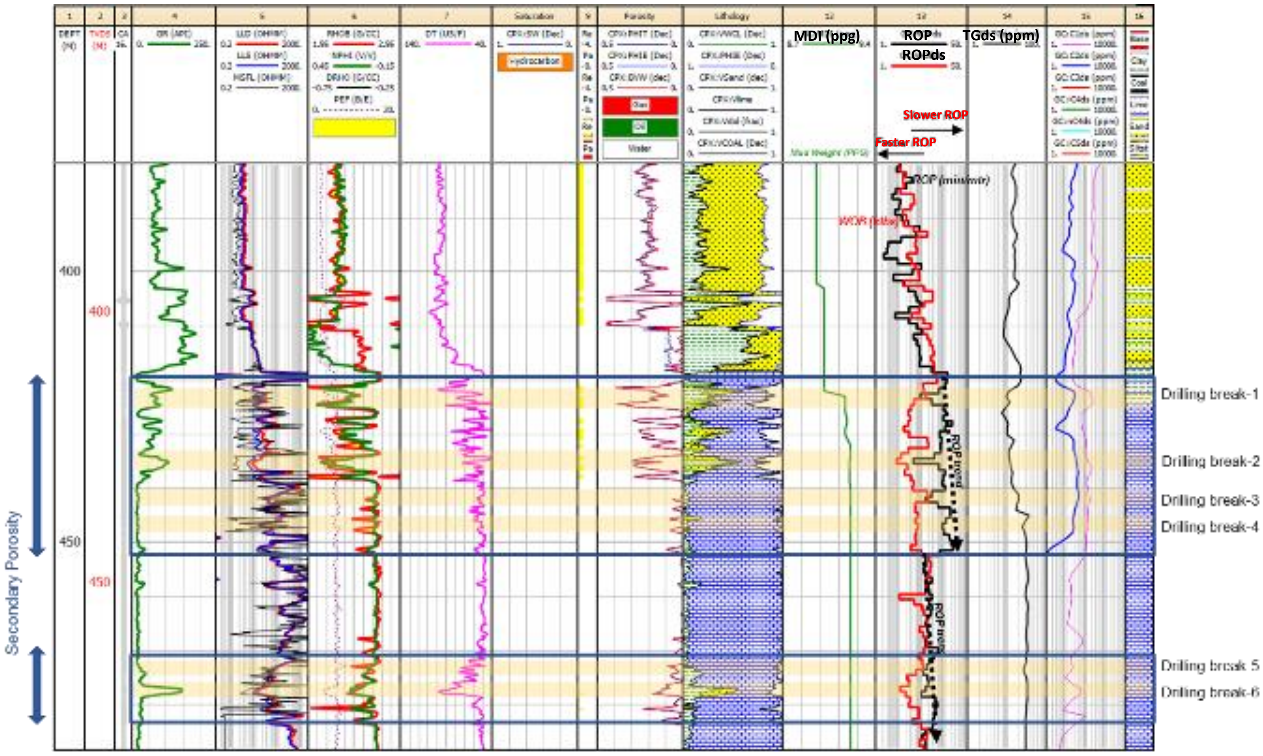

Figure 6. Drilling break events in carbonate basement of "X-1"well (highlighted in brown) as the proposed well testing interval in "X-1"well.

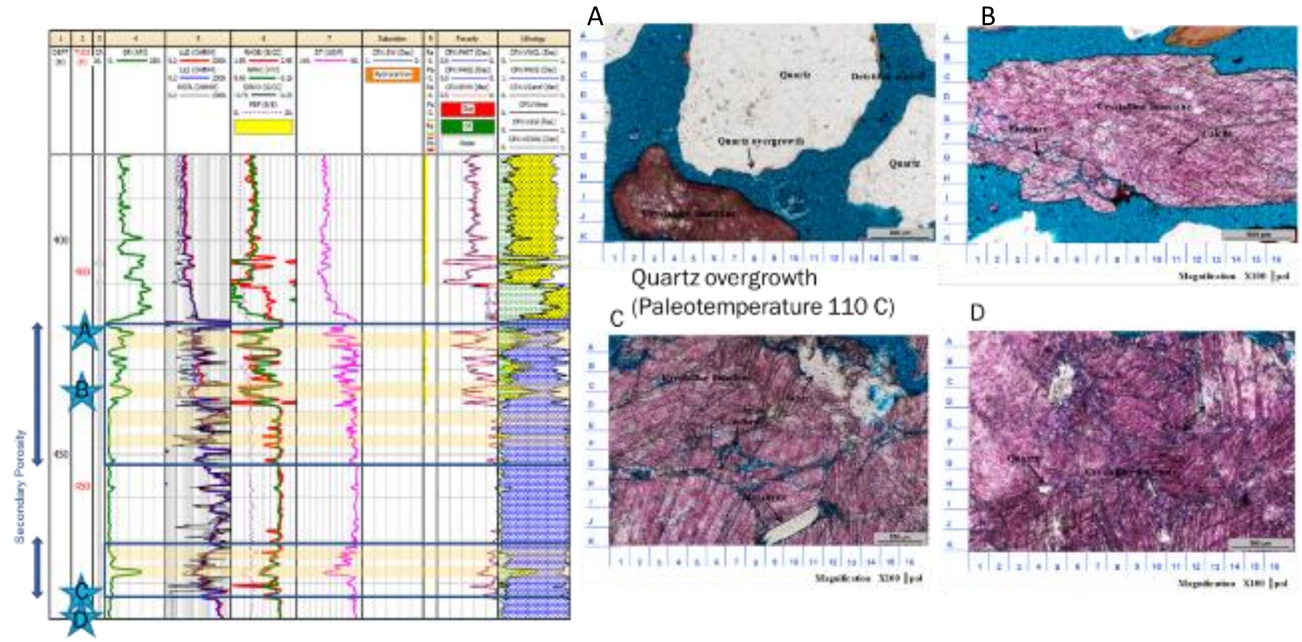

Figure 7. The evidence of fracture in recrystallized limestone and the location of sample in the well log

Table 1. Proposed well testing interval in the Carbonate basement of “X-1”well.

No	Depth (mMD)	Lithology	Density-Por Min-Max (Avg)	Sonic-Por Min-Max (Avg)	SPI Min-Max (Avg)	Drilling Parameter				Notes
						ROP (min/mtr) (avg/trend)	Tgas (unit)	C1 (ppm)	C2 (ppm)	
1	420-426	Limestone	0.085-0.44 (0.24)	0-0.215 (0.1)	0-0.37 (0.13)	6/15	12.8	22-231 (114)	2-25 (15)	Drilling Break-1
2	433-437	Limestone	0.07-0.38 (0.27)	0.01-0.08 (0.04)	0.01-0.28 (0.19)	5/19	11.8	93-189 (138)	23-40 (32)	Drilling Break-2
3	441-443	Limestone	0.04-0.07 (0.06)	~0	0-0.036 (0.02)	8/11	18.8	136-145 (141)	33-42 (38)	Drilling Break-3
4	445-449	Limestone	0.11-0.17 (0.14)	~0	0-0.04 (0.022)	16/24	29	103-131 (120)	12-23 (20)	Drilling break 4
5	474-479	Limestone	0.004-0.18 (0.075)	0.02-0.08 (0.05)	0-0.11 (0.05)	7/12	31	9-59 (30)	-	Drilling Break 5-6