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Depositional Environment and Stratigraphic Evolution of Hartha Formation in Balad and East Baghdad Oil Fields, Central Iraq

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Abstract

Five subsurface sections and a large number of thin sections of the Hartha Formation (age Late Campanian – Early Maastrichtian) were studied to unravel the depositional facies and environments. The Hartha Formation is important as an oil reservoir in Iraq.

Petrographic and microfacies analysis of selected wells from Balad and East Baghdad oil fields in Central Iraq, enable the recognition of three main Sedimentary paleoenvironments. These are restricted marine, the shallow open marine environment within the inner ramp, deep outer ramp.

The studied Formation represents by two asymmetrical cycles bounded below by sequence boundary (SB1) the contact between Hartha and Saadi Formations. The deep outer ramp facies of the transgressive systems tract continue with the lower part of the Hartha Formation. Two depositional sequences consist of transgressive system tract and high stand system tract, separated by maximum flooding surface. These happened and represented the transgressive systems tract of the cycle that continues until the Shiranish Formation, which overlies the Hartha Formation.

Keywords:- Depositional Environment, Sequence stratigraphy, Hartha Formation. Balad oil field, East Baghdad oil field, Central Iraq.

البيئة الترسيبية و التطور الطباقي لتكوين الهارثة في حقلي بلد و شرقي بغداد في وسط العراق

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الخلاصة

يعتبر تكوين الهارثة (الكامباني المتأخر – ماستريختي المبكر) تكوينًا مهمًا بسبب خصائصه الصخرية والبتروفيزيائية التي تجعله خزانًا للنفط في بعض المناطق.

مكن التحليل الصخري والسحنات الدقيقة لآبار مختارة من حقلي بلد و شرقي بغداد في وسط العراق التعرف على ثلاثة بيئات ترسيبية رئيسية. هذه هي: البيئة البحرية المقيدة ، بيئة بحرية مفتوحة ضحلة ضمن منحدر داخلي و بيئة منحدر خارجي عميق.

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يمثل التكوين المدروس بواسطة دورتين غير متماثلتين تحدهما من الاسفل حدود طباقية (SB1) كحد غير متوافق بين تكوينات الهارثة والسعدي. ان سطوح المنحدرات الخارجية العميقة لمسار انظام التقدم البحري المستمرة مع الجزء السفلي من تكوين الهارثة. هناك تتابعان مترسبان يتألفان من نظام تقدم بحري و نظام عالي الوقوف ، مفصولة بأقصى تقدم بحري ، وقد حدثا ويمثلان مسار نظام التقدمي للدورة حتى يستمر الى تكوين شيرانيش الذي يعلو تكوين الهارثة.

Introduction

The Hartha Formation deposited in Late Campanian – Early Maastrichtian is an important carbonate formation in Iraq due to its petrographic and petrophysical characteristics that make it an oil reservoir in some regions. The Hartha Formation was defined by Rabanit in 1952 from well Zubair-3 in the Mesopotamian Zone in southern Iraq [1].

In central Iraq, the Hartha Formation is divided into upper and lower Members [2]. Sadooni identified five lithofacies based on petrographic and petrophysical characteristics. These include local rudist biostromal carbonates; echinoderm-rich packstones and grainstones with shallow–water larger foraminiferal shoal facies; and peloidal facies separated by deeper–water marly and fine-grained muddy carbonates. The formation is interpreted as an open platform deposition in central Iraq [3].

The lower contact of the Formation is usually an unconformity with Saddi Formation, often marked by a basal conglomerate. The upper boundary in the south of Iraq is conformable, and the Formation is often overlain by pelagic sediments of the Shiranish Formation [4].

The Hartha Formation was deposited in the forereef to shoal environment. Locally lagoonal backreef facies occur around the margins of the Stable Shelf. Reef facies may be present around Khlesia High, as indicated by the reef limestone debris in the detrital limestone beds in the formation in some wells [4].

Al-Zaidy, et al., 2013, [5] studied sequence stratigraphy and reservoir characterization of The Hartha the formation in Ahdab oilfield. Recognized six main facies associations in the studied succession; these are basinal, open shelf margin, fore slope, rudist biostorm, shoal and restricted platform (lagoon), and nine petrophysical horizons.

The tectonic and stratigraphic settings of the Late Campanian- Maastrichtian cycle begins with a widespread transgression and almost cover the whole of Iraq which occurred after the termination [6]. The sediments of the Late Campanian- Maastrichtian cycle were studied due to their importance in the oil industry in both the northern and southern parts of Iraq.
Major onlap occurs in Late Campanian – Maastrichtian, the whole of Iraq was submerged by the Maastrichtian (Figure 1). It is characterized by strong westerly onlap on to a regional unconformity [3]. The Hartha Formation is the main lapping unit within the Late Campanian-Maastrichtian cycle. Over most of the Khleisia High and Stable Shelf (Figure 2), it is overlain by the Shiranish Formation [2]. These units pass towards the north and east, and locally within deep half-graben, into Shiranish Formation [3].

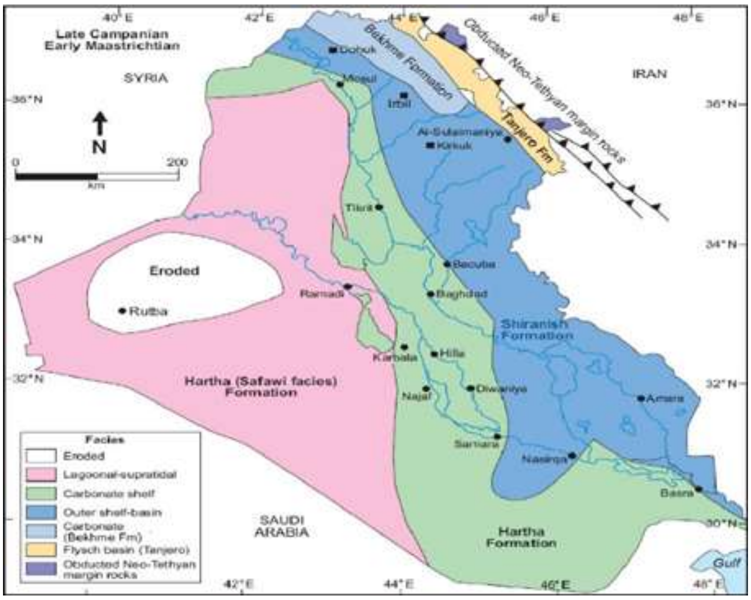


Figure 1: Late Campanian – Maastrichtin Paleogeography [3]

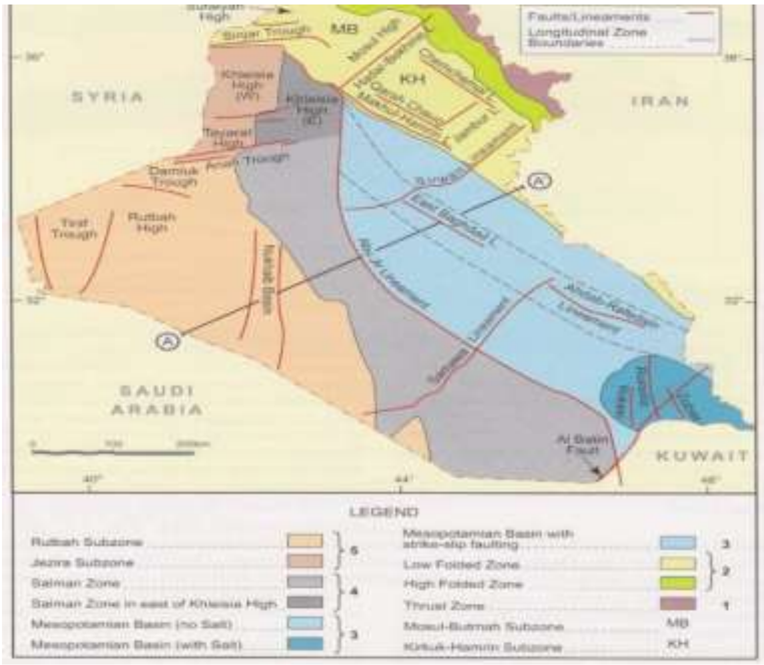


Figure 2: Tectonic framework of Iraq [3]

The aim of the present study is microfacies analysis to define the depositional environments of the Hartha Formation and stratigraphic sequence development in selected wells from Balad and East Baghdad oil fields.

The studied area is including two oil fields located in central Iraq East Baghdad and the Balad oil field (Figure 3).

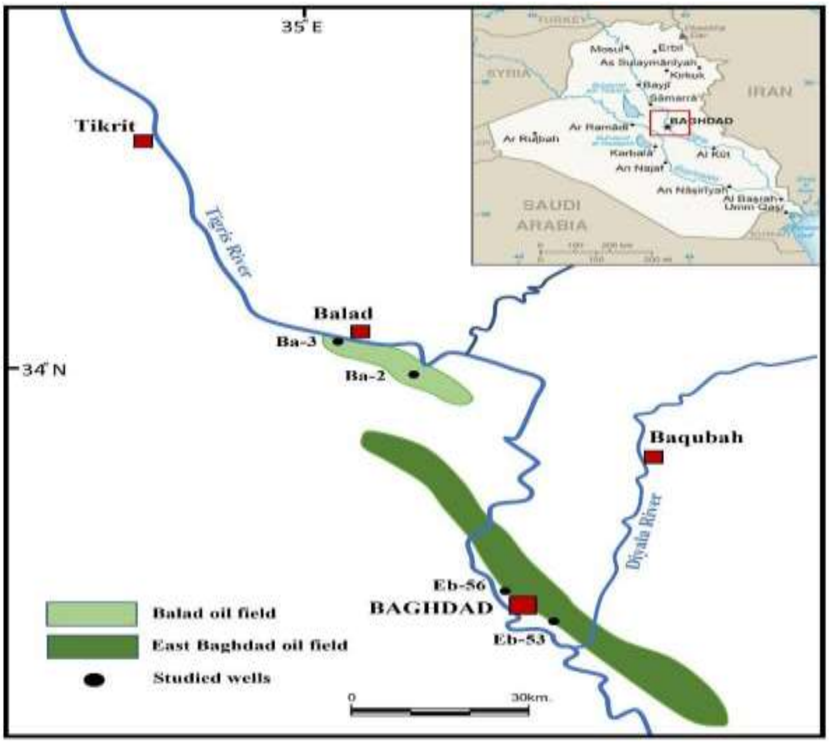


Figure 3: Location map for the study area

Methodology

Five subsurface sections were selected from the wells of two oil fields: Balad and East Baghdad in the middle of Iraq, including East Baghdad: EB-53, EB-56, and EB-102; Balad: Ba-2 and Ba-3 to analyze the microfacies and to determine the depositional environments of the Hartha Formation and stratigraphic sequence (Figure 3). For this purpose, more than 430 thin sections previously prepared by the north and center Oil Companies, were described, interpreted and were studied petrographically by applying the modified Dunham, 1962 [7] classification by Embry and Klovan, 1971 [8]. Analysis of gamma-ray, density, neutron, sonic, and resistivity logs was used to study the volume of shale, porosity types, and fluid saturation, which was applied. The thickness of Hartha Formation in the studied wells are range from 222.5 to 248 m for the East Baghdad oil field and from 314 to 593 m for the Balad oil field (Table 1).

Table 1: Thickness of the Hartha Formation in the studied wells

No.	Well ID	Top	Bottom	Thick.	No. of thin sections	Study method
1	Balad-2	1680	1994	316	134	Logs & core
2	Balad-3	1681	2274	593	169	Logs & cuttings
3	East Baghdad- 53	1680.5	1903	222.5	68	Logs & cuttings
4	East Baghdad- 56	1600.5	1849	248.5	18	Logs & cuttings
5	East Baghdad-102	1638	1865	227	41	Logs & cuttings

Results and Discussion

The Hartha Formation is a conformable overlaying by the Shiranish Formation,while the lower contact of this formation is usually an unconformity by often marked a basal conglomerate with Saddi Formation.

Depositional Microfacies

The Hartha Formation carbonates were classified following Dunham's (1962) [7] and Embry and Klovan 1971[8], into mud- or grain-supported textural types. Moreover, the microfacies descriptions have identified the environments according to Flügel, 2010 [9]. In this study, the Hartha Formation is divided into nine principal microfacies units through all the studied wells depending on the present fossils and lithological characters as a basis for division. The main factor responsible for facies developments and their distribution is relative sea-level frequent fluctuations. It appears that each of the selected wells characterized by definite microfacies units may be of similar or different constituents. Each microfacies unit is discussed in the following:

1- Lime Mudstone Microfacies

Micrite is the main component, which is slightly affected by recrystallization and dolomitization processes(Plt.3-A). Few shell fragments and echinoderm fragments are recognized, generally less than 10% (Plts.1-A and B). The noticed diagenetic processes are the recrystallization of micrite to micro-sparite due to the neomorphsim process, and dolomitization that affected this microfacies due to the existence of the anhedral - subhedral fine dolomite crystals which indicate an early dolomitization. In some parts, fractures are noticed that are caused by the compaction diagenetic process.

This microfacies reflects the deposition of low-energy under a deep quiet water environment. It can extend from basinal to mid-ramp compared with the RMF5 [9].

2- Orbitoides Wackestone Microfacies

Orbitoides sp. are the main allochems in this microfacies. *Orbitoides* sp. is semi-sessile benthic fauna, and are restricted to a shelf environment (0-100m) within the photic zone [9].
Many *Orbitoides* sp. are represented in this microfacies such as (*orbitoides medius* d'Archiac, *orbitoides apiculatus* Schlumberger, *Orbitoides gensacicus* Leymerie, and *orbitoides tissoti)* Schlumberger is an index species to shallow warm water within middle shelf [10], with few bioclastic like coral and echinoderm fragments (plt.1-E).
Dissolution, cementation, compaction, floating dolomite rhombohedral and a few authigenic iron oxides are the main diagenetic features in this microfacies.

The presence of Orbitoids in a high number suggested the warm shallow marine (50-100m) or fore reef environment [11]. Therefore, it is concluded that this facies was deposited in the open marine environment in association with the inner ramp. This microfacies correspond to RMF 13 [9].

3- Rotaliida Wackestone Microfacies

The main constituents of this microfacies are Rotaliida sp. indicated by *rotalia* sp, *suloperculina sp., sirtina sp.,* and *siderolites calcitropoides* Lamark, *valvulineria cretacea*. As well as, shell fragments of mollusks, echinoderms, algae, and coral are also present (Plt.1-F). The main diagenetic features affected this microfacies are dissolution, cementation, and compaction.

The abundance of Rotaliida in some cases may reflect the tolerance of hypo salinity or hyper salinity as well as normal marine salinity as a characteristic of the shallow marine environment [12]. This microfacies indicates the deposition in open and restricted marine (inner ramp) facies association compared with RMF 13 [9].

4- Miliolids Wackestone Microfacies

This microfacies is observed in the East Baghdad oilfield. The main constituents of this microfacies are Miliolids sp. such as *Pyrgo* sp., *Quinqueloculina* sp., and *Pralvolina* sp. Small benthic foraminifera, peloids, bioclastic particles, and shell fragments are also found in this microfacies (Plt.1-G).

In general, the rate of imperforate foraminifera indicates a restricted depositional environment. Furthermore, whole imperforate foraminifera often dominates near-shore environments in water depths of less than 50m and can live in an environment with extreme temperature and salinity [13]. Miliolida in some cases has been tolerant of hypo salinity or hyper salinity [12]. It's comparable with RMF16 [9].

5- Bioclastic Wackestone Microfacies

This microfacies is principally dominated by different types of bioclastic of various sizes such as echinoderms fragments, coral, Mollusca fragments, and algal debris (Plt.1-D).

Many differentiated accumulations of benthonic foraminifera are also found in this microfacies. Dolomitization indicated late diagenesis (Plts. 3-D and 3-G). Moreover, the euhedral crystal of dolomites along the stylolite could be a good indication of late diagenesis, cementation, dissolution, and neomorphsim. Authigenic minerals are the main diagenetic processes affecting various particles as well as the micritic groundmass. The nature of bioclastic in this microfacies suggests open marine in the inner ramp corresponds to RMF 14 [9].

6- Foraminifera - Bioclastic Wackestone – Packstone Microfacies

It represents one of the common microfacies in the Hartha Formation. It's composed of many types of bioclasts of various sizes such as Mollusca shell fragments, echinoderm plates, calcareous algae, coral, rudist association with differentiated assemblages of benthonic foraminifera such as Orbitoides, Rotaliida, loftusia and omplalocyclus and few peloids (Plts. 1-C and H). These microfacies have been affected by many diagenetic processes (neomorphism, cementation, authigenic mineral (pyrite crystals), chemical compaction (stylolitization), while the euhedral fabric indicates late dolomitization (Plts.3-F and 3-C) Dolomitization is record in both the matrix as a scattered crystals dolomite and allochems.

Some genera of foraminifers were indicted to environments such as Nodosaria, which was founded only in normal marine salinity so it could be tolerant of shallow marine also Orbitoides lived in shallow marine.

This microfacies belong to the open marine facies in the inner ramp and is correlated to RMF 14 [9].

7- Bioclastic Peloidal Packstone Microfacies

This microfacies is recorded at the East Baghdad oil field and very rare in the Balad oil field. The main constituents are peloids (Plts.2- G and H). Also contain different benthic foraminifers' like Miliolids and Rotalids with many types of bioclastic and shell fragments.

Cryptocrystalline carbonate grains are generally smaller than other carbonate particles [13].

Cementation, neomorphsim, dissolution, and micritzation are the main diagenetic processes.

The nature of bioclastic in this microfacies suggests very shallow marine water. The low diversity in this microfacies indicates restricted marine of the inner ramp [14]. Furthermore, the packstone texture indicates a relatively moderate energy system. The microfacies is related to RMF 13 [9].

8- Echinoderm Bioclastic Packstone Microfacies

This microfacies is principally composed of abundant echinoderm fragments. Few shell fragments, algae with benthonic foraminifera like Orbitoides, and few peloids are associated as well (Plts.2-A and B). Cementation, neomorphsim and dolomitization may indicate late diagenesis processes (Plts. 3- C and E). The authigenic minerals are affecting this Microfacies as well.

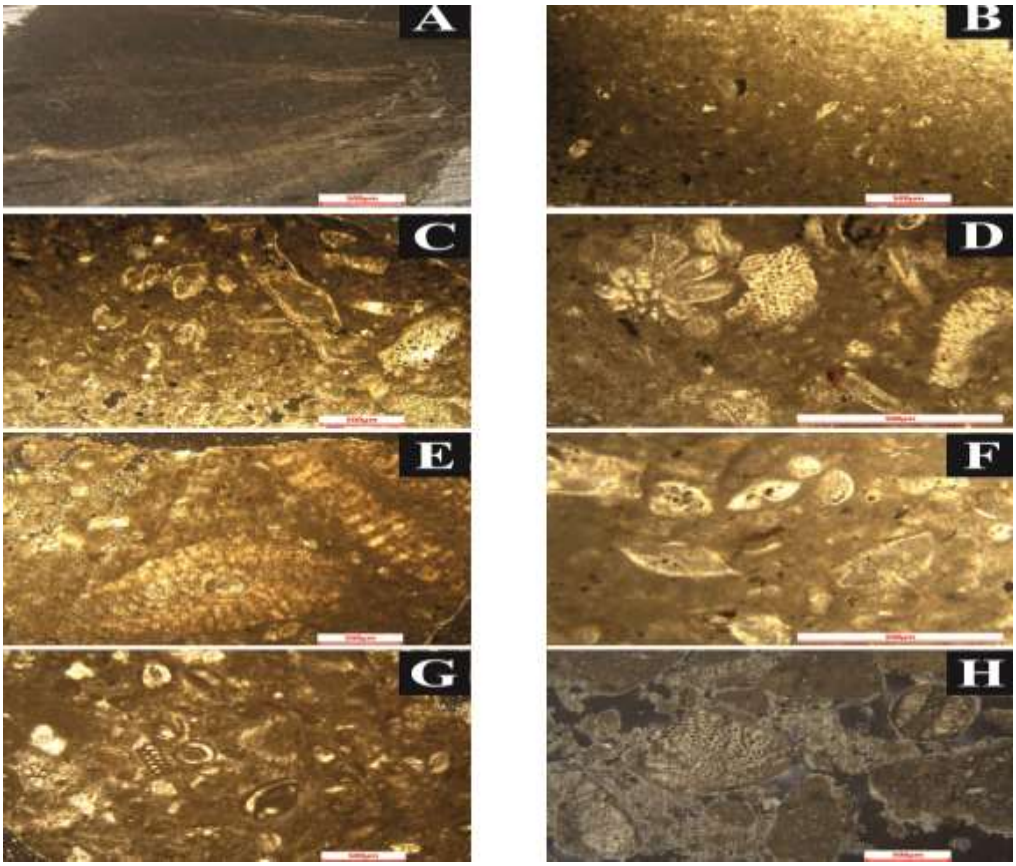
The presence of high levels of fragments indicates moderate energy. This microfacies ranges from mid ramp to inner ramp (open and restricted marine) and correspond to RMF7 [9].

9- Planktonic Microfacies

This microfacies consists of planktonic foraminifera as a main component in different percentages and texture such as *Globotruncana* sp. and *Globogerinelloids* sp., associated with small benthonic foraminifera and shell fragments (Plts.2- C, D, E, and F). The abundance of planktonic foraminifera suggests an open marine setting reaching slope of more than 200m and indicating basinal depositional environment [14].

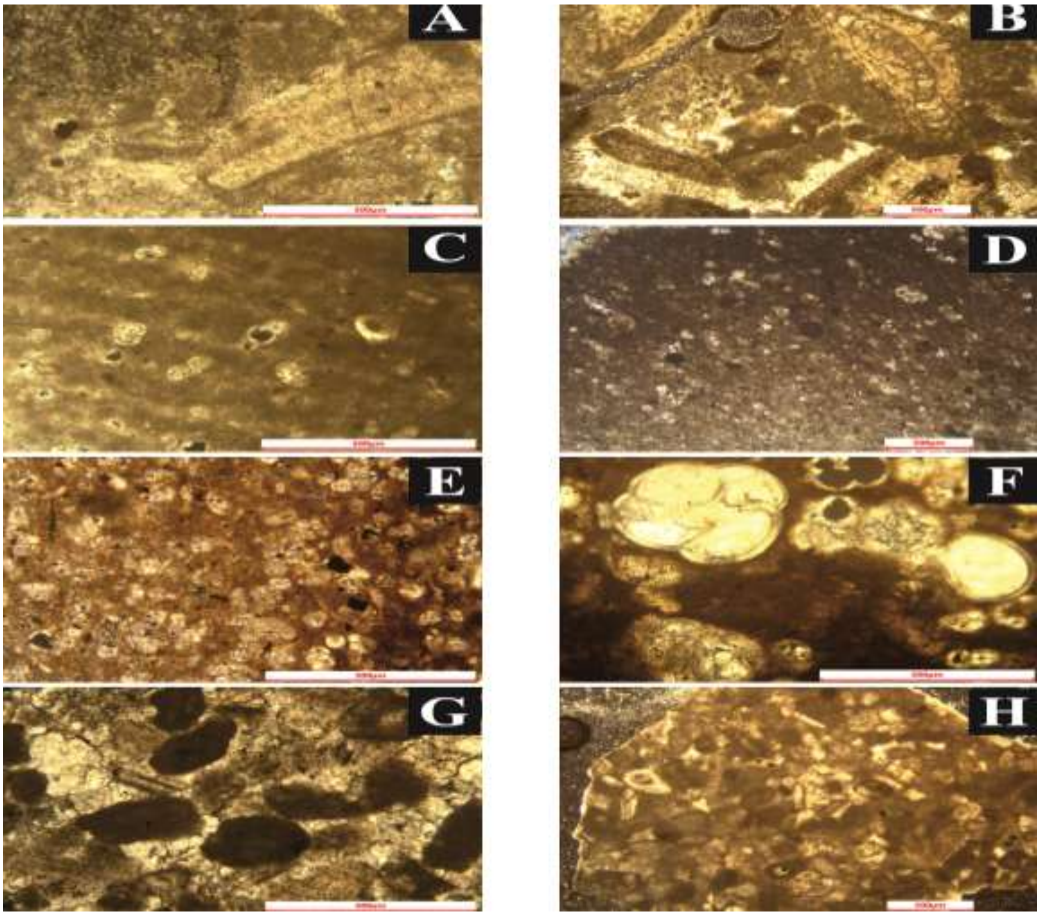
The low energy hydrodynamic regime indicates deposition below the normal wave base [9 and 14]. This microfacies is reflecting a pelagic mudstone-wackestone correspond to RMF 5, [9]. This microfacies represents an environment ranging from a deep marine to basinal environment, and the Planktonic foraminifera are dominant in deep and quiet conditions of open sea environment [15].

Plate 1



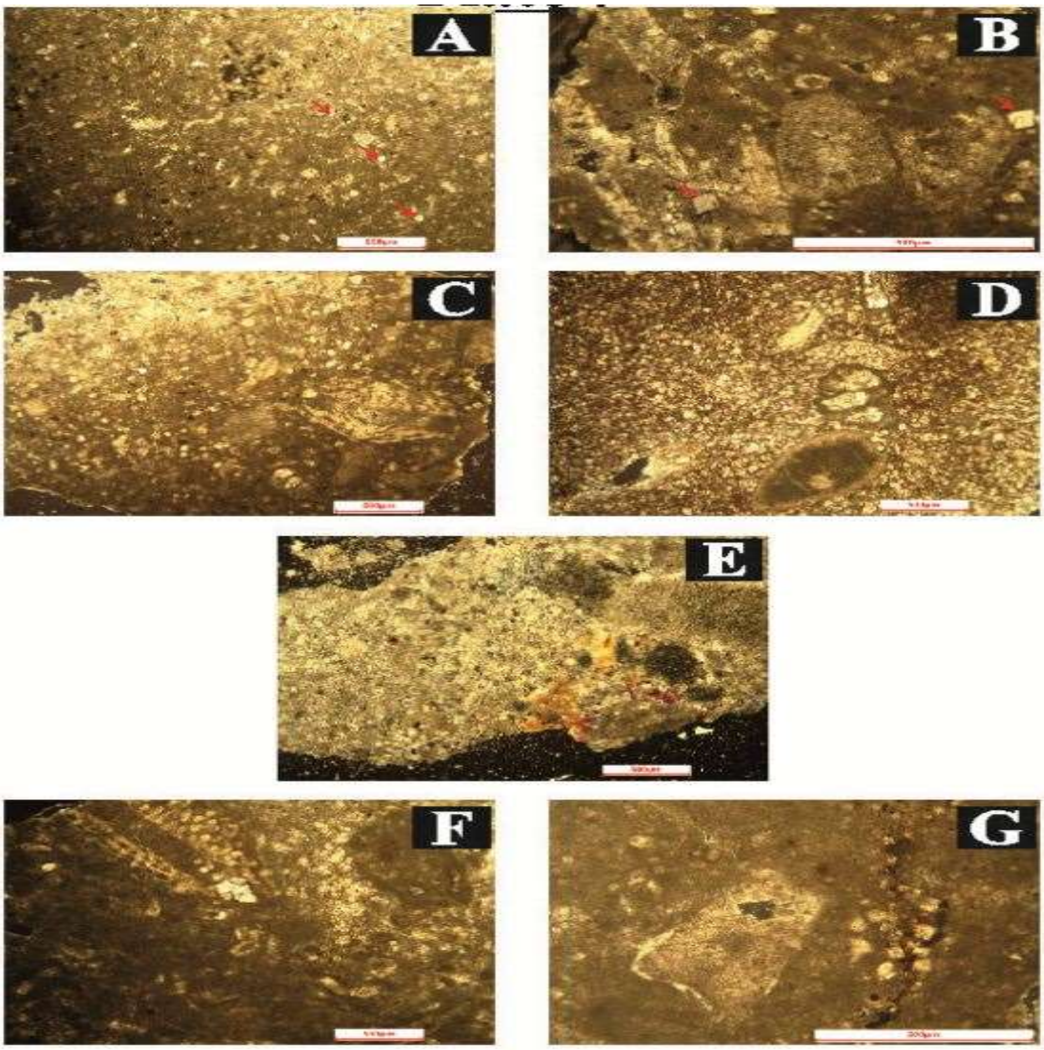
A- Lim mudstone microfacies; EB-102 Depth 1690m.
B- Bioclastic mudstone microfacies; Ba-3 Depth 1814.
C- Foraminferal bioclastic wackestone – packstone microfacies, Ba-2 Depth 1710m.
D- Bioclastic wackestone microfacies, EB-56 Depth 1744m.
E- Orbitoides wackestone microfacie s, Ba-2 Depth 1762m.
F- Rotalida wackestone microfacies, EB-56 Depth 1750m.
G- Miliolid wackestone microfacies; *Pyrgo* sp., EB-56 Depth 1632m.
H- Bioclastic foraminferal wackestone microfacies; EB-102 Depth 1830m.

Plate 2



A- Echinoderm packstone microfacies, Ba-2 Depth 1716m.
B- Echinoderm packstone- grainstone microfacies, with *Orbitoides apiculatus*, Ba-2 Depth 1758m.
C- Planktonic mudstone microfacies; Ba-3 Depth 2074m.
D- Planktonic mudstone – wackestone microfacies; EB-102 Depth 1760m.
E- Planktonic wackestone microfacies; EB-56 Depth 1624m.
F- Planktonic packstone microfacies; *Globogerinelloids* sp., Ba-2 Depth 1786m.
G- Bioclastic Peloidal packstone; EB-56 Depth 1628m.

Plate 3



A- Bioclastic mudstone - wackestone microfacies, with fine dolomite crystals; Ba-3 Depth 1960m.
B- Echinoderm bioclastic wackestone-packstone microfacies, Euhedral dolomite crystal scatter in matrix; Ba-2 Depth 1853m.
C- Foraminiferal bioclastic wackestone microfacies, affective of dolomatization appered in matrix and skeletal grains; Ba-2 Depth 1730m.
D- Bioclastic wackestone microfacies, with dolomitization of the matrix; Ba-3 Depth 1685m.
E- Echinoderm packstone microfacies, with dolomitization of the matrix; EB- 56 Depth 1620m.
F- Foraminferal bioclastic wackestone microfacies, dolomite crystal in the foraminifera; Ba-3 Depth 1778m.
G- Bioclastic wackestone microfacies, dolomite crystals associated stylolite; Ba-2 Depth 1724m.

Depositional Environments

Three major environments were indicated within the Hartha Formation in the studied wells. These include open and restricted marine belonging to the inner ramp and outer ramp environments. These environments were interpreted depending on the description of texture and type of carbonate grains and considering the standard microfacies classification suggested by Wilson and its latest modification adopted by Flügel, 2010 [9], (Figures 4, 5, 6, 7, and 8).

Restricted marine Environment

The microfacies observed in this environment are Miliolids wackestone, Rotalide wackestone, Peloidal bioclastic packstone – grainstone, and Echinoderm bioclastic packstone – grainstone. The fossils are principally peloids with rudist fragments bioclasts, benthic foraminifera (miliolids), and planktonic foraminifera.

Open marine Environment

This environment is recorded in all studied wells. It is characterized by microfacies which are deposited in open marine inner ramp Orbitoides wackestone, Bioclastic wackestone, Foraminifera bioclastic wackestone – packstone, and Echinoderm bioclastic packstone – grainstone. Many important fossils are included in this facies such as benthonic foraminifera, echinoderm fragments, coral, and shell fragment.

Outer ramp Environment

This environment was characterized by planktonic microfacies and lime mudstone microfacies. These microfacies contain mostly small bioclasts and shell fragments, planktonic foraminifera being less abundant.

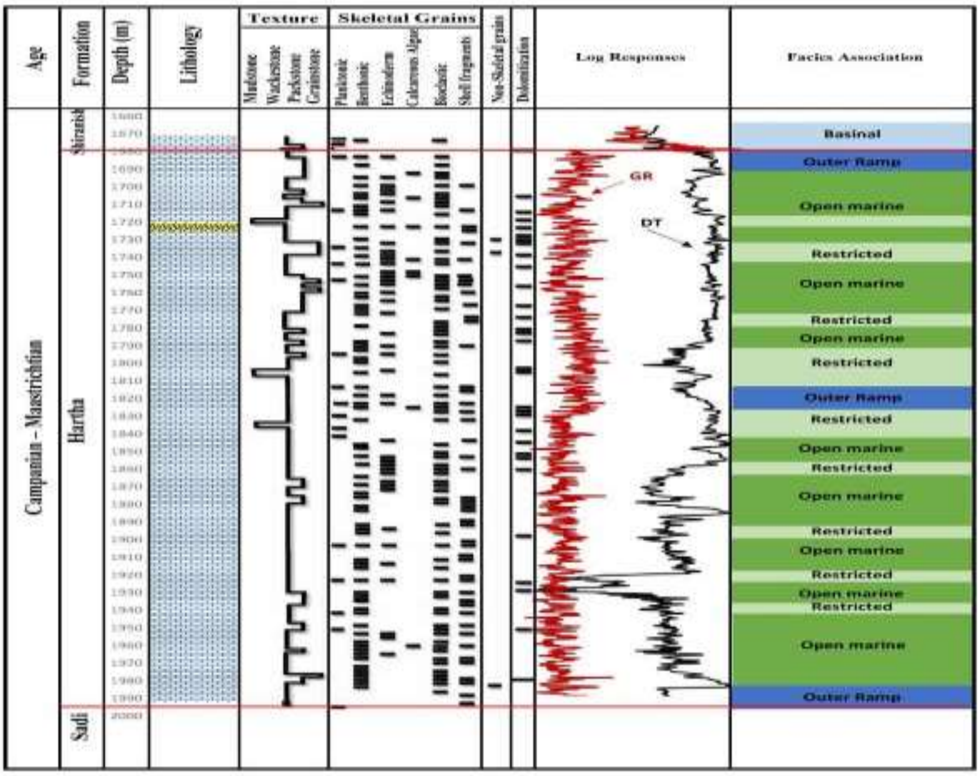


Figure 4: Stratigraphic Column of the Hartha Formation at well Ba-2.

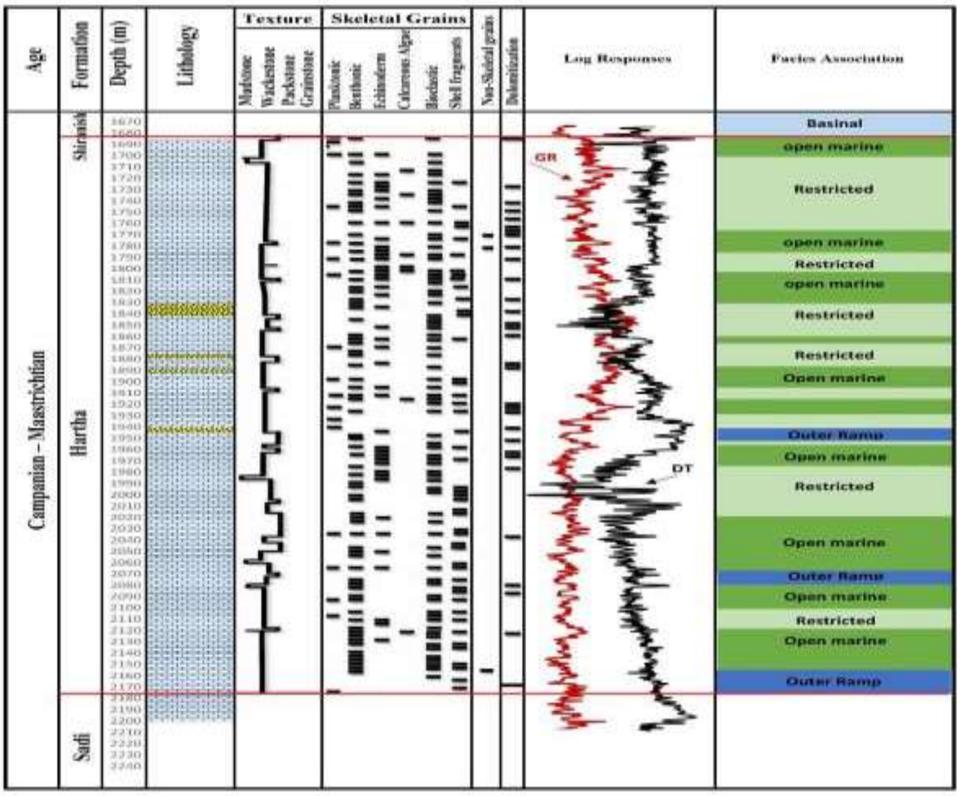


Figure 5: Stratigraphic Column of the Hartha Formation at well Ba-3.

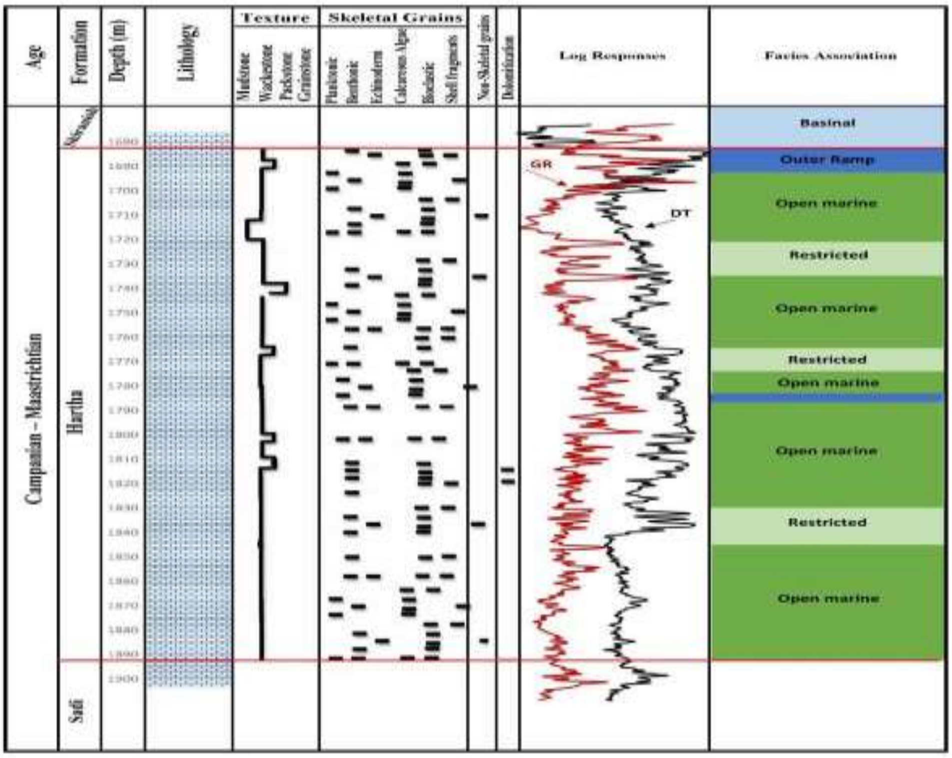


Figure 6: Stratigraphic Column of the Hartha Formation at well EB-53.

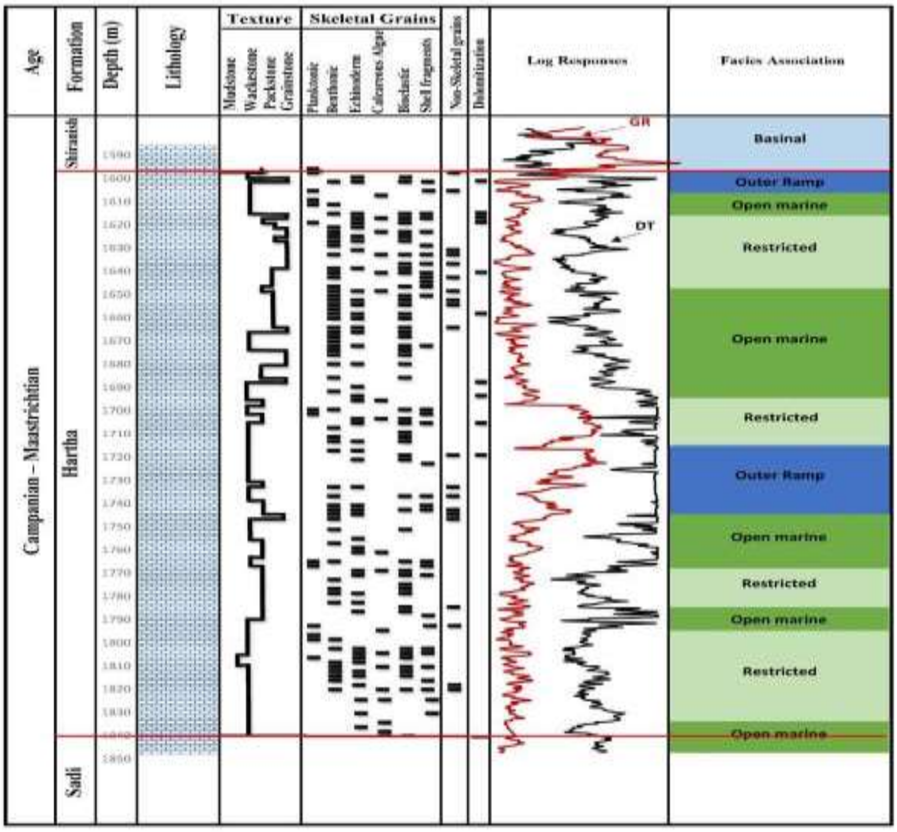


Figure 7: Stratigraphic Column of the Hartha Formation at well EB-56.

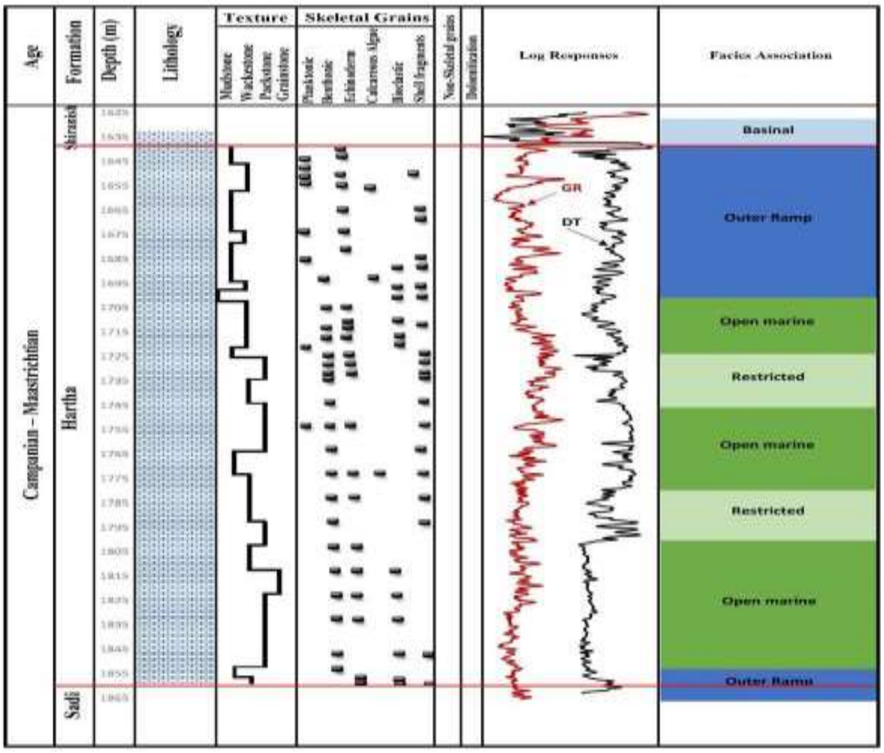


Figure 8: Stratigraphic Column of the Hartha Formation at well EB-102.

Conclusions

The following conclusions are indicated from the relationships of the biota, texture, lithofacies, and vertical facies distribution, as well as the interpretation of the logs (Figure 9).

1- The absence of reef building facies, and widespread open marine deposits, are evidence that the Hartha Formation was deposited on a carbonate ramp.

2- The interpretation of microfacies allows for the recognition of nine facies associations that are assignable to ramp environments.

3- The depositional model and the facies model are presented from the inner to the outer ramp, corresponding with the distribution pattern of biota and foraminifera.

4- The facies model shows a depth gradient from:

(a) Restricted marine inner ramp of low energy depositional environment, partially restricted hypersaline basin characterized by three microfacies association, which are Miliolids wackestone, Bioclastic Peloidal packstone, and Rotaliida wackestone microfecies.

(b) Highly transparent and shallowest part of inner ramp characterized by the association of five microfacies. The paleo-environmental condition is open marine in inner ramp system are characterized by low to high energy richly fossiliferous bed. This carbonate system is represented by larger foraminifera, echinoderm, corals, calcareous algae, and shell fragments.

(c) Outer ramp settings with two microfacies association, which are lime-mudstone and planktonic microfacies. Sediments of the outer ramp system are characterized by low energy, a specific type of foraminifera (planktonic), and little bioclastic debris that may reflect all organisms living below the photic zone.

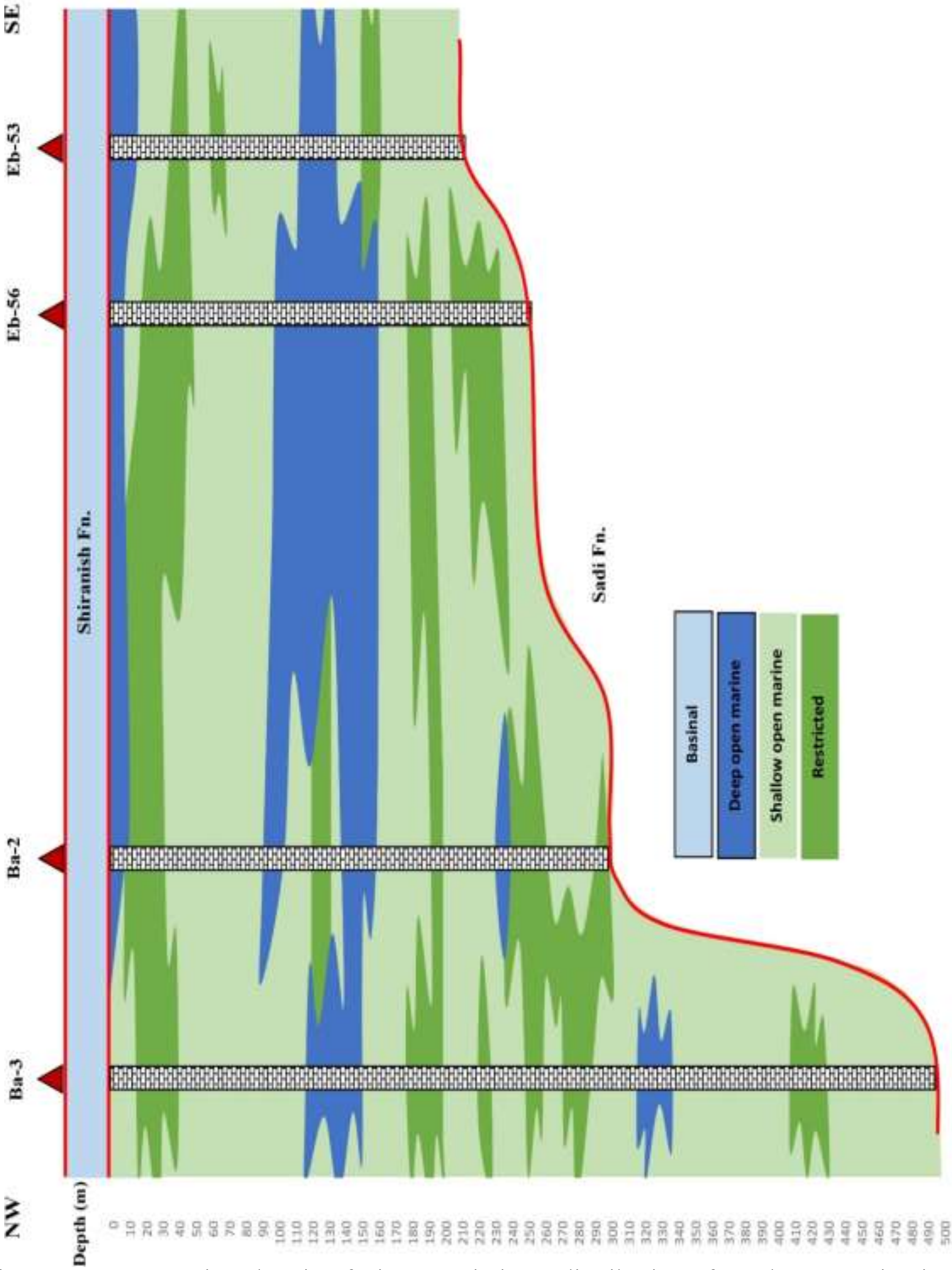


Figure 9: Cross section showing facies associations' distribution of Hartha Formation in Balad and East Baghdad oil fields.

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