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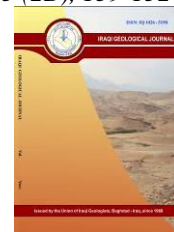


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Depositional Properties of the Middle Miocene Fatha Formation, in K Oilfield, Southern Iraq

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Abstract

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The Fatha Formation, formerly known as the Lower Fars Formation, was deposited in a shallow basin, southern Iraq during the Middle Miocene. By using the description of the cores, we found large heterogeneity in the lithology; contains a mixing of limestones, mudstone, marl, marly limestone, sandstone, and gypsum, or anhydrite. In this study, the Fatha Formation was divided into three main units according to lithofacies, namely, marl, marl-anhydrite, and limestone, in addition to, the presence of thin evaporitic and sandstone layers along with the formation but thicker with marl. X-ray diffraction and SEM tests which are accurate methods to identify the mineralogy enable inference of a high percent of the dolomite, calcite, and anhydrite; this may be attributed to the formation environment, In addition to the presence of some clay minerals such as illite and palygorskite. The petrographic details, microfacies analysis, and depositional environment studies led to recognition of four main microfacies including mudstone, wackestone, packstone, and grainstone; and nine sub microfacies were deposited in a shallow part of the inner ramp at three zones: peritidal, lagoon, and shoal.

Keywords: Fatha; Microfacies; Lagoon; Peritidal; Depositional environment

1. Introduction

The Fatha Formation was described by Busk and Mayo (1918) in Fars Province, Iran (Van Bellen et al., 1959). Then Jassim et al. (1984) gave this formation in the Al Fatha Gorge a new name (Fatha) where the Makhul-Hamrin Range (Al-Rawi et al., 1993). The Fatha Formation, which stretches across Iran, Syria, Kuwait, Saudi Arabia, and Iraq, is an aerielly wide extension and economically significant formations in Iraq. The thickness of the formation in the studied oilfield varies from 300m to 400m, bounded from the bottom by the Ghar Formation and from the top by the Dibdiba Formation. Fatha Formation is mainly marly limestone, consisting of numerous sediments of marl, limestones, gypsum, anhydrite, and sandstone. These sediments and facies refer to shallowing deposition. This formation gives sealing layers to the reservoirs in Iraq, so it is very important in the oil production system. It is considered a reservoir formation in one of the northern oilfield (Dunnington, 1958; Metwalli et al., 1974). Shawkat and Tucker (1978), described cryptalgal and stromatolites ,this study was carried out for the Fatha Formation in the northern part of Iraq and said that the marl, limestone, and gypsum cycles is made up the sequence of the formation. Stromatolite microstructures are studied and compared to

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current algal mat microstructures. The cryptalgal limestones' characteristics, as well as the occurrence of calcite pseudomorphs after gypsum, refer to a depositional environment in the intertidal zone. In the Shaqlawa area, the Lower Fars sequence stratigraphy is mainly composed of evaporates, clastic silt, and calcite and said that the formation can be divided into two portions of varying thickness based on geological variations. The research showed numerous sedimentary environments in this area: first, the river delta, second, the continental sabkha, third, supratidal environments, and fourth, open marine (Alsultan and Awad, 2021). The sulfur isotope composition in the Fatha Formation gypsum closely resembles that of marine sulfate. As a result, it is primary gypsum precipitated chemically as precipitation from an oversaturated solution that was isolated as a lagoon from marine water without bacterial action (Awadh and Al-Ankaz, 2016). Abdullah et al. (2021) published a study of deposits of Middle Miocene on the Zagros basin, A flooding surface separates between 10 and 40 depositional cycles, recording general basinward progradation. Each cycle has an upward trending shallowing tendency, from the microfacies of the calcareous mudstone (low energy) at the base to the microfacies of rudstone and grainstone with algae (high energy) above. The subsequent cycle will start by a flooding surface as well as a comeback to calcareous mudstones. This study aims to explain the relationship between the facies and their deposition conditions to determine the sedimentary environment, by an accurate description of the thin section slides, core description, and using the wireline logging data.

2. Materials and Methods

To make a correct study about the formation we have collected the previous studies, core samples, structural contour map, final geological reports, and well logs data. After that, the core was described in the oilfield to determine the lithology and structural features. In the laboratory work, three wells were studied using cores and logs data; more than 30 slides were described in the laboratory to determine the diagenesis process and microfacies distribution to determine the depositional environment; ten XRD samples identification to determine the mineralogy and the clay minerals content. In the laboratory, we used the SEM test to get pictures of the minerals in the Fatha Formation. Finally, used software: Surfer-13 is used to draw a contour map for the study area, and Geolog is used to calculate some petrophysical properties and draw the lithology according to gamma-ray, density, and resistivity logs responses.

3. Study Area

The studied oilfield is a productive and important oil field in Iraq, and it's around 25 kilometers north-northwest of Basrah (Fig.1). The oilfield is located in the Mesopotamian zone of the Arabian Platform's unstable shelf, according to Buday and Jassim's (1987) tectonic divides. The Zubair subzone contains the oilfield according to Jassim and Goff (2006).

4. Geological Setting and Stratigraphy

The sequence of the Miocene (middle Miocene) when a marine transgression and during the stage of strong subsidence, was deposited in a large broad basin that was nested with the margins of an Oligocene early Miocene basin. (Fig. 2). The Fatha Formation is represented by a shallow-water carbonate sequence in the intra-shelf section, which is covered by marls, evaporites, and limestone. (Jassim and Goff, 2006). In the south of Iraq, the formation overlays by the Dibdiba Formation and underlying by the Ghar Formation (Fig. 3). The oilfield has an oval elliptical structure, where at the beginning of the initial phase, the basement uplift formed by the rising of the Infra Cambrian salt from the Cretaceous Period and ending at the Tertiary Period resulted in salt pillow development to the creation of the salt structure It was called a salt pillow structure because of its oval form at the above (Almutury, 2007).

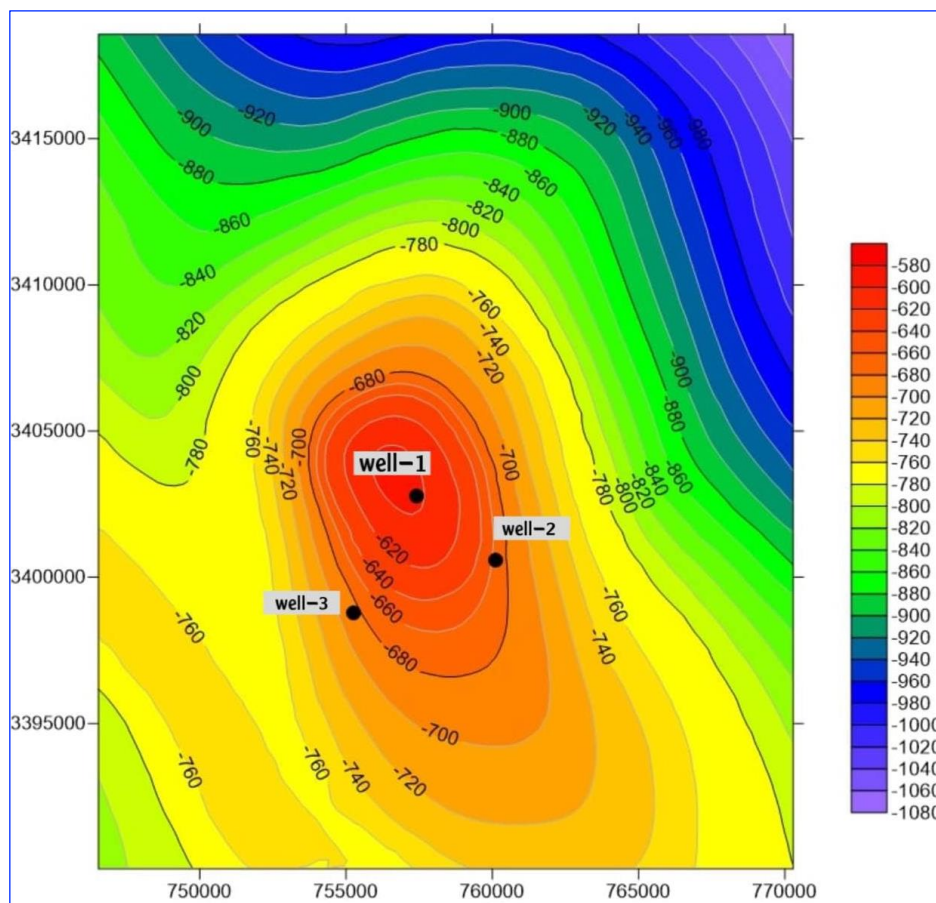


Fig.1. Contour map of the Fatha Formation showing 3 wells understudy

Period	Epoch	Stage	Iraq	Iran		Kuwait and Southeast Iraq	Saudi Arabia	AP11	MFS	
				Lurestan	Khuzestan					
TERTIARY	Pliocene		Bakhtiari			Dibdibba	Hofuf			
			Injana	Agha Jari						
	Miocene		Fat'ha	Gachsaran	Fat'ha	Dam			Ng 40	
			Jeribe	Asmari	Ghar	Hadruk			Ng 30	
			Kirkuk Group						Ng 20	
	Oligocene		Jaddala	Pabdeh	Shahbazan	Pabdeh	Dammam	Dammam		Ng 10
		Upper	Pila Spi and Avana							
		Middle	Aaliji	Khurmala and Sinjar	Taleh Zanc		Rus	Rus		
	Paleocene						Radhuma	Radhuma		

Fig.2. The regional correlation appears the formations of the Tertiary in Iraq, Iran, Kuwait, and Saudi Arabia (James and Wynd, 1965)

Age		Formation Name	Lithological Description	Depth (m) sea level
Tertiary Period	Late Miocene – Pliocene	Dibdiba	Sand and gravel of igneous rock	216
	Early/Middle Miocene	Fatha	Evaporate (Anhydrite, Gypsum) interbedded with Lst., and marls	325.8
		Ghar	Sands and gravels with rare Anhydrite, clay, sandy Lst.,	631.6
	Middle Late Eocene	Damam	Chalky, detrital, dolomitic Lst., and Dolomites, Marl, Shales	739.4
	Paleocene - Early Eocene	Um-Eradhuma	Dolomitic anhydritic Lst., dolomite, chert	1020.2

Fig.3. The stratigraphic column of the studied oilfield, modified from Braspetro,(1979)

Stratigraphy, The Fatha Formation consists of sediments that form a strong sinking basin, these deposits are separated from the open sea by the ridges (Buday, 1980). The Fatha Formation on the stable shelf southwest of the Euphrates River is only visible as a tiny stripe. At the Jazira basin, the formation encompassed the entire stable shelf. The main areas of the distribution of the formation are the Mesopotamian zones and the Foothill zones. The formation is missing in the High Folded Zone (Bellen et al. 1959). The formation towards the southeast extends into the Iranian territory where the facies is changed. The Fatha Formation in the northern portion of the high folded zone is made up partly of clastic, but in the Imbricated Zone, it is made up of terrigenous clastic red beds and limestone. The formation of Govanda limestone is equivalent to the Jeribe Formation (Fig. 2), in this case, the overlying beds of Merga Red beds are contemporaneous with the Fatha Formation (Jassim and Goff, 2006).

5. Results and Discussion

5.1 . Microfacies Analysis

Depending on sedimentology and petrographic studies of the Fatha Formation, nine microfacies types can be organized into three groups. These included the (A) Peritidal; (B) lagoon; (C) and shoal.

5.1.1. Peritidal microfacies

- MF1: Intraclast silt mudstone

These facies are typically micrite in texture with fewer than 10% silt grains, and they occur in low-energy conditions and quiet water (Flügel, 2009). These microfacies include a high content of more than 40% lime mud very clearly, with intraclast fragments and silt grains transforming from outside the basin of deposition. Correlated with RMF24 (Intraclast mudstone\wackestone) and the zone of occurrence is Peritidal zone FZ8 located in the middle part of the Fatha Formation (plate1-a).

- MF2: Siliciclastic-lime mudstone

These microfacies were observed in both sections, in the upper part and the different parts of the middle section of the Fatha Formation. The sands come in a variety of sizes, from fine and medium to coarse., with quartz particles accounting for around 7-10%, a matrix containing 65 percent with lime, and cement accounting for 10-20%. More of the quartz grains are angular (plate 1-b). This facies is

located in the Peritidal zone FZ8, RMF22 microfacies. In coastal locations, the change from clastic to limestone happens when the waves erode the grains, which are then transferred to the sea.

- MF3: Anhydritic-wackestone with pyrite

These microfacies have a high distribution, and it is recorded in upper and middle units. Anhydrite crystals appear with their distinctive optical properties where the bright second interference colors and the high relief, these crystals can be filling pores and fractures or found in porphyroblast patterns (plate 1-c). Gray-colored gypsum crystals can also be observed, but rarely compared to anhydrite. These crystals are ingrained in the micritic matrix. The dark spots are bituminous carbonate and pyrite minerals. Occurrence: Peritidal FZ8 correlated with RMF25.

- MF4: Dolomitic wackestone

The rhombic dolomite grains appear clearly and in good proportion; of more than 12% with sand grains, where they overlap with the dolomite grains (plate 1-d), which indicates a warm and arid environment, perhaps in the upper part of the Peritidal region FZ8, correlated with RMF24. Diagenetic processes, particularly dolomitization, have had a significant impact on these facies. It can also be observed in the lagoon environment FZ7, and it is recorded in the lower unit of the Fatha Formation.

5.1.2. Lagoon microfacies

- MF5: Unfossiliferous mudstone

Facies with high mud ratios are concentrated in environments with very low energy, which are represented in this study by the lagoon and the tidal region (Flugel, 2009). The zone occurrence of these sub microfacies are FZ7 and FZ8 and correlate with RMF19. In the lower part of the middle unit and lower units, these microfacies contribute to preventing living beings from forming grains inside its due to the high content of lime and mud (plate 1-e).

- MF6: Algal wackestone

Sparite and micrite filled Calcareous algal shells and shell fragments, which range in size from medium to coarse, with sand grains surrounding the algae in these facies. Algae are often found with fragments of shells, especially Pelecepods (Plate 1-f). Protected reef flats and sheltered lagoons are suitable areas for the expansion of green algae. These microfacies can represent open-circulation shallow marine waters standard microfacies types RMF20 and FZ7 and they can be recorded in middle and lower units.

- MF7: Benthic foraminifera packstone

It is the most common facies in the Fatha Formation, as it is recorded in most core samples, especially those taken from the limestone unit. It is composed of a high percentage of benthic foraminifera like Elphidim, which is very abundant, *Ammonia*, *Rotalia*, and *Miliolina*. In addition to algae and *Gastropoda* (plate 1-g). These facies are correlated with RMF20 and the occurrence zone with lagoon zone FZ7. These microfacies are recorded in all three units.

5.1.3. Lagoon and Shoal microfacies

- MF8: Pelletic-bioclastic grainstone

Fine-grained matrix with various types of bioclasts and non-skeletal grains creating packstones and grainstones microfacies the bioclasts particles are transported from high-energy environments and deposited in low-energy environments. In addition, more than 55% of Millimeter- to centimeter-sized pellets, predominantly form a grain-supported fabric associated with bioclasts (plate 1-h). correlated with RMF26. Edge sand areas in open-marine (FZ 6) and lagoons (FZ 7) were common environments for pellets grainstones facies. recorded in the lower unit.

- MF9: Mollusca-bioclastic grainstone

The facies of Mollusca-bioclast are characterized by the presence of one type of shell, which is abundant, such as *pelecypods* and *gastropods*, in addition to different types of algae. constant-wave environments that remove mud are ideal for deposition of this type of facies, but sometimes the shells may retain the mud without removal (plate1-i). These facies are correlated with RMF27 and occur in shoal environment FZ6 recorded in the lower unit of the Fatha Formation.

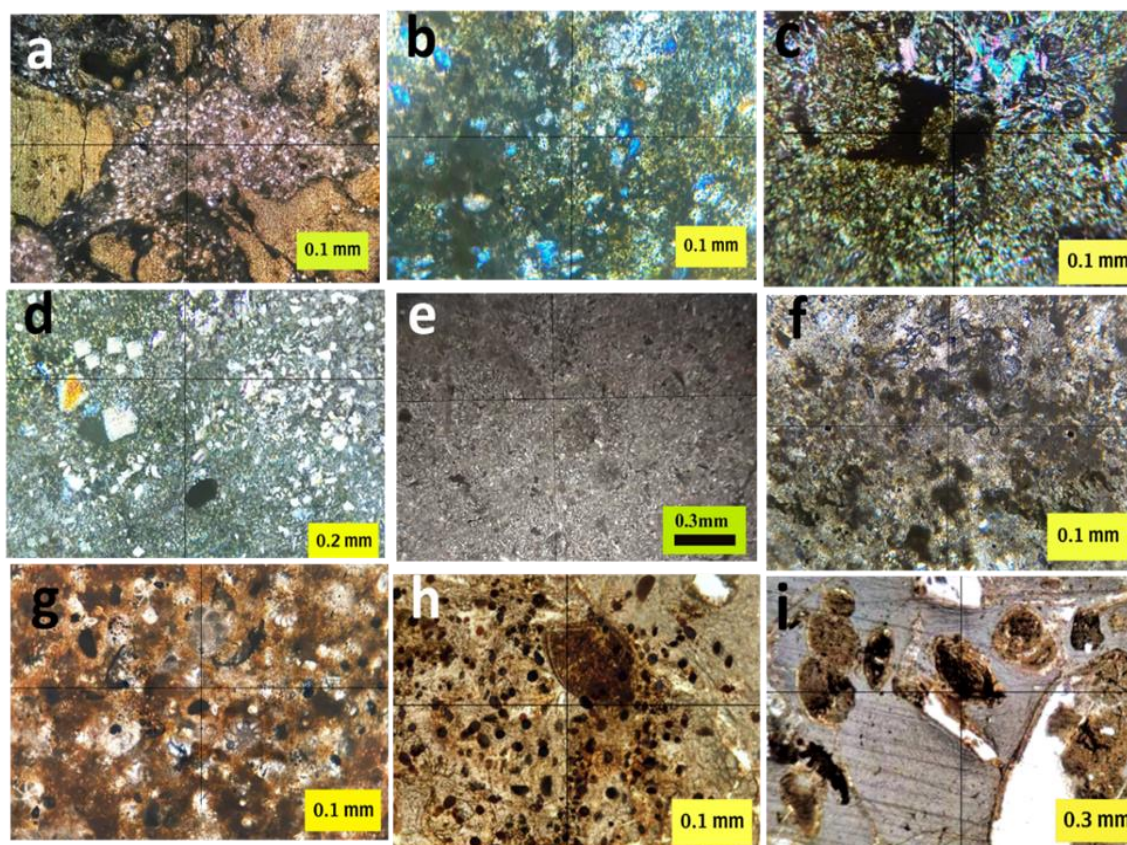


Plate 1. Microfacies analysis (a) Intraclasts silt mudstone; (b) Siliciclastic lime mudstone; (c) Anhydritic-wackestone with pyrite; (d) Dolomitic wackestone; (e) Unfossiliferous mudstone; (f) Algal wackestone; (g) Benthic foraminifera packstone; (h) Pelletal-bioclastic grainstone; (i) Mollusca-bioclastic grainstone

6. Depositional Environment

According to microfacies description, the Fatha Formation environments in K oilfield deposited in shallow depth marine environment, and it can be divided into three environments based on Flugel as shown in Fig. 4, these environments are (A) Peritidal zone; (B) lagoon zone; and (c) shoal zone. After recognition of the microfacies and their classification, it can be concluded some evidence like a large quantity of lime mud reflects a quiet and unagitated environment. (plate 1-b,e). the presence of benthic forams, Gastropoda, and algae with abundant suggests a lagoon with water circulation that give nutrient-rich and adequate salinity conditions (Shirazi and Jahromi, 2013). The tidal flat facies zone consists of intraclast mudstone and wackestone associated with early fine-medium size dolomite. The presence of dolomites indicates the internal part of a tidal flat setting (plate1-d). The facies with anhydrite crystals indicate to Peritidal zone. The grainstone facies have a high Mollusca bioclast and pellets indicated to the shallow part of the shoal environment. In summarizing, The Fatha Formation has a carbonate Ramp depositional model, and the part investigated was located at the shallowest part of the inner ramp (Fig. 4).

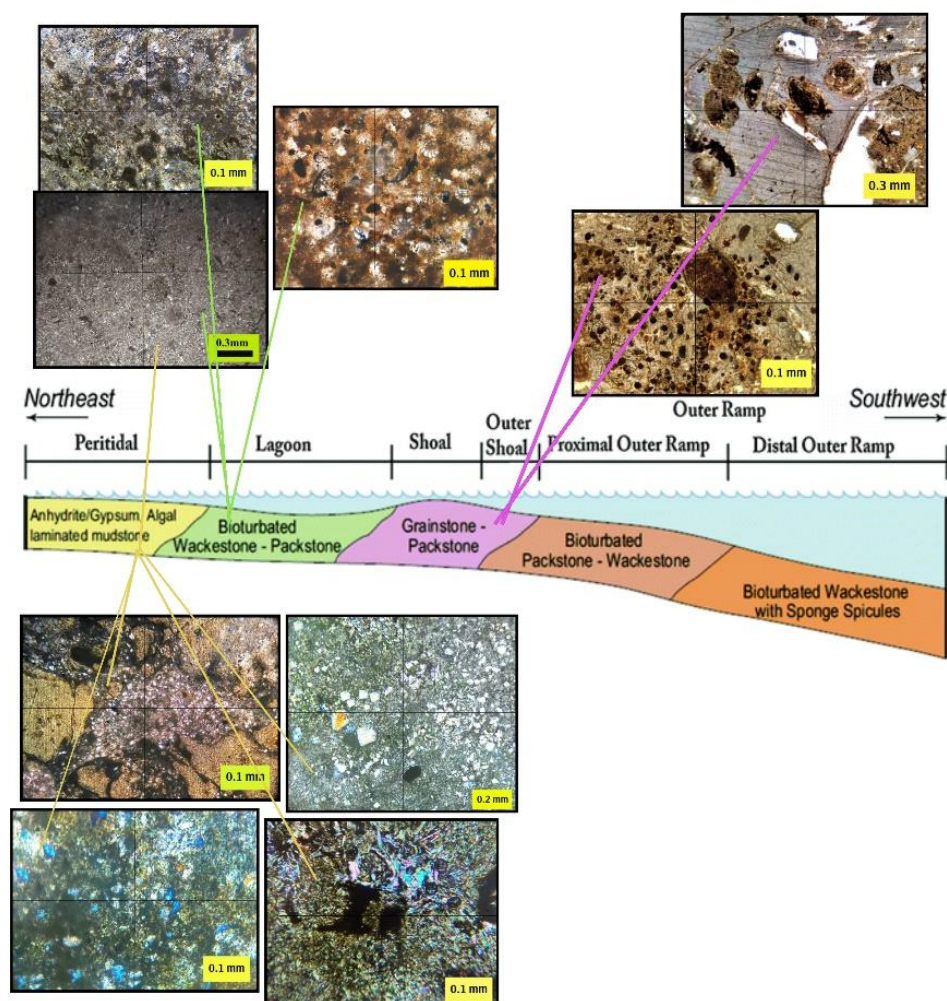


Fig.4. Depositional model for the Fatha formation, southern Iraq

7. Diagenesis

Several diagenetic features are identified based on sedimentary-petrographic analysis of the Fatha Formation in the studied thin section including dissolution, cementation, dolomitization, micritization, mechanical and chemical compactions, and pyritization which are existed in varying degrees (Plate 2). The dissolution is the most common process in the Fatha Formation, which leads to secondary porosity. The type of porous may be filled with calcite in the cementation process. Another common process is dolomitization, it is composed mainly of clear, medium, euhedral-subhedral dolomite rhombs grains, which are concentrated in tidal facies groups. The micritization process is mostly, associated with fossils, where the micrite fills the chambers of *Elphidium* and *Ammonia* (plate 2-d). In the studied section, the pyritization process occurs mainly along stylolite and fills the fossil cells and dissolution cavities. Chemical and mechanical compaction processes are limited in the formation, but some types of compaction are observed in lime mudstone, and after the evaporite minerals were excreted, a pressure solution developed and then appears as black arrows. The high-amplitude columnar stylolites consist of clay and pyrite (Plate 2-e,f).

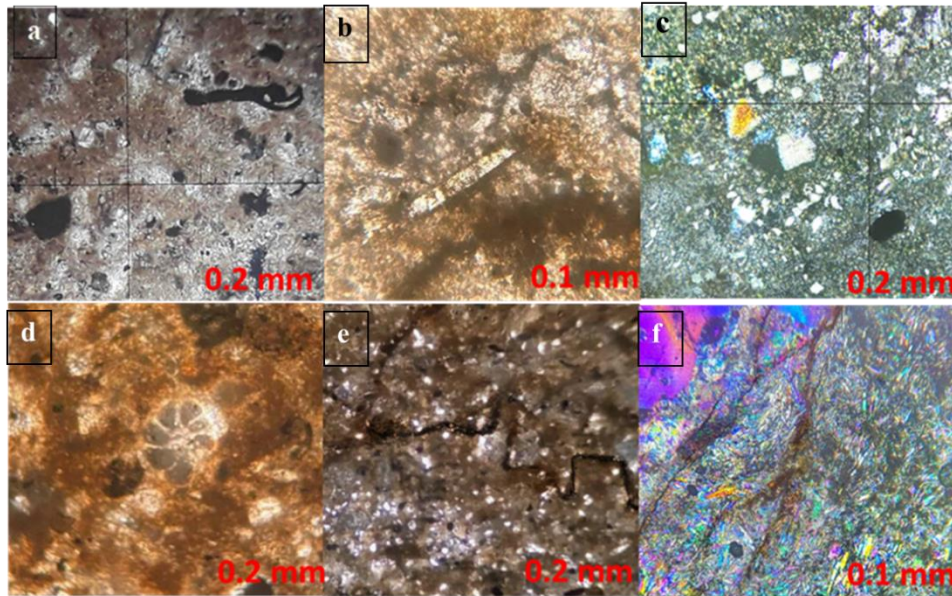


Plate 2. Diagenesis processes (a) Vugs and cavern porosity well3-569m depth; (b) Drusy cement well3-562m depth; (c) Dolomitization well2-430m depth; (d) Micrite filled the *Elphidium* chambers well3-668m depth; (e) pressure solution well2-686m depth; (f) Chemical and mechanical compaction process well3 583.35m depth

8. Lithofacies of the Fatha Formation

The Fatha Formation contains a mixing of several main lithofacies some of it is repeated continuously, in this study, the Fatha Formation is divided into three units according to the lithology which was described by the core and according to gamma-ray, density, and resistivity logs responses, where the height and decrease in the response of these logs indicate the type of lithology, and this is what was done in this study (Figs. 5, 6, and 7); these units are:

- The upper unit: from the top of the formation where the Marl (as the main facies of the upper unit), Marly Limestone, and sandstone. This unit is the largest and overlapping by layers of evaporites and thick siliciclastic layers.
- The Middle unit: consists of interbedded marl – anhydrite layers, the anhydrite layers increase in this unit.
- The lower unit: this unit is less thickness than the upper Fatha, starting with the limestone layers to the bottom of the formation. Consists of limestone (as the main facies of the lower unit), marly limestone, siliciclastics, evaporate, and dolomite. This unit is characterized by the presence of hydrocarbons in limestone layers in good quantities and these layers can be considered an oil reservoir.

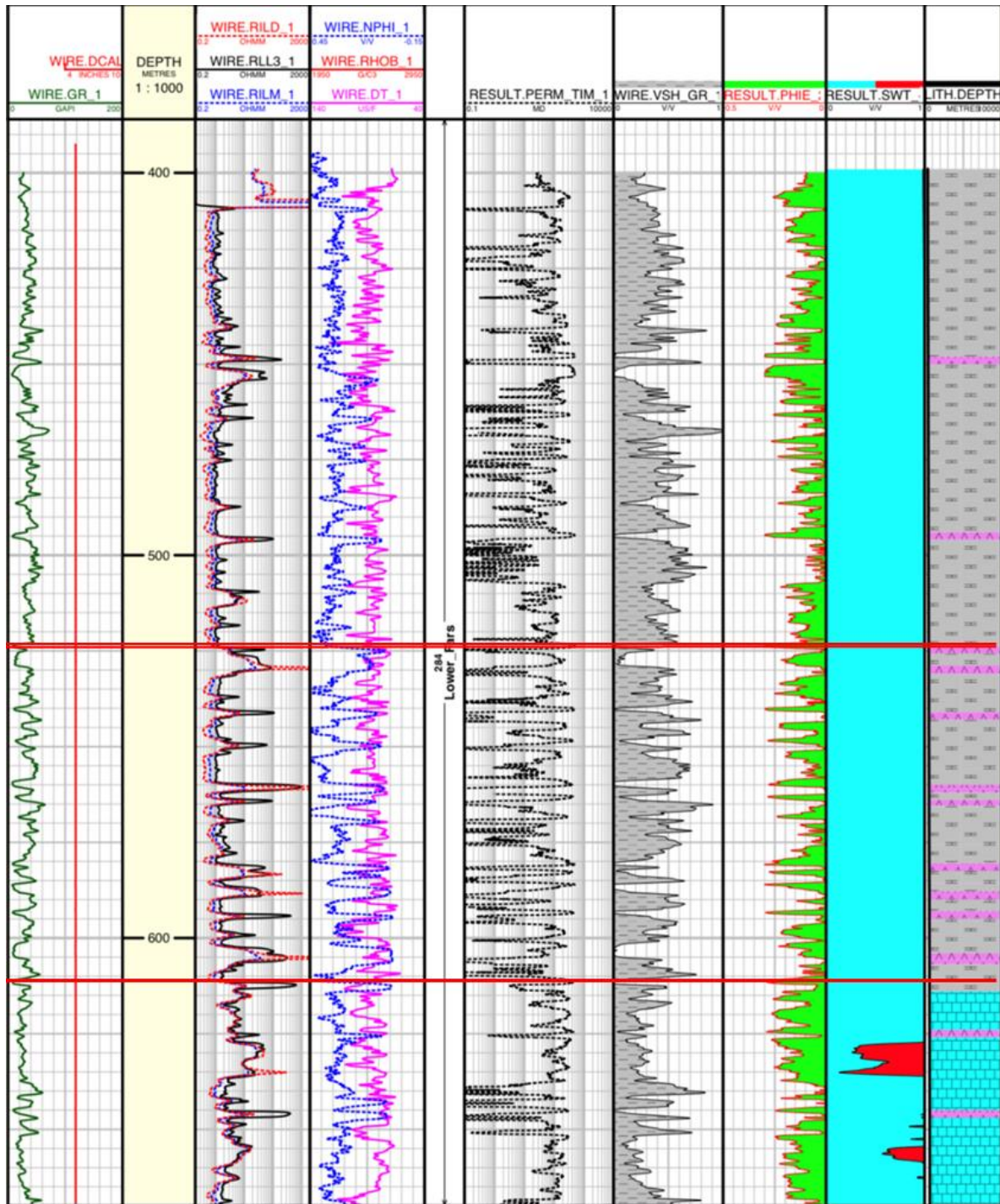


Fig.5. Gamma-ray, caliper, resistivity, density, neutron, and sonic logs, petrophysical properties (permeability, shale volume, effective porosity, and water saturation), and units of the Fatha Formation of Well-1 Scale 1:1000

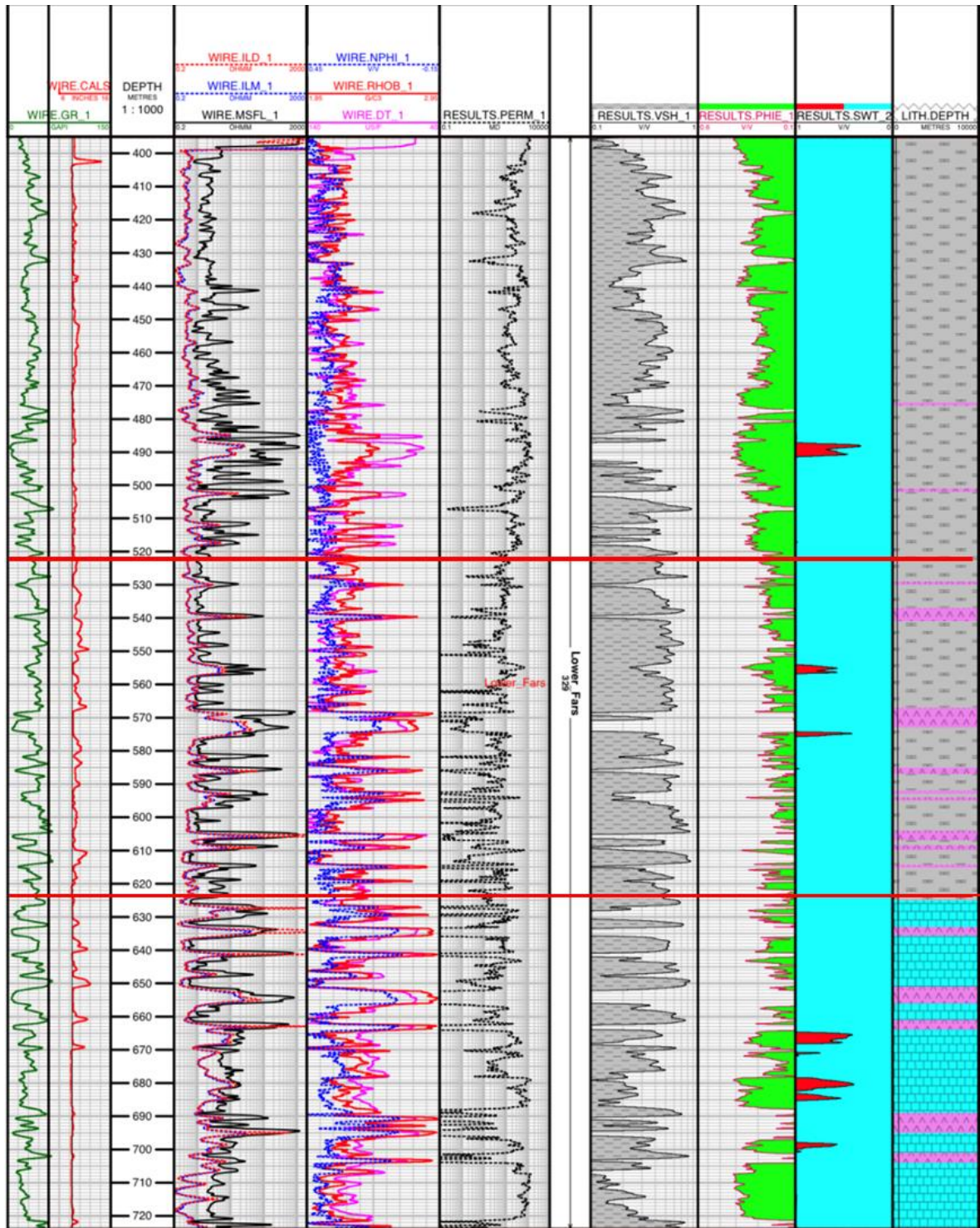


Fig.6. Gamma-ray, caliper, resistivity, density, neutron, and sonic logs, petrophysical properties (permeability, shale volume, effective porosity, and water saturation), and units of the Fatha Formation of Well-2 Scale 1:1000

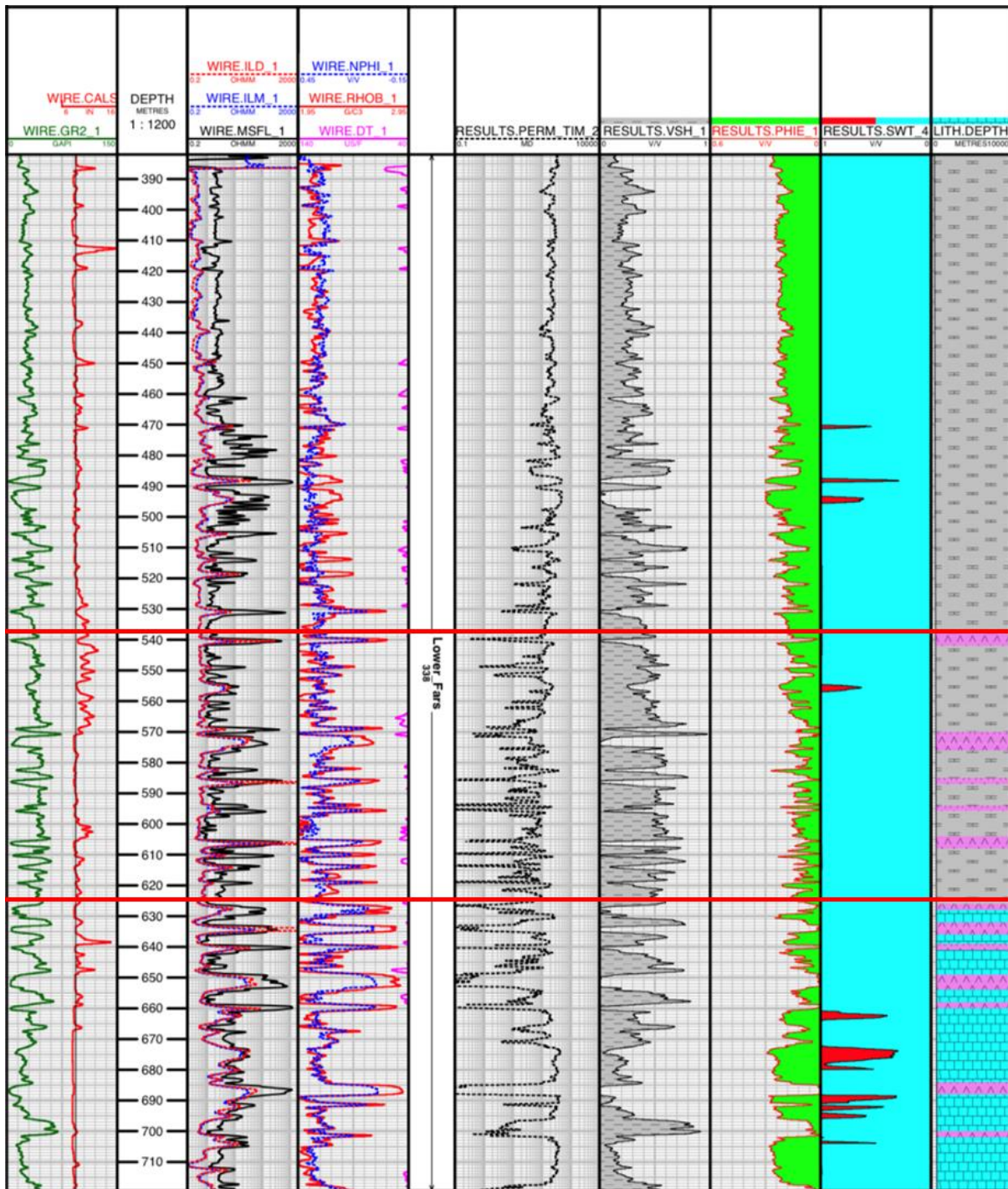


Fig. 7. Gamma-ray, caliper, resistivity, density, neutron, and sonic logs, petrophysical properties (permeability, shale volume, effective porosity, and water saturation), and units of Fatha Formation of Well-3 Scale 1:1000

8.1. Determination of Lithology by using Density vs. Neutron Cross Plot

Lithology is a broad term that refers to the study of all components of rocks, including the minerals that form the rock. By using the logs and their interruption in the standard petrophysical cross plots, the lithology of the Fatha formation was determined. One of the oldest quantitative interpretation techniques is the neutron–density cross plot. It was the most common way of determining the lithology of a formation by simply contrasting neutron and density log responses, then plotting the two points on

a custom graph or visually splitting the curves (Mohammed and Mahdi, 2019). Fig. 8 illustrates the density of the points increases at the line of marl and limestone, followed by sandstone with a high density as well. As for the anhydrite rocks, they are medium to few points. This indicates that the evaporites of the Fatah formation are found in an average way in southern Iraq, especially in the studied field, compared to the evaporites of the formation in northern Iraq. marl and limestone are the main lithologies of the Fatah Formation.

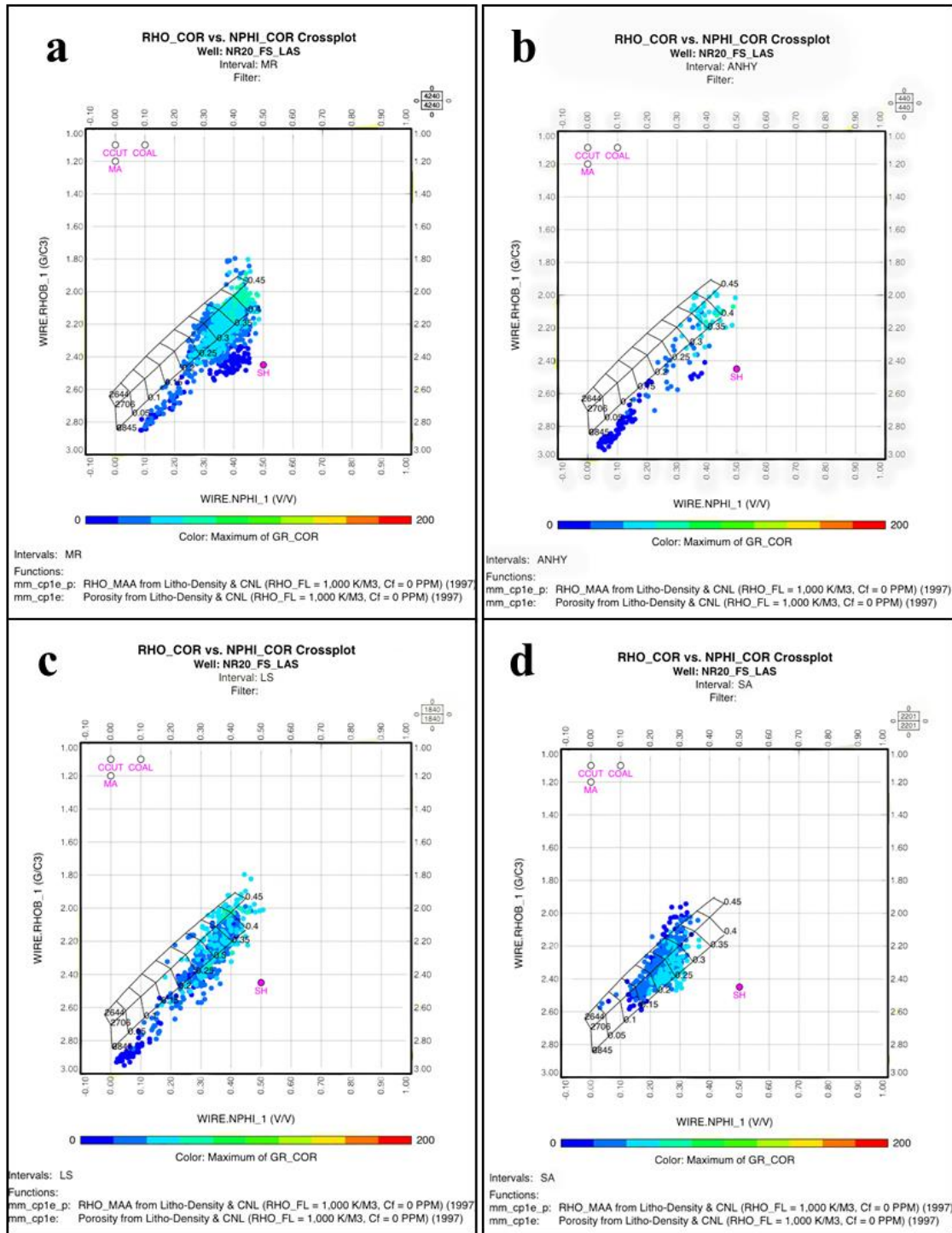


Fig.8. RHOB vs PHIN Cross plot for well 3, (a) Marl lithology; (b)Evaporite lithology; (c) Limestone lithology; (d) Sandstone lithology

9. Conclusions

- The Fatha Formation's major lithology in the K oilfield south of Iraq is marl, marly limestone, limestone, sandstone, and evaporite.
- The Fatha Formation is divided into three units according to the lithology which was described by the core and wireline logs data these units are; upper, middle, and lower units
- The research showed nine different microfacies, all of which point to the Fatha Formation is been contained in shallow zones of the carbonate environment ramp, ranging from the Peritidal, lagoon, and shoal environments.
- The bioclastic grains mainly belong to benthonic foraminifers, other skeletal grains show a diversity of species, which include gastropods, pelecypods, and algae.
- Several diagenesis processes are noted in the formation, but the dissolution is predominated; this indicates a good reservoir formation and it is increasing at the lower unit.
- According to this study, it was observed that there are good oil quantities of the oil in the lower unit of the formation, which represents the carbonate unit. While the upper unit (marl layers) of the formation, were free of oil.

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