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Interpretation of Mud Losses in Carbonates Based on Cuttings Description, Well-Logging, Seismic and Coherency Data

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Abstract

Hartha Formation is an overburdened horizon in the X-oilfield which generates a lot of Non-Productive Time (NPT) associated with drilling mud losses. This study has been conducted to investigate the loss events in this formation as well as to provide geological interpretations based on datasets from nine wells in this field of interest. The interpretation was based on different analyses including wireline logs, cuttings descriptions, image logs, and analog data. Seismic and coherency data were also used to formulate the geological interpretations and calibrate that with the loss events of the Hartha Fm.

The results revealed that the upper part of the Hartha Fm. was identified as an interval capable of creating potential mud losses, resulting in high NPT. This is due to its diagenetic features such as succrosic dolomites and vuggy zones that could act as thief zones. Seismic potential was used for the prediction of the geological related non-productive drilling time in the Hartha interval. The seismic data quality in this interval was good, with geological observations already made. Detailed interpretation and analysis of the Hartha interval were performed and integrated with the existing seismic interpretation, rock properties, and NPT database to calibrate wells with the loss events to the seismic observations.

Keywords: Hartha Formation, Seismic Analysis, Coherency Data, Loss Circulation.

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1- Introduction

Lost circulation is a common drilling problem in highly permeable formations, depleted reservoirs, and fractured or cavernous formations [1]. Lost circulation problems may occur in shallow or unconsolidated formations to deeper or consolidated formations because of the rock tensile fracturing as a result of high mud weights. [2]. Subsurface NPT in X-oilfield is largely concentrated within two stratigraphic intervals in the overburden, the Dammam, and Hartha Fm. Hartha Fm. has the second highest NPT associated with drilling mud losses in X-oilfield after Dammam Fm. [3]. Despite many wells that passed through the Hartha Fm., understanding of losses events is still questionable. No clear understanding of the geological settings that control the losses is existed yet [4, 5].

This study presents a geological interpretation developed based on data from nine wells taken from the field of interest as well as understanding the lateral extent and the stratigraphic depths of losses using the NPT database along with seismic amplitudes. This is to investigate if mud losses in the Hartha Fm. can be correlated to a series of channels that have been identified in seismic data, and to attempt for calibrating the losses events with the recent seismic data across relevant intervals of the field. This analysis was based on available wireline logs, cuttings descriptions, image logs and analogue data. Additional limited seismic data in the form of spectral decomposition images and seismic ties were also used to formulate a geological interpretation for the formation.

1.1. Hartha Formation

The Hartha Fm. is the second zone that is usually prone to lost circulation problems. A 94% of the NPT of Hartha Fm. is associated with loss problems [4, 5]. It is deposited during Upper Campanian – Maastrichtian times across large areas of Iraq. It is comprised of pale yellow/brown dolomites, chalky limestone, and argillaceous limestones. Hartha Fm. overlies the Sadi Fm., and it is overlain by the Shiranish Fm. as it is shown in Fig. 1 [6]. Complete mud losses in Hartha Fm. usually occurred after penetrating only 6 meters. In the Upper Hartha (0-30m), severe/complete losses are sometimes encountered in the southern and northern parts of the X-oilfield. The Saddle area of this field sometimes encountered severe/ complete losses in the Mid Hartha (50 -150m below its top). Mud losses in the Hartha Fm. are more complicated than Dammam Fm. This zone is deeper (formation top 1660 m), and it is located below transitional zones like Tayarat

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and Ummer-Radhuma zones which have abnormal pressures and H_2S flow [5].

There are very few published studies describing the geology of the Hartha Fm. in Iraq. The main study was by Sadooni who published a type of log and a depositional model for Hartha Fm. in the Ahdab oil field. His study was based on core and wireline log data [7]. The Hartha Fm. in X-oilfield shows similar characteristics to the Hartha Fm. in the Ahdab oil field based on the cutting descriptions from older wells. The formation can be split into two sections [6], the lower section is dominated by basinal, slope and foraminiferal bank deposits while the upper section with a fully developed rudist is dominated by a carbonate platform with lagoonal sediments. In this model, both the lower foraminifera pack/grain stone banks and rudist platform were topped by a 3rd order regional sequence boundaries as presented in Fig. 1. The paper presented by Sadooni did not describe the development of a channelized system in the Hartha Fm. However, channels are associated with time equivalent stratigraphy in Kuwait, Abu Dhabi, and Oman [8, 9].

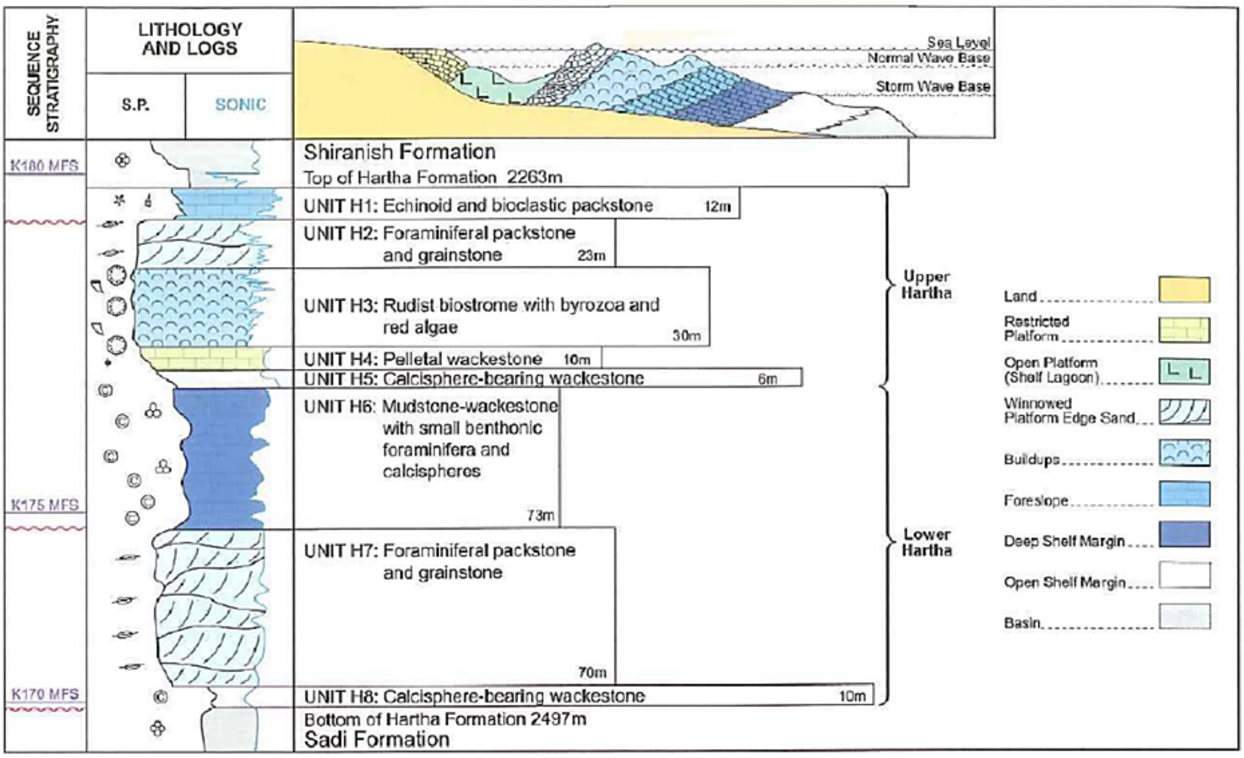

Fig. 1. Geological Model for Hartha Fm. in the Ahdab Field, Iraq [8, 10]

A depositional model was constructed based on available cuttings descriptions and image logs. Environments have been identified based on both lithological and biostratigraphic information. Data suggests that significant proportions of the Lower Hartha were deposited in water depths >50m shown by abundant pyrite and glauconite. Large benthic forms found in the Lower Hartha are likely derived from a shallow water shoals/banks. In contrast, the Upper Hartha is dominated by shallow platform top facies ranging from fore-reef to lagoonal facies. This is shown by a large proportion of rudists and bryozoan and diverse lagoonal benthic foraminifera and ostracods. The Shiranish interfingered with the outer ramp/lower slope Hartha sediments and ultimately drowned the platform during deposition. Significant dolomitization and vuggy porosity affected the Upper Hartha possibly due to exposure of the platform top during sea-level low stands. Areas of the Upper Hartha affected by the development of succrosic dolomite and vuggy zones could lead to drilling losses and significant NPT [7- 10]. Fig. 2 shows the depositional model is constructed in X-oilfield for Hartha Fm. A very clear change in color and texture occurs at the top of Hartha. Light grey homogeneous Shiranish argillaceous limestone gives place to light brown, white, glauconitic, pyritic Hartha limestone as shown in Fig. 3.

1.2. Analyzing of NPT across X-oilfield/Hartha Formation

Over 19% of NPT have been occurred in the Hartha Fm. (Fig. 4a). Since more than 260 wells have been drilled in X-oilfield in 2010, an average of 31 hours of NPT per well has been observed. The vast majority of that NPT was caused by mud losses, both partial and complete, which took place during drilling and casing installation (Fig. 4b). As shown in Fig. 5, the Hartha NPT is higher in the south of the field than in the north. Significant efforts are being made to mitigate these events and to predict areas where they could occur. With this knowledge, it could be possible to plan a well to avoid these events or at least to be prepared to mitigate a possible loss event. Fig. 6 shows an example of X-1 well in X-oilfield with 363 hr of NPT due to losses.

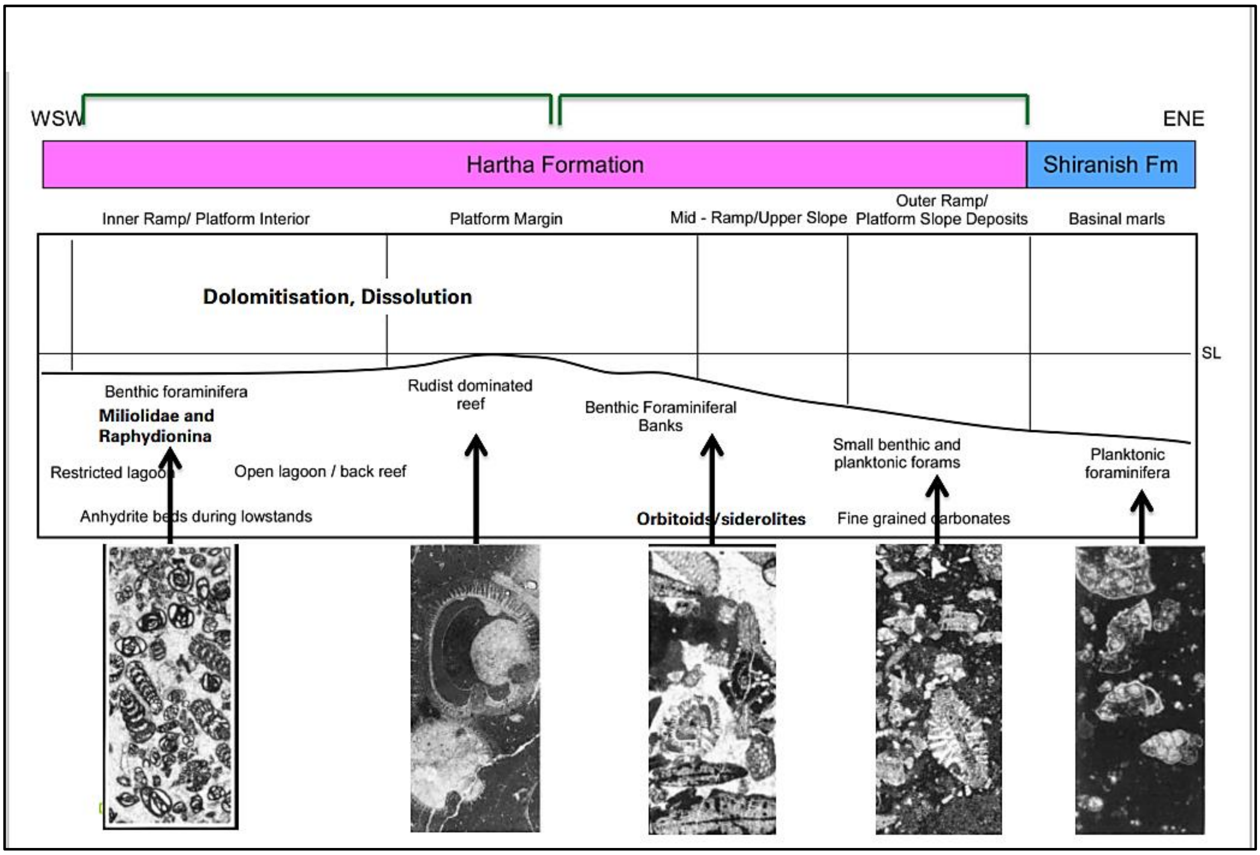

Fig. 2. Depositional Model for Hartha Fm. in X-Oilfield [13]; SL – Sea Level

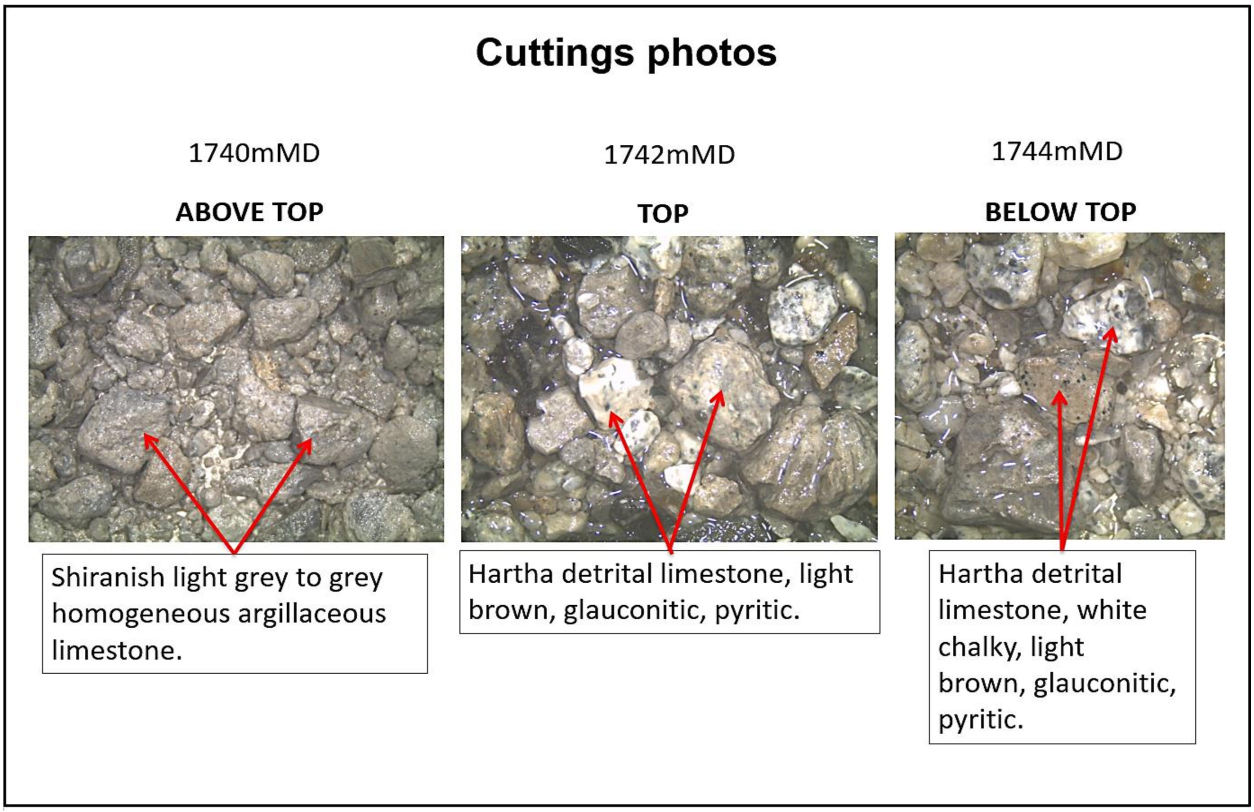

Fig. 3. Cuttings Description of Hartha Fm. in X-Oilfield [13]

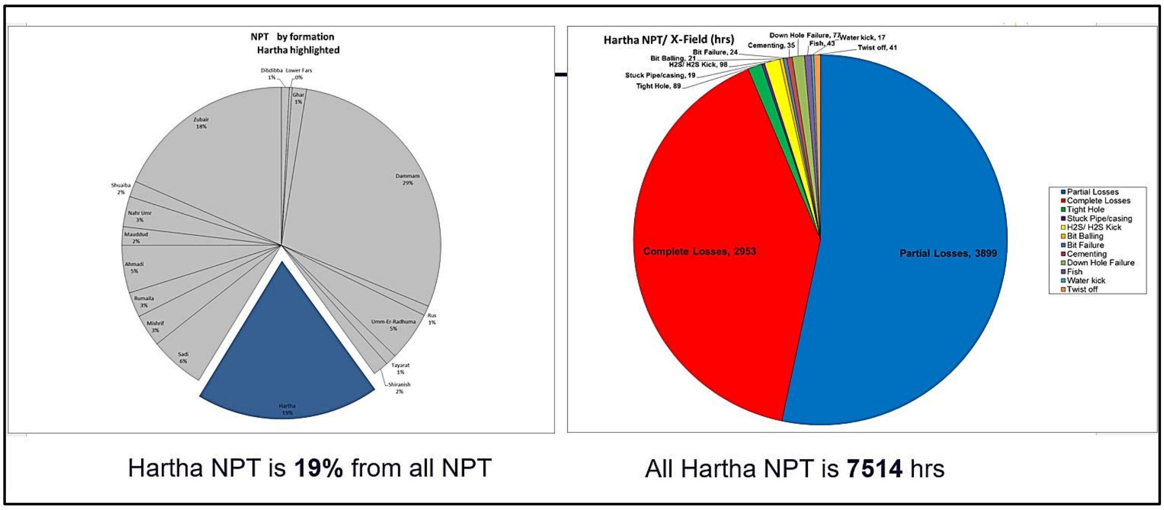

Fig. 4. Total NPT in X-Oilfield (since 2010), a) NPT by Formation (to the left) and b) Hartha Formation NPT by Cause (to the right)

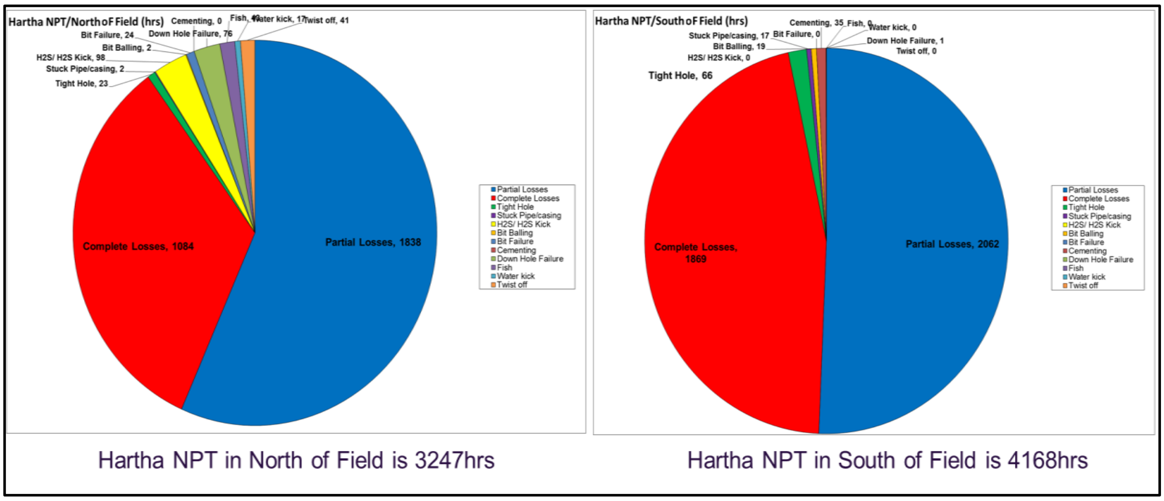

Fig. 5. The Hartha NPT Distributed in South and North of the Field

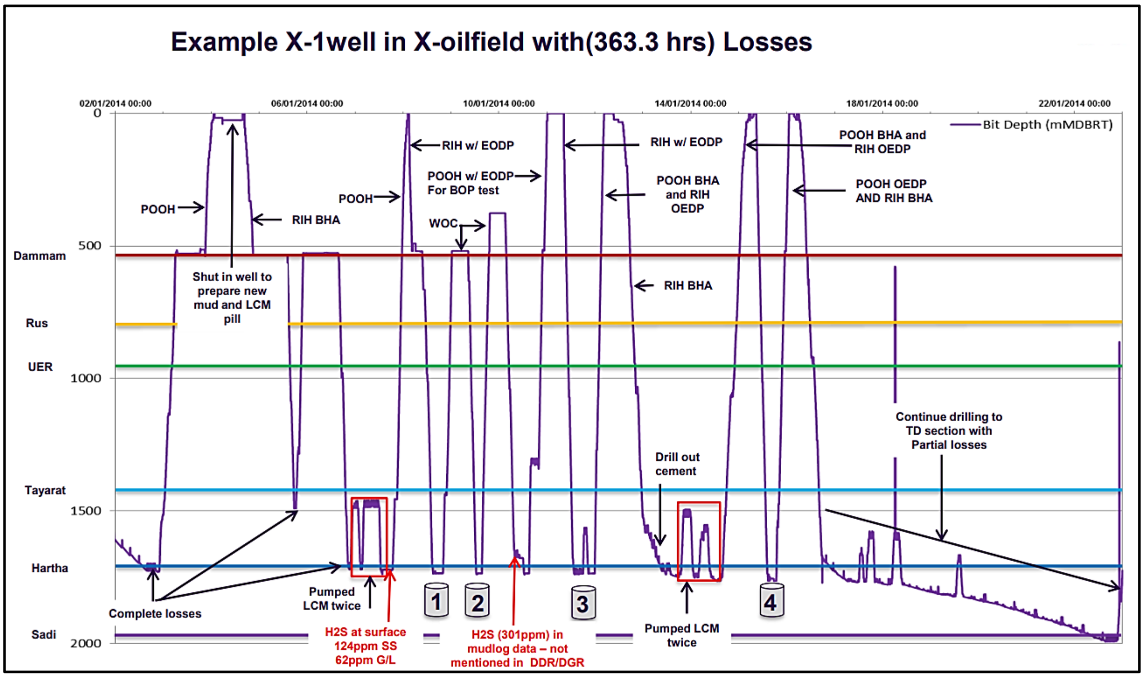

Fig. 6. Example of Well X-1 in X-Oilfield with (363.3hr) NPT due to Losses

2- Creation of Correlation Panels

By using available wireline logs such as Gamma ray (GR) from four X-wells in X-oilfield, the correlation panels were created to understand the better position, lateral distribution, and thickness of the loss zones as well as to check the predominance of the loss events to specific units of the Hartha Fm. formation.

Based on the results of the correlation panels, Hartha formation can be divided into 11 units based on GR results, loss events are mostly related to the upper and the lower units of Hartha formation, small thickness of the loss zones (2-10 m in thickness), and distribution of the loss events are not laterally extensive as shown in Fig. 7.

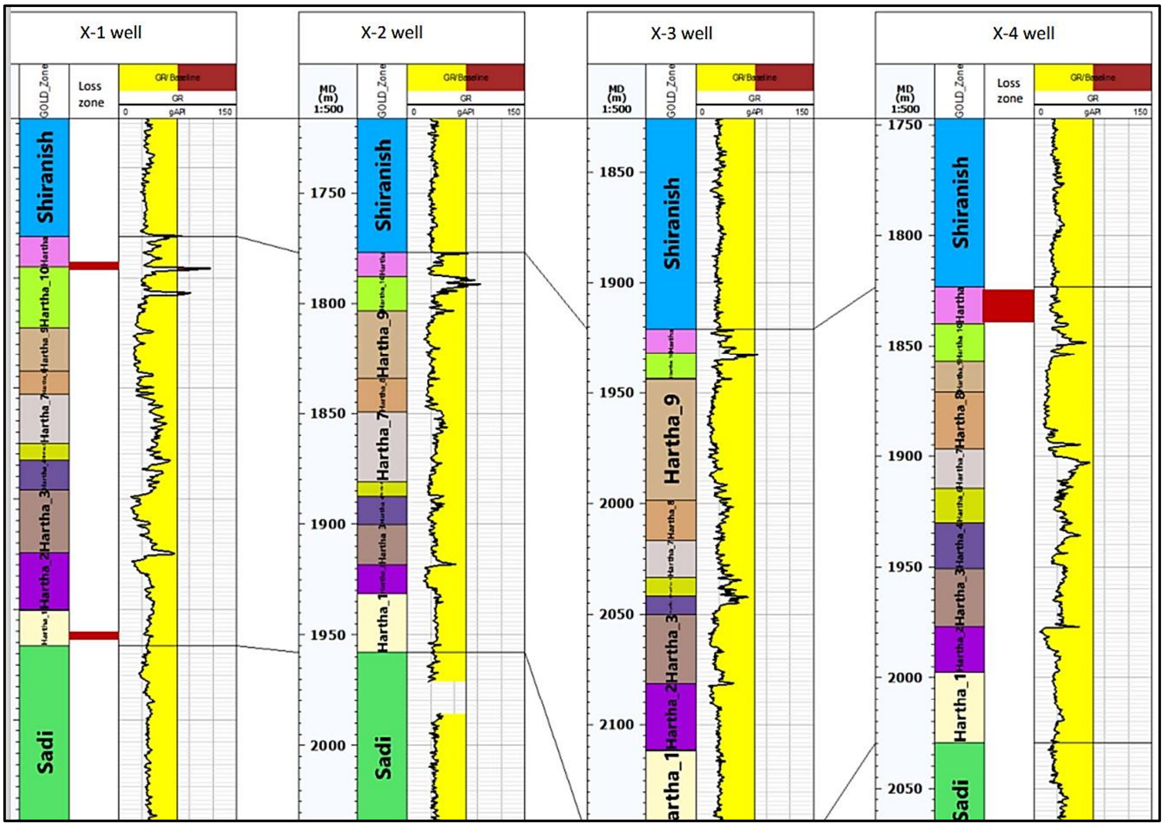

Fig. 7. The Correlation Panels from Four X-Wells

3- Well logs Interpretation

Two examples of X-wells are presented with available wireline logs such as Gamma ray (GR), Caliper Log (CALL), Neutron Porosity (NPHI), and Bulk Density (RHOB) as shown in Fig. 8. Through these wireline logs it was found that loss zones may be associated with an elevated signal of the caliper, high NPHI and low RHOB, indicating potential presence of karst zones. The presence of a high GR spike at the top of Hartha -11 may indicate the existence of an erosional surface and a flooding surface. Additionally, the significant increase in bulk density (RHOB) with a value of 2.9 suggests the potential occurrence of dolomitization in Unit 10, which is strongly supported by the detailed description of the cuttings.

4- Cuttings Description

Lithological description of Hartha units is presented by correlating cuttings observations with wireline response and loss events. Fig. 9 illustrates the shape and color of five cuttings samples taken from five different depths from X-1 Well with conventional well logs such as GR & CALL (track-4), and NPHI & RHOB (track-5). Red to orange color of cuttings may suggest the oxidation of sediments due to erosion. Cuttings confirm the presence of the karst zone and correlate with loss zones. Cuttings indicate that they are largely composed of grained carbonates. Shale fragments in the channel deposits are possible evidence for reworking and entrainment of underlying argillaceous carbonates. However, shale fragments in potential channel fill may also be due to contamination from overlying units. Sediments from Mid Hartha interval are more shale/argillaceous prone than any other sediments in the Lower-Mid Hartha.

5- Image Log Interpretation

Borehole image log from X-well (X-5 well) was used to better understand the facies distribution of the Hartha formation and to identify the erosional surfaces and potential presence of karts zones. Image logs from the Lower Hartha were examined to identify major differences between sediments in this interval including features that could be possible channel bases, channel lags or channel fills. Fig. 10 shows the static and dynamic image log (FMI) of that well with conventional wireline logs, describing in detail the facies of the whole Hartha formation in X-oilfield.

Results from the analysis of image logs from the Lower Hartha show that the interval is comprised largely of heterogeneous and laminated carbonates. Major surfaces identified in the zonation, i.e., Top Sadi, Hartha 1 and Hartha 2, show evidence of reworking and active erosion. The image log shows the presence of low resistivity bands within Hartha 4, which correlate with the GR peaks and sonic slowness events observed in the well, while in Hartha 5 shows a clear basal lag/channel base at the bottom of the zone. The basal lag contains potential mud rip-ups and clasts. The Hartha 5 deposit lacks the low resistivity bands found in Hartha 4 but does contain a considerable amount of laminated heterogeneous and low resistivity facies. This suggests that the majority of the Hartha 5 "channel" fill is represented by low energy fine grained muddy carbonate. This observation matches the historical cuttings descriptions.

6- Karst Model of Hartha Formation

All geological, geophysical, and geomechanical properties of subsurface formations have a role in causing various drilling issues, particularly circulation loss problems. Some of the distinguished formation characteristics are represented by rock matrix and structural units, lithological composition and mineralogical variation, structural features and associated defects, mechanical integrity characteristics, load bearing and pressure tolerance capability. Either alone or a combination of these characteristics might cause a loss of circulation problem, causing the drilling operations to be considerably delayed. The severity of the problem is linked to the geological characteristics such as depositional history, sedimentation environment, and post-depositional mechanical, chemical, hydrological, and thermal weathering, as well as the influence of diagenetic and tectonic activities on altering the rock fabric [14]. By nature, unconformity is a structural feature resulting from all these factors, and controls the lost circulation problems.

Exposure of the carbonate platform on surface during sea level drop may lead to high erosion and karst formation (Fig. 11). Well log analysis revealed small scale karst zone within Hartha 11, suggesting exposure surface of the top of the Hartha, which is also supported by seismic interpretation. However, biostratigraphic analysis and cuttings observation suggest the position of the karst zone is lower (top of Hartha-10). The karst zone within unit 11 may be explained by smaller scale sea level fluctuation. Confirmed by the descriptions of cuttings, the potential location of a third-order sequence boundary has been established. Higher resolution of seismic data explains the difficulty of karst zone identification. Fig. 12 shows the karst zone by image log from X-6 well sample.

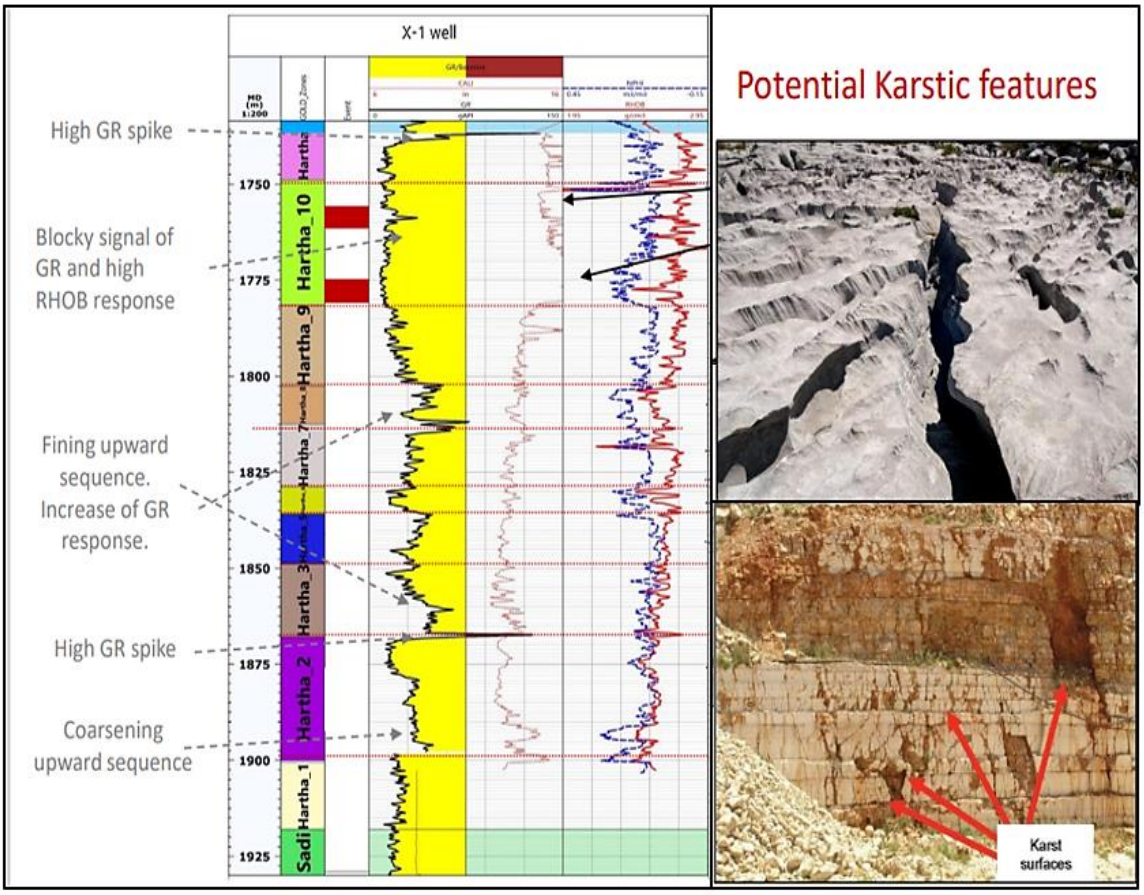

Fig. 8. Summary of Well Log Interpretation in Two X-Wells (left) with Illustrative Examples of Karstic Features Observed on Surface Outcrops of Hartha Fm

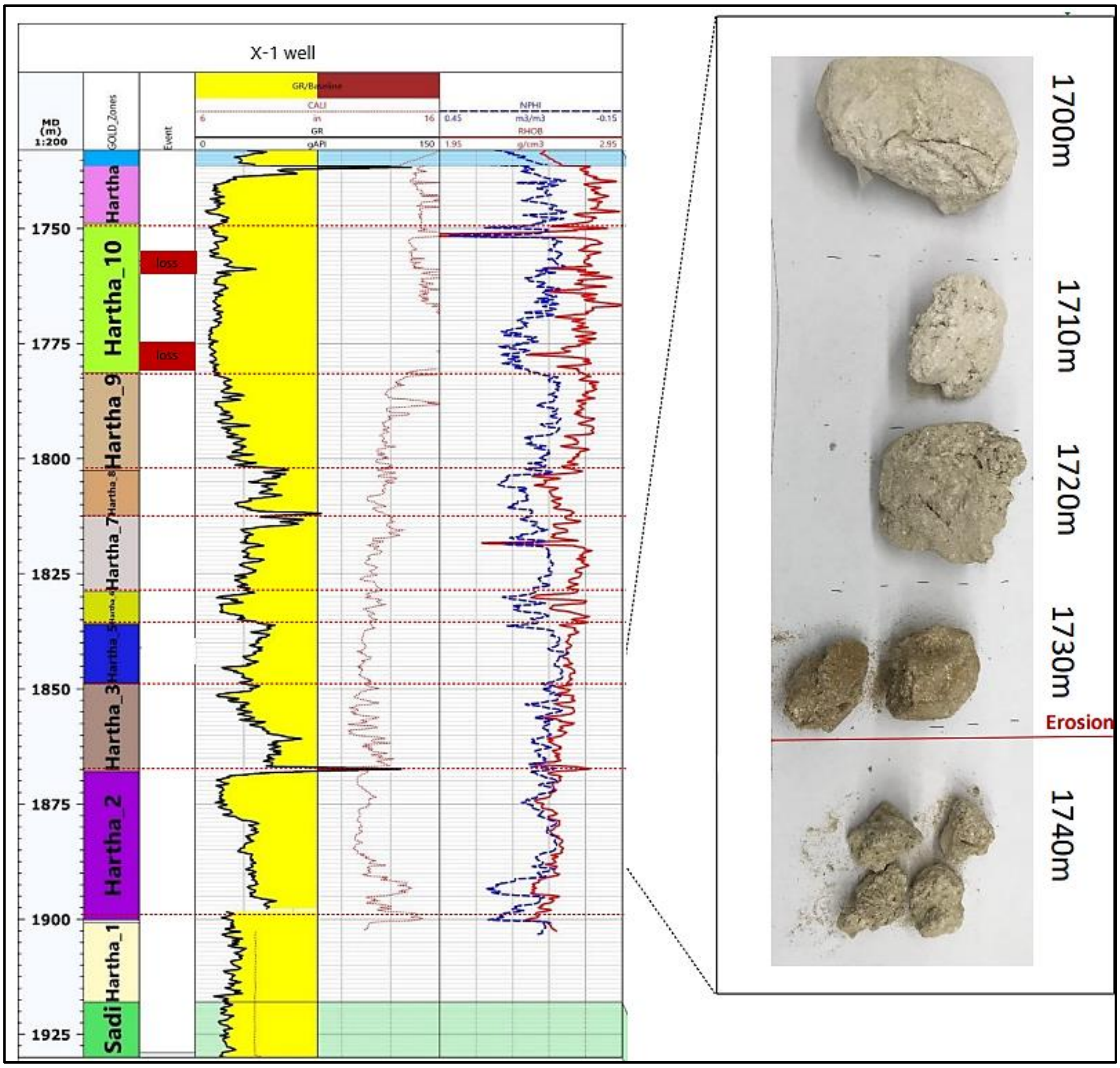

Fig. 9. Correlation of Cuttings Observations with Wireline Response and Loss Events

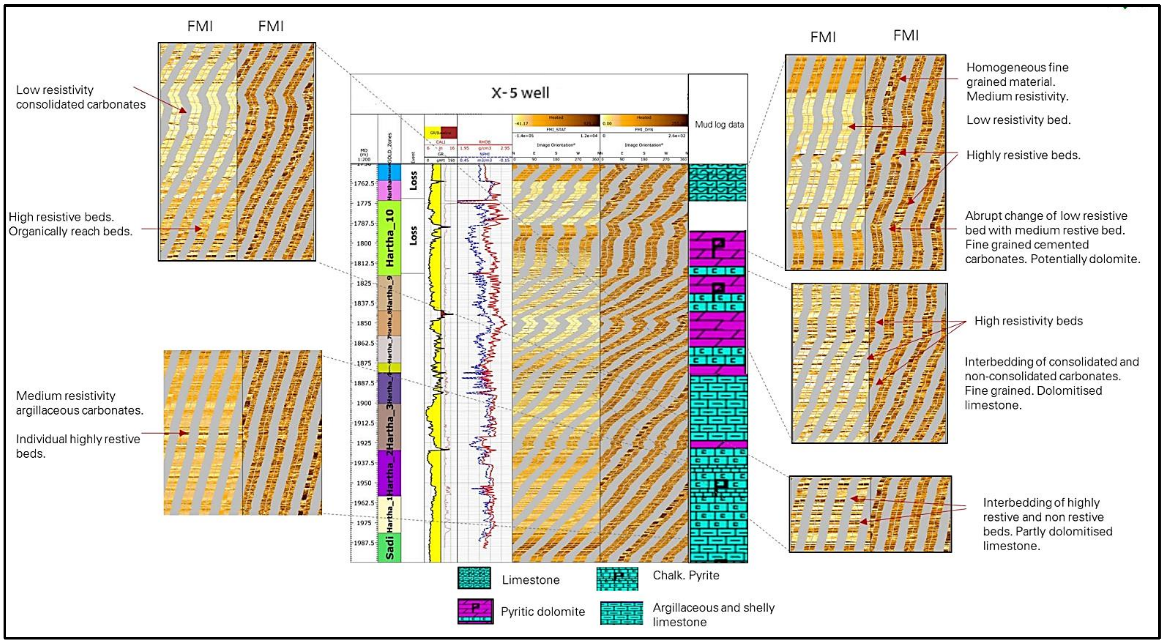

Fig. 10. Image Log Interpretation of the Hartha Formation (X-5 well), FMI – Formation Micro-Imager

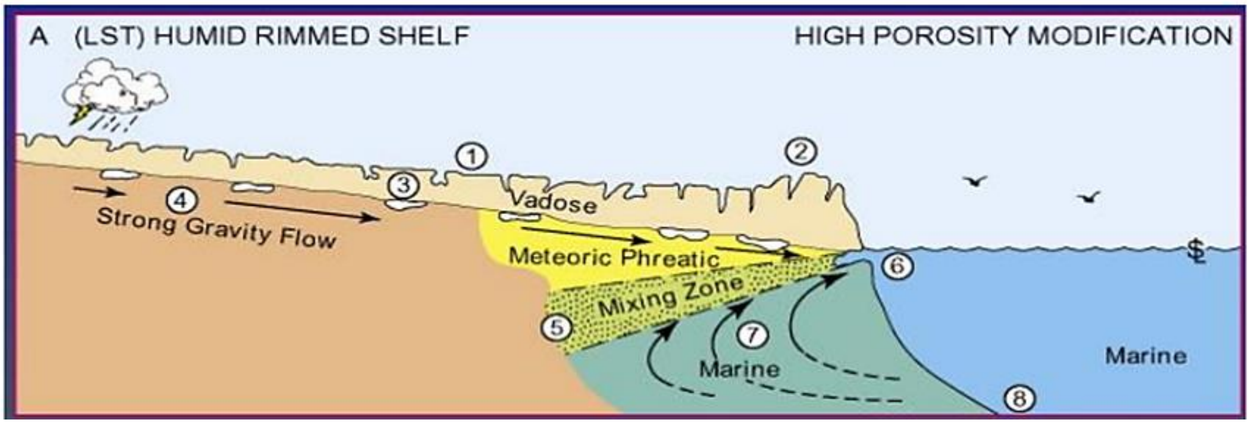

Fig. 11. Diagenetic and Porosity Model for the Ramp during Sea-Level Lowstand under Humid Climatic Conditions [8]

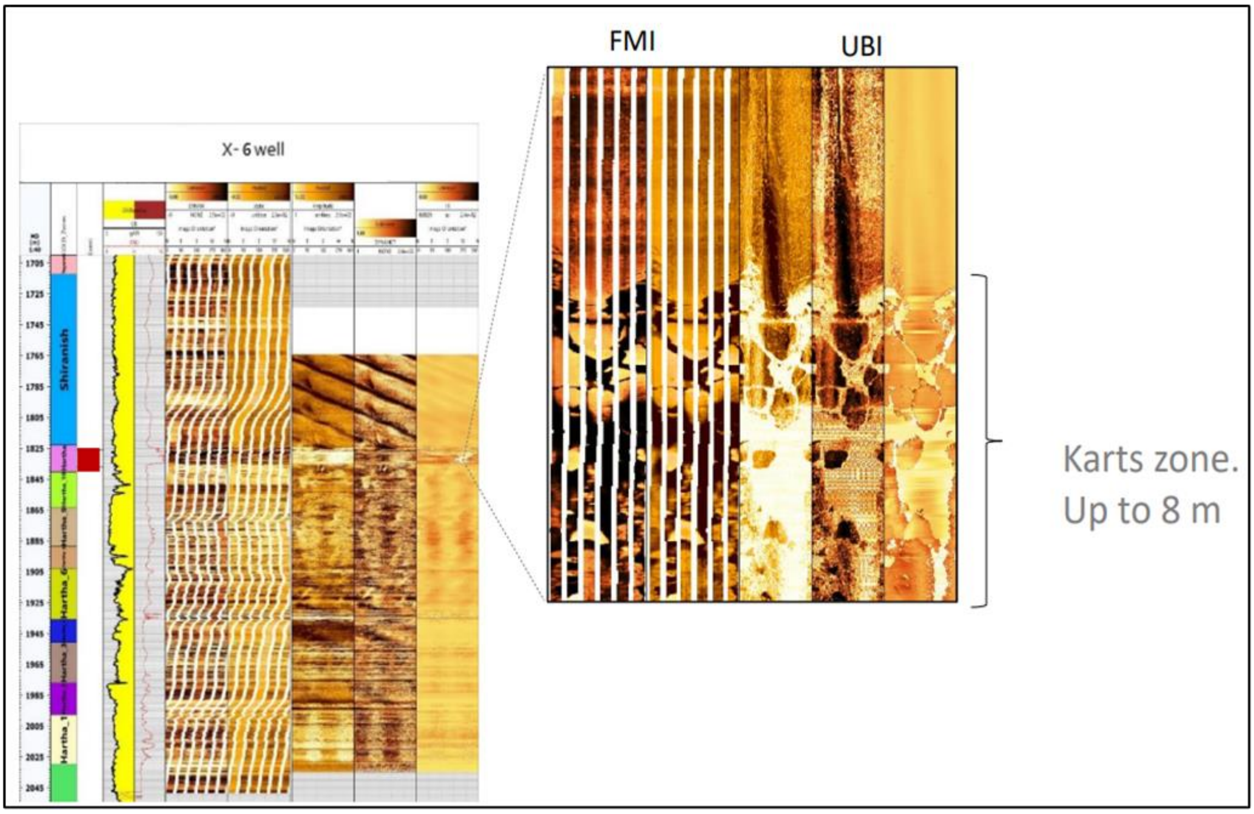

Fig. 12. Karst Zone in Hartha Formation (Sample X-6 well)

7- Calibration of Seismic Observation with Loss Event in the Hartha Formation

Seismic data with coherency data were acquired from three X-field's wells. It was used together to calibrate loss events in Hartha formation in X-oilfield. Seismic data is used to fill the data gaps and provide a fundamental data to reservoir study while coherency data is generated from seismic data, and it indicates the continuity of seismic data event [11, 12].

When the continuity of seismic event is better, the value of coherency data is small, meanwhile when the seismic continuity is worse or the seismic events is broken, the value of coherency data is bigger. So, coherency data is always used for predicting the faults and fractures in seismic data interpretation. All the amplitude and phase variations in seismic data have their response in coherency data especially faults, channels, and sinkholes reflections. Fig. 13 shows seismic data section compared with the coherency data section for the same part of the Hartha zone.

Using horizon slice of coherency data has the clear superiority to recognize sinkhole or vugs reflection features compared with seismic data. Sinkhole gets developed in carbonate terrain, typically it results in karst features. Seismic data shows broken and separated weak reflections events. But in coherency data it shows clearly strong amplitude characterized as a shape of irregular circles [11]. By using coherency data, channels can be recognized clearly, which have a similar feature with minor faults. In the environment of carbonate sediments, a fluvial system can cut the surface terrain and generate channels, especially when the carbonates undergo diagenesis in a shallow water environment, it is controlled by water system and channels are developed [12].

Generally, Hartha formation was influenced by channel system when it was deposited and subsequently exposed at the surface. The channels have the direction from West to East. A possible reason is that the channels were developed at different transgressive and regressive periods, where they were later deposited or eroded by the water system. The mud losing event in the Hartha formation appears to be closely related to the channels developed in the formation. Perhaps it can be divided into three zones (zone-1, zone-2, & zone-3) based on the areas where mud losing event took place from the southern to the northern part of X-field as shown in Fig. 14.

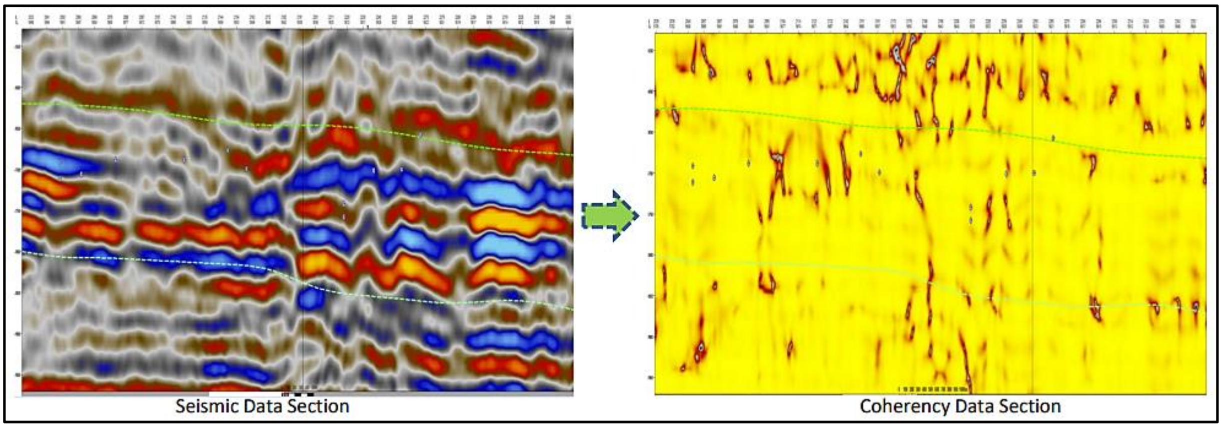

Fig. 13. Seismic Section Compared with Coherency Data Section for Part of Hartha Zone

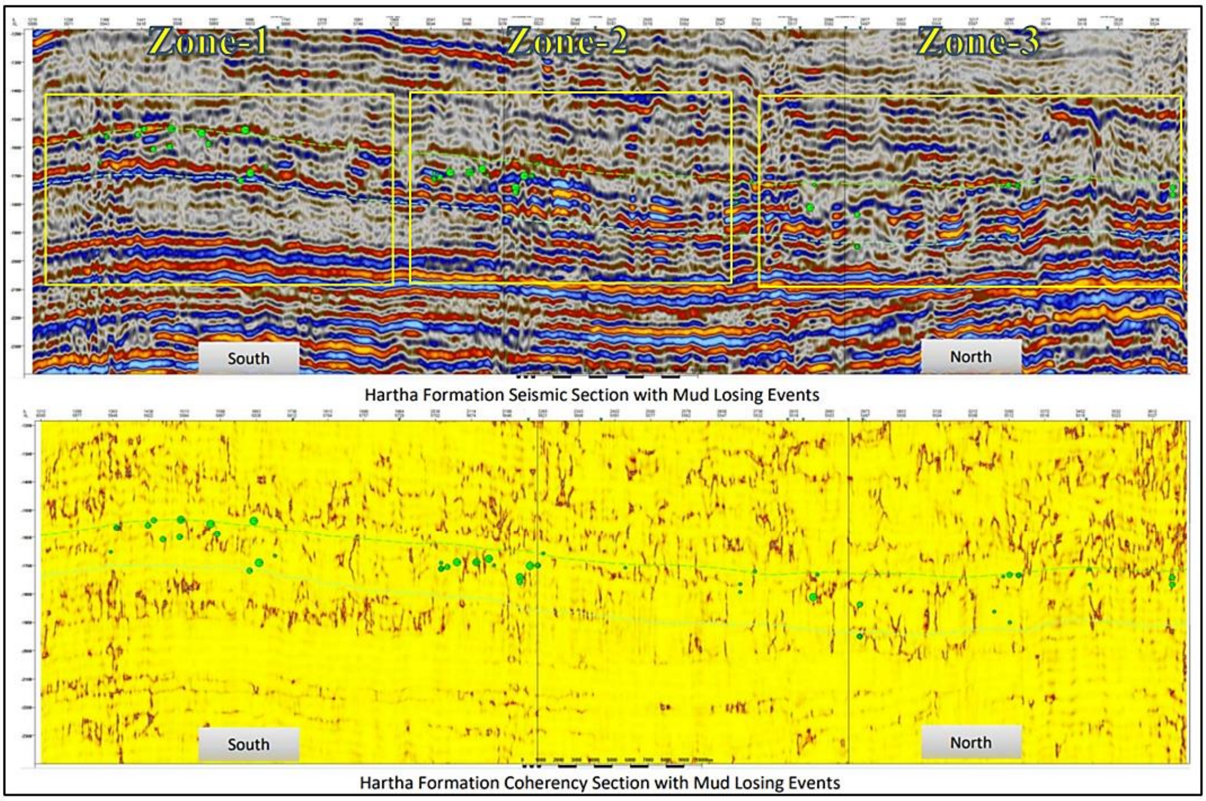

Fig. 14. Mud Losing Event in the Hartha Fm. based on Seismic and Coherency Data Section

The depth of the Hartha formation varies from shallow to deep. Based on the interpreted loss event features in seismic reflection image and the places where mud losing events occurred, two X-wells were chosen based on these zones, as X-7 well is located within zone-2, and X-8 well is within zone-3. These two wells were chosen to study the loss event issues in Hartha formation.

For X-7 well, it is located within zone-2. Based on the final well report, this well met the serious mud losing problem in Hartha formation, 22 cement plugs were used and total of 1253 NPT hours were recorded. It took more than 43 days to resolve the mud losing issues. By checking up seismic section with the isobathic slice at depth -1698m, it was found that the well is located in abnormal area of separated amplitudes, which always indicates a fractured geological body. It is also close to a phase broken nearby, which indicates minor faults or a channel border in the East. In the seismic section, the event takes place at a very short seismic reflection and is broken in both the eastern and northern parts. It usually indicates an environment of variation lithology as shown in Fig. 15.

Then, by inspecting the coherency section with the isobathic slice, it was found that the well is located at a zone where there is a clear anomalous coherency data in both the eastern and southern portion. It indicates the well is close to a sinkhole or a vug in the south and a possible minor fault or a border of a channel in the east. In coherency data, section 1 shows that there is a minor vertical fault that is developed inside the formation. There is another minor fault close to the well in the EEN direction as shown in Fig. 16. The conclusion is that seismic data have the capability to explain, why X-2 well has met serious mud losing problem within the Hartha formation.

For X-8 well**,** it is located within zone-3. Based on final well report, this well dealt with serious mud losing problem in the Hartha Fm. Total of 17 cement plugs was used and 200 NPT hours were recorded. It took more than 7 days to handle the mud losing problems. Isobathic slice at -1812m shows that the well is located in a zone where seismic amplitude and phase vary frequently, while the seismic sections display that the well is located in the area where seismic event is broken in both directions. It indicates the well is possibly located at the middle of a channel or a sinkhole as shown in Fig. 17.

By checking up coherency section with the isobathic slice, it was found that in the slice, there are clear coherency anomalies surrounding the well, especially in the north and west portion. In coherency sections, the channel features is clearly pronounced, especially in the south. Generally, the well is located at channel-controlled area, possibly in the middle of the channel, and any mud is lost to the formation due to the near channel boundary or located where the formation does not have a stable depositional environment, as shown in Fig. 18. The conclusion is Seismic data has a better response to X-8 well mud losing event.

8- Potential Reasons of Loss Events in Hartha Formation

The described mud loss events resulted from presence of vugs or caves or minor fracturing, as mentioned earlier. Fig. 19 presents the main causal factors for the loss problems in the Hartha formation, together with summarization of observed/analyzed evidence for them.

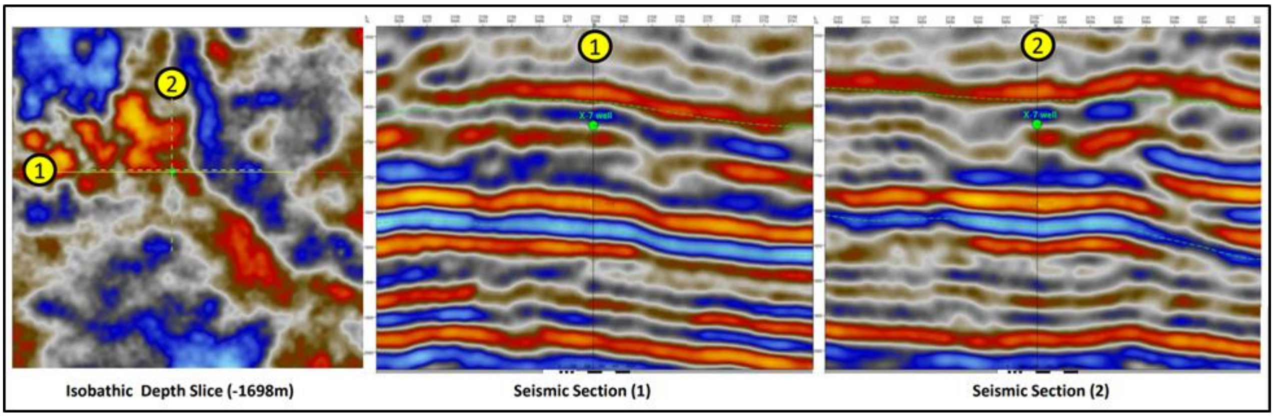

Fig. 15. Seismic and Isobathic Sections with Indication of X-7 Well

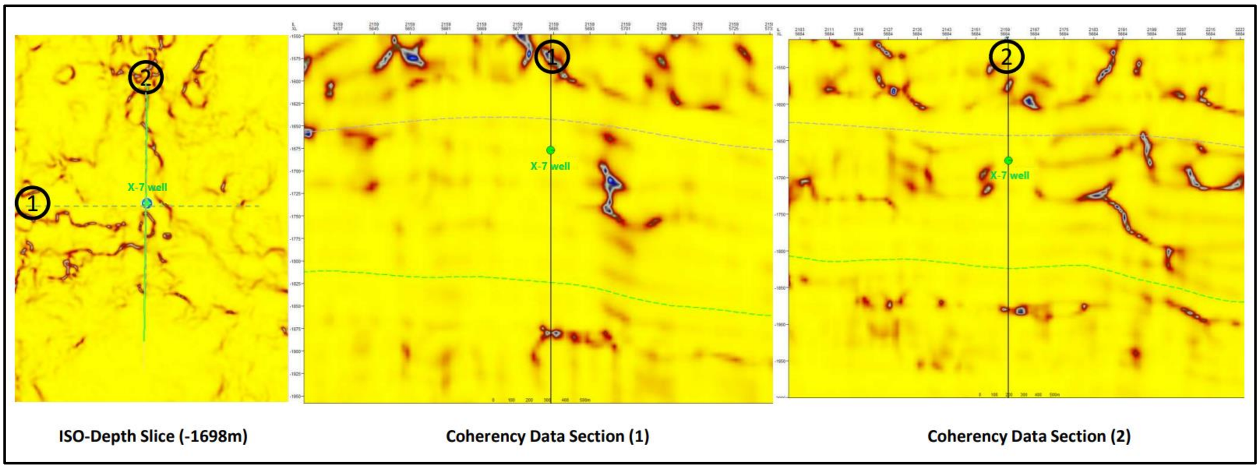

Fig. 16. Coherency and Isobathic data Sections with Indication of X-7 Well

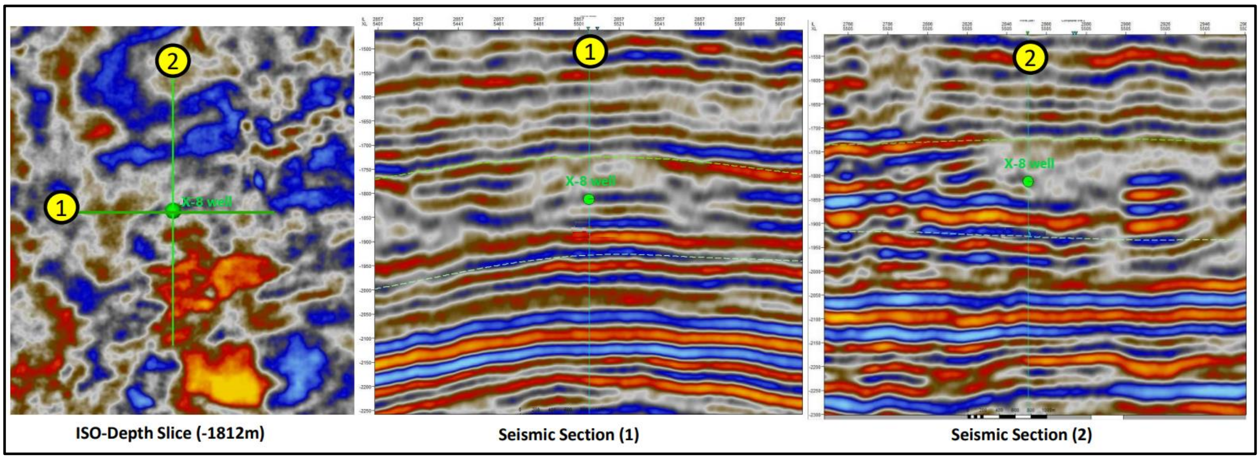

Fig. 17. Seismic and Isobathic Sections with Indication of X-8 Well

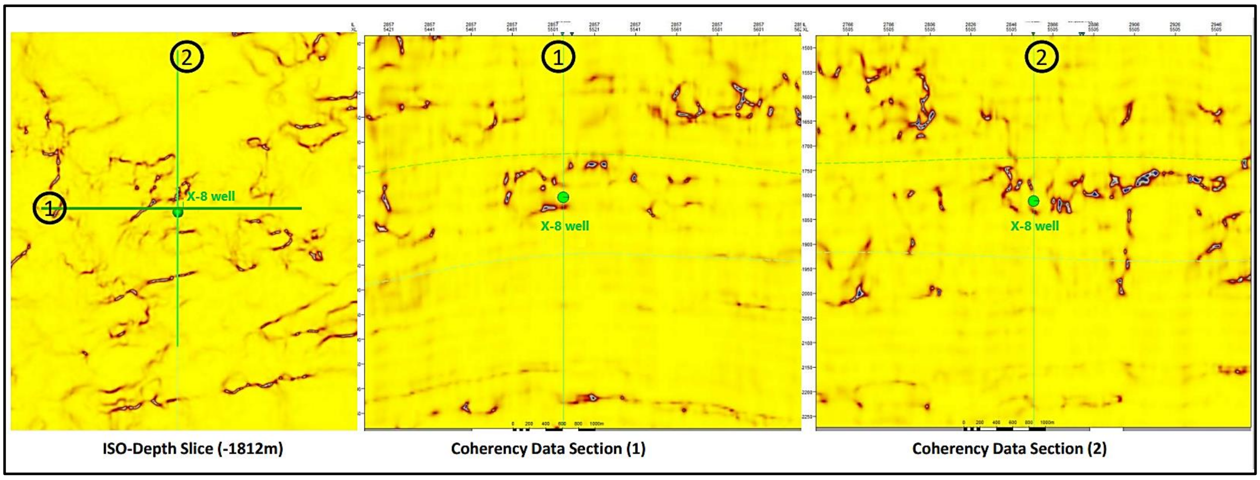

Fig. 18. Coherency and Isobathic Data Sections for Hartha Section (X-8 well)

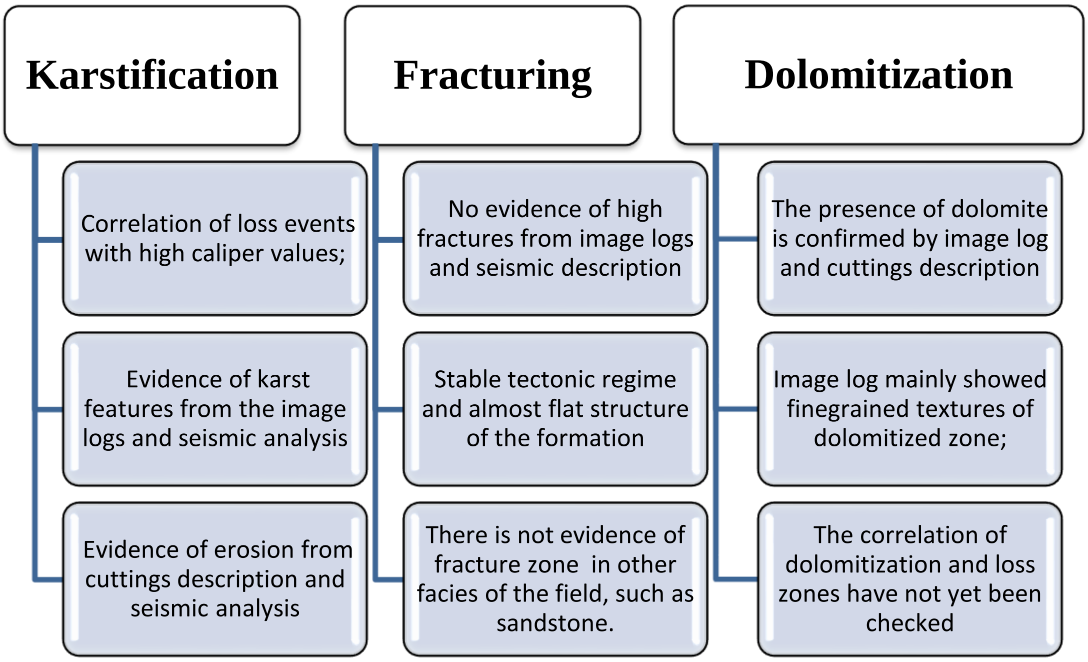

Fig. 19. The Summarization of Main Reasons of Loss Problems within Hartha Fm

9- Geological Interpretation of the Hartha Formation

Based on the results of this study (correlation panels, wireline logs interpretation, cuttings descriptions, image log interpretation, seismic analysis), the geological interpretation of the Hartha formation in X-oilfield is as follows. The Lower Hartha (zones 1-2) consists of a series of shoaling upwards cycles comprising 3rd order high stand deposits capped by a regional 3rd order sequence boundary. These cycles were largely formed in relatively deep marine waters >50m deep, as shown by the presence of significant amounts of glauconite. Parasequences are capped by facies formed in shallower waters with possible development of foraminiferal banks. A marine transgression (Hartha 3) with argillaceous deposits (Hartha 4) formed towards the top of the Lower Hartha. This interval was incised by channels ranging from 15-25m in depth that can be identified regionally (Hartha 5). Channels were likely to have been influenced by a tectonically induced 4th order sea-level fall. The Upper Hartha represents a 3rd order high stand systems tract comprised of shallow subtidal-intertidal carbonate facies deposited in environments ranging from fore-reef to lagoonal settings (Hartha 7-10). The Upper Hartha has been extensively modified by dolomitization and meteoric/marine diagenesis. Following a 3rd order sequence boundary, a marine transgression restored conditions associated with Hartha 1-2 (Hartha 11). The Hartha was eventually drowned by a marine transgression that covered the area with basinal marls of the Shiranish Formation.

10- Conclusion

A geological interpretation and analysis of mud loss circulation events were conducted for the Hartha Formation in the X-oilfield based on datasets from nine wells. The interpretations were based on available wireline logs, cutting descriptions, and image logs. Additional seismic data with coherency data were also used to formulate a geological interpretation and to calibrate the loss events for the formation. A new zonation was developed for the formation based on 11 depositional zones, which were put into a 3rd-order stratigraphic framework with higher order parasequences.

The loss zone in the Hartha Formation appears to be concentrated in the upper third of the interval. The fluid loss, which is at several levels, can be attributed to the shallow/deep cycles that are indicated based on the geological analysis. This zone may be attributable to the diagenetic alteration of the calcium carbonate parent rock to dolomite, creating sub-regional permeable zone. The degree of porosity/permeability would be expected to vary spatially to some degree, but overall, this appears to be a field-wide problem.

Observations of the seismic data appear to offer insight into the occurrence of mud loss in the Hartha Fm., which is the most common problem in the south of this field. It is not clear, whether this is a subsurface related issue, it might relate to observations of a thinner isochore in the south indicative of less accommodation space/shallower water more prone to secondary porosity through dolomitization and/or prone to benthic communities and thus the development of a vuggy primary porosity.

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تفسير فقدان طين الحفر في الكربونات بناءً على وصف الصخور المحفورة، تسجيل الابار، البيانات الزلزالية والتماسك

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الخلاصة

تشكل تكوين الهارثة افقا مثقلا في حقل النفط (اكس) والذي يولد الكثير من الوقت غير الانتاجي المرتبط بفقد الطين. تم إنشاء هذه الدراسة للتحقيق في حدث الخسارة الذي حدث في تكوين الهارثة وتقدم تفسيرًا جيولوجيًا تم تطويره بناءً على بيانات من تسعة آبار. اعتمد التحليل على السجلات التقليدية المتاحة ، وأوصاف القطع، وسجلات الصور والبيانات التناظرية. كما تم استخدام البيانات الزلزالية الإضافية وبيانات التماسك لصياغة تفسير جيولوجي ومعايرة أحداث الخسارة للتكوين. تم تحديد الهارثة العليا على أنها فترة زمنية قادرة على خلق خسائر طينية محتملة. ويرجع ذلك إلى الخصائص التنموية مثل الدولوميت النضري ومناطق فاجي التي يمكن أن تكون بمثابة مناطق اللصوص. تم استخدام الإمكانات الزلزالية للتنبؤ بوقت الحفر غير المنتج الجيولوجي (NPT)في فترة الهارثة. كانت جودة البيانات الزلزالية في هذه الفترة جيدة، مع إجراء ملاحظات جيولوجية بالفعل. ثم أجرى تفسيرًا تفصيليًا وتحليلًا لفاصل الهارثة ودمج مع التفسيرات الزلزالية الموجودة وخصائص الصخور وقاعدة بيانات الوقت الغير انتاجي لمعايرة الآبار مع حدث الخسارة للملاحظات الزلزالية.

الكلمات الدالة: تكوين الهارثة، التحليل الزلزالي، بيانات التماسك، فقدان دورة سائل الحفر.