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University of Babylon/ College of Science

Department of Applied Geology

The Hartha Reservoir Petrophysical Properties in Ahdab oil Field, Middle Iraq

A Thesis Submitted to the College of Science at the University of Babylon

As Partial Fulfillment of the Requirements for Bachelor Degree in Geology

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وقل رب زدني علما

Dedication

To my beloved family who supported me in each step. Which

They have been my inspiration and motivation for continuing

to improve my knowledge and move my career forward.

To my dear friends who made days pass.

To everyone who helped me with a word, a smile or a simple

Acknowledgments

I am hugely appreciative to Dr. Amer Jassim Al Khafaji , for his encouragement, advice, direction, support, availability and patience during this endeavor. his has been a true source of knowledge and motivation for me over the past months and I will be forever grateful to him.

Ali

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Abstract:

The Hartha Formation (Late Campanian-Maastrichtian) is one of the most important carbonate hydrocarbon reservoirs in Iraq. Previous studies focused on the stratigraphic and lithological characteristics of the Hartha Formation in the central and southern parts of Iraq, while this study focuses on reconstructing its facies architecture and stratigraphic sequences in five oil fields in the northern and northwestern parts of Iraq. Their thickness was recorded for all wells studied, in addition to the presence of benthic foraminifera, rhododendrons, echinoderms, corals, algae, and piloids. The main diagenetic processes affecting formation include dolomitization, cementation, silicification, compaction, and milling. Eleven microfacies were identified, representing four facies associations: outer shelf, fore-reef, shallow-water reef, and restricted platform. And lagoon. These facies associations occur in a predictable order that reflects shallow-upward regressive sequences. Lateral facies contrast demonstrates that fore-reef and shallow-water environments dominate the Hartha succession, suggesting that it conforms to a slope-type carbonate platform deposition model and the

Petrel program was used to evaluate the lithological, petrophysical, and properties Determine the saturation of water and hydrocarbons.

Chapter one

Introduction

1.1 Introduction

The Hartha Formation is one of the most important formations of the late Campanian–Maastrichtian cycle in central and southern Iraq. It has acquired its importance because of the presence of quantities of hydrocarbon, and this is due to its petrophysical characteristics (Dunnington and Morten, 1953). Hartha Formation was defined by (Rabinit in 1952) from well Zubair-3, south of Iraq (Owen and Nasir, 1958), where it is composed of organic detrital, glauconitic limestones, with grey and green shaly interbeds (Jassim and Goff, 2006). The thickness of the Hartha Formation is changing, mainly because the formation is passing both laterally and vertically with the marly limestones of the Shiranish Formation.

The average thickness of the formation in south Iraq ranges between 200–250 m, and in northern Iraq the thickness is up to 350 m (Buday, 1980). The upper contact of the Hartha Formation is conformable with the Shiranish Formation while the lower contact of the formation is unconformable with the Sadi Formation and is often marked by conglomeratic basal beds (Jassim and Goff, 2006). The true distribution of petrophysical properties in reservoir units is a result of different processes such as diagenesis and facies change. It is possible to interpret and capture the extent of these processes within a reservoir but remains how the distribution of petrophysical properties unknown. So, the constructions of geological models that simulate the physically significant features somewhat illustrate how these characteristics are distributed (Pyrcz and Deutsch, 2014).

Constructing reservoir models has become a significant step in resource development as reservoir modeling provides a spot to integrate and compile all available data and geologic concepts. The successful application of these reservoir models is used to calculate reserves of hydrocarbon and to predict their presence in places where there are no drilled wells (Philip Ringrose, 2015).

This study deals with the construction of two-dimensional models for the Hartha Formation in the Ahdab oil field by using Rockworks software (2016). The geological model is built for facies and petrophysical properties (effective porosity and water saturation). Where the petrophysical properties were studied and deduced through Computer Processing Interpretation (CPI) by using Interactive petrophysics (IP) software, while facies association for the formation was taken from microfacies analysis for core and cutting samples.

Many studies were carried out on the Hartha Formation which described the reservoir quality, stratigraphy, and depositional environment, such as (Al- Sadooni, 1996) divided the Hartha Formation into five microfacies in Central Iraq and (Al-Sammarai, 2010) studied the Petrophysical reservoir properties of Hartha Formation in Balad Oil Field, Salah Al-Dain Area, and Central Iraq. Also, (Al-Zaidy et al. 2013) studied the reservoir properties of the Hartha Formation also studied the sequence stratigraphy for the formation in the Ahdab oilfield, and (Al-

Kilaby 2017) studied the sequence stratigraphy and reservoir characterization of the Hartha Formation, southern Iraq.

Previous studies of it have focused on the middle and southern parts of Iraq. The present work is intended to fill in the gap of information about this important formation in the north and northwestern parts of Iraq. (Fig. 1.1)

Fig. 1.1 Location of the studied wells from northern Iraq

1.2Geological Setting

Cretaceous successions occur throughout Iraq except in its western parts (the Ga'ara uplift), due to later tectonic movements in this area (Buday 1980). The effect of these movements is obvious in the late Campanian–Maastrichtian successions (including the Hartha Formation) resulting in transgression covering the area of study with deposition of various lithofacies in different depositional environments in the northern part of Iraq (Chatton and Hart 1961).

The study area lies in the tectonically unstable shelf (the foothill zone) of Iraq (Jassim and Buday 2006). The Hartha Formation represents the upper part of the late Turonian–Danian megasequence (AP9) which includes the Tayarat, Digma, Aqra, Bekhme, Shiranish, Tanjero, and Hadiena formations.

The late Cretaceous lithofacies are divided into three main types; the deep (flysch) facies of the Tanjero Formation, the deep basinal facies of the Shiranish Formation, and the shallow platform facies of the Hartha, Aqra, and Bekhme Formations (Dunnington 1958; Ditmar et al. 1971). The Hartha Formation, as noted earlier, is distributed across most parts of Iraq except the west. It interferes (as a tongue) with the Shiranish Formation in northern and middle Iraq but is absent in the northeast where the Shiranish Formation entirely replaces it. To the west, the Hartha Formation is replaced by the Tayarat Formation (Fig. 1.2).

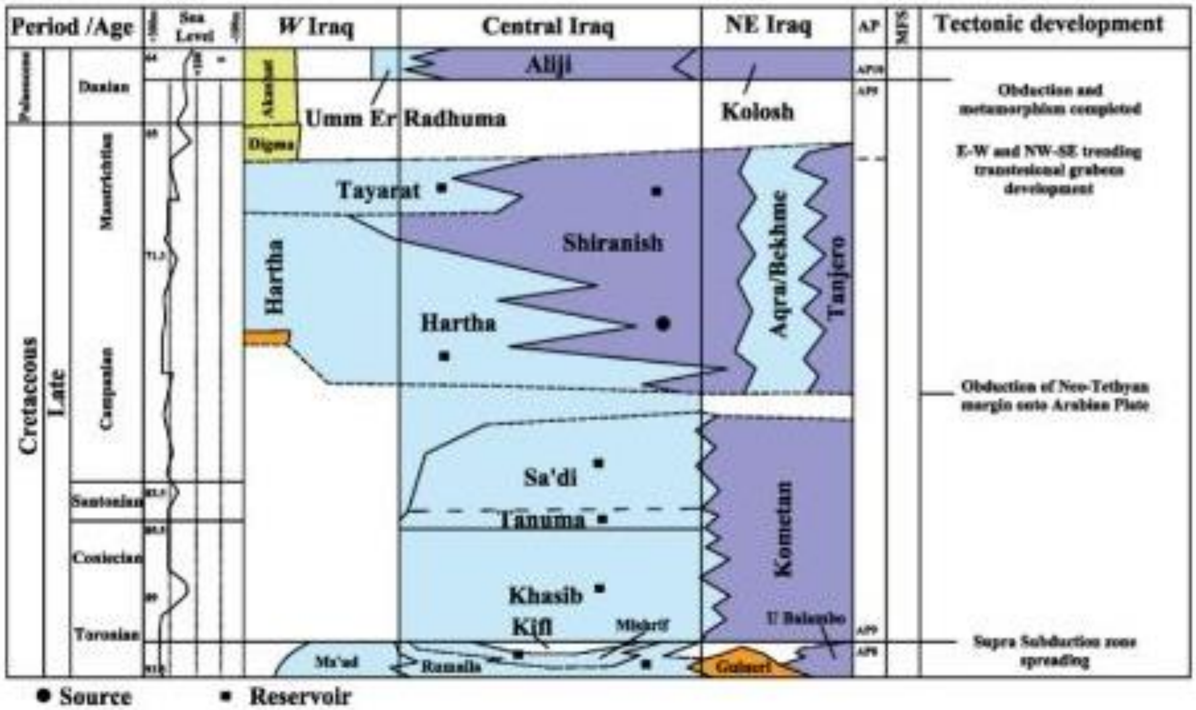

Fig. 1.2; Stratigraphic correlation of the formations in the late early Turonian–Danian Megasequence. Modified after Jassim and Buday (2006)

To the southeast, the Bahrah Formation correlates with the Hartha Formation. The Hartha Formation correlates with the Aruma Formation of Saudi Arabia and with the Tayarat Formation in northwestern Kuwait. The thickness of the Hartha Formation varies greatly among the studied wells. It is 133 meters thick in the Qasab-11 well but only 12 meters thick in the Bai Hasan86 well (Fig. 1.3).

These differences reflect the paleotopography of the depositional basin resulting from the intense tectonic deformation of the area during the late Cretaceous (Jassim and Buday 2006). The Hartha Formation has unconformable contacts with both the underlying and overlying formations. An abrupt change from shallow marine facies of the Hartha Formation upward to the deep marine basinal facies with the Shiranish Formation is evident in the gamma log data (Fig. 1.2) and marked by the predominance of glauconite (Fig. 1.4a) in the latter. There are unconformable contacts between the underlying deep marine Saadi Formation and the shallow marine Hartha Formation (Fig. 1.2). The same nature of contacts is also recorded in central and southern Iraq (Buday 1980).

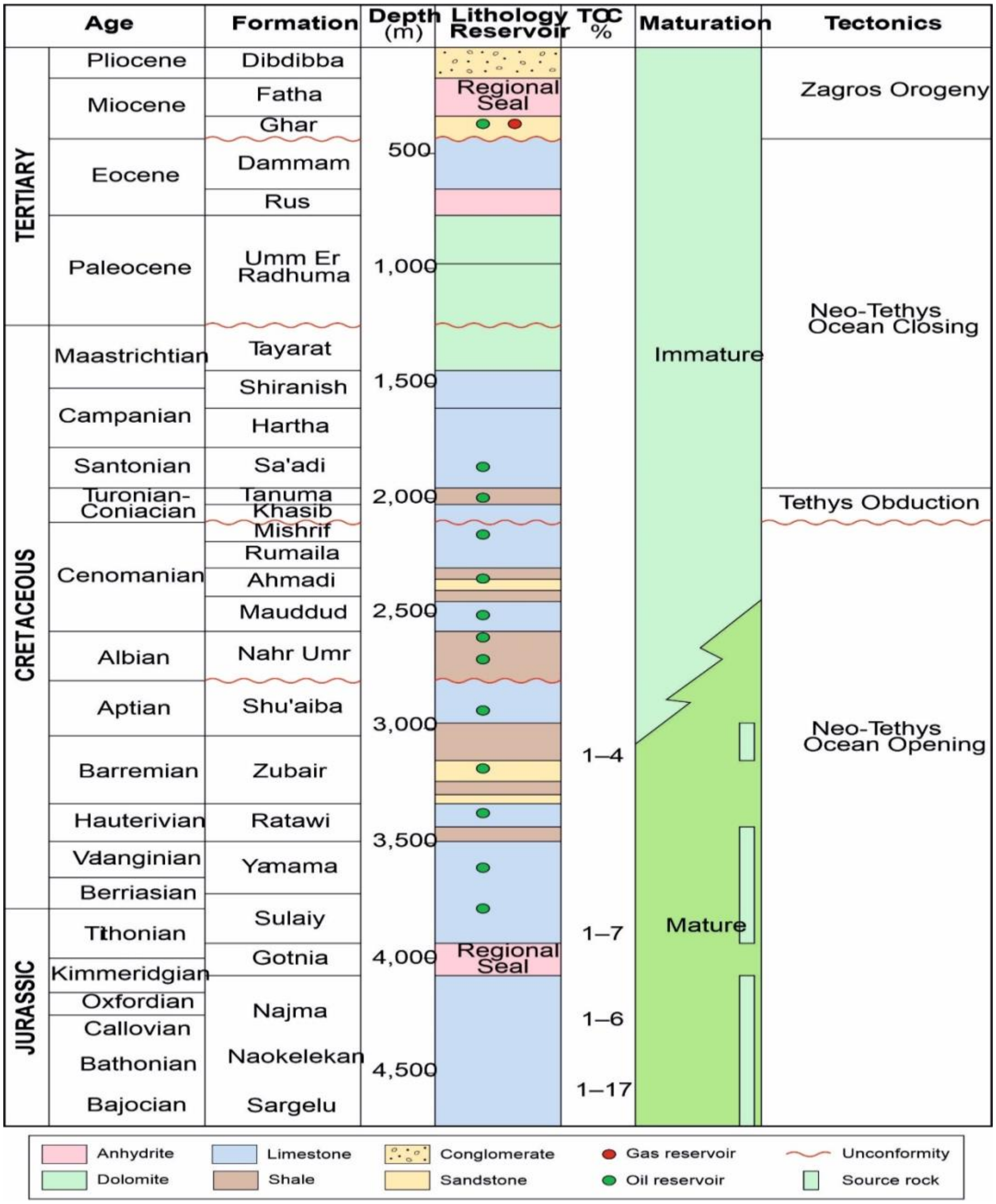

Fig. 1.3; Stratigraphic sections of the studied wells

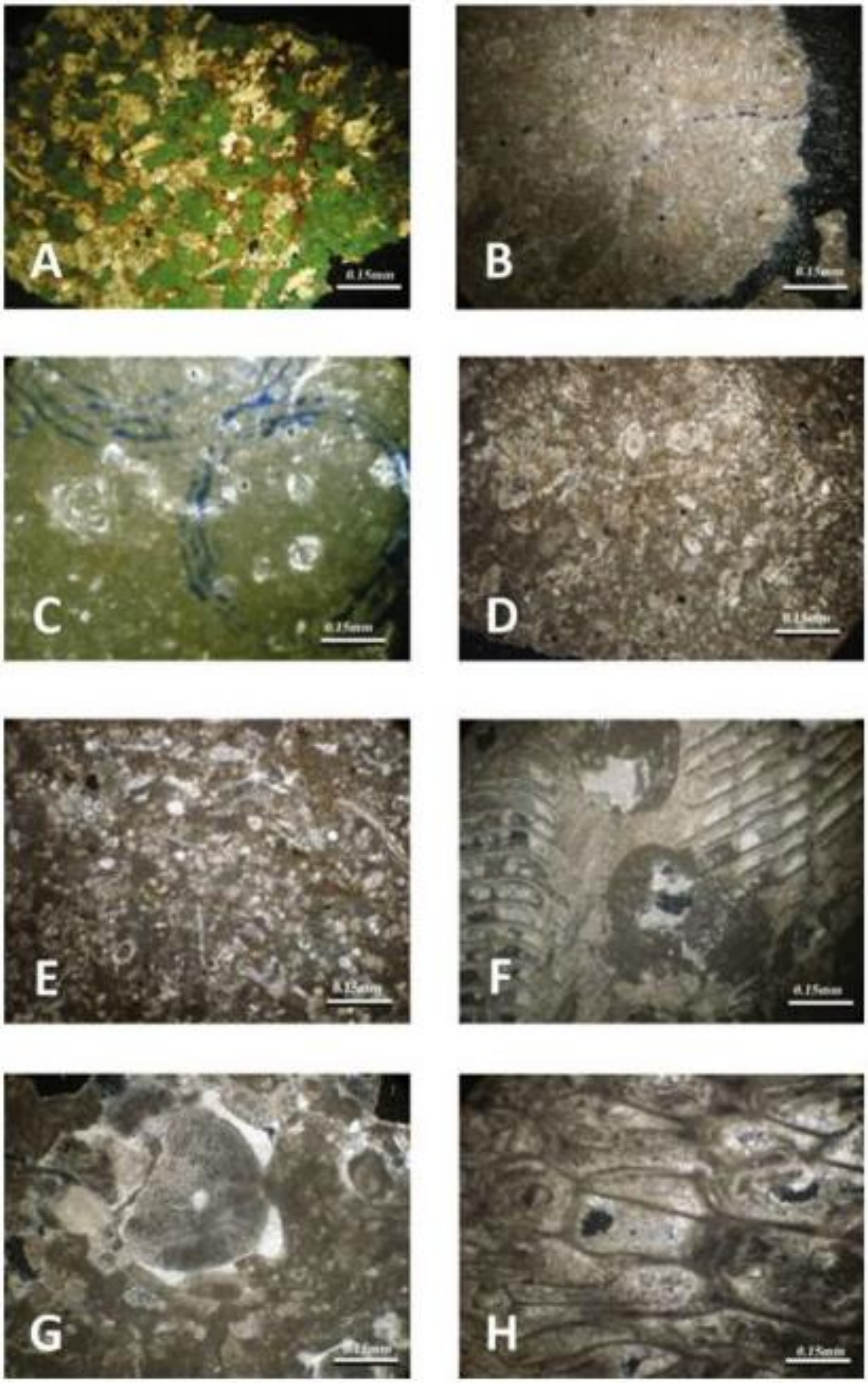
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Fig:1.4 . a; Glauconite concentration in the contact between Hartha and Shiranish formations, Bh-86 (1655–1654 m). b; Monolepidorbis spp benthonic foraminifera in Monolepidorbis—Bioclast wackestone microfacies, Mr-1 (956–979 m). c ;Different species of Miliolid wackestone microfacies and intraparticle porosity, Qs-11 (720–721 m). d; Different species of planktonic foraminifera in planktonic foraminifera wackestone microfacies, Bh-86 (1662–1663 m). e; Calcisphere wackestone microfacies, Ib-1 (1337–1338 m). f; Blocky cement in rudist pores in Bafflestone microfacies, Qs-11 (738 m). g Snytaxial 426 rim cement around echinoderm, Ib-1 (1313–1315 m). h; Coral fragments in bindstone microfacies Qs-11 (749–750 m)

The Hartha formation include includes important carbon deposits that can be produced In central and southern Iraq. It gains its importance due to the presence of quantities of hydrocarbons, due to the petrophysical properties (Dunnington and Morton, hydrocarbon, and this Are due to the petrophysical properties (Dunnington and Morton, (Owen and Nasser, 1958), as the Hartha Formation consists of organic clastic limestones, with gray and green rock layers (Jassim and Joffe, 2006).

The thickness of the Hartha Formation changes, mainly due to the formation passing sideways. And Vertical with marly limestone of the Shiranish Formation. The average thickness of the formation in southern Iraq ranges between 200-250 m, and In northern Iraq its thickness reaches 350 m (Buday,1980). The upper contact of the Hartha Formation Is consistent with the Shiranish Formation while the lower contact of the Formation is not consistent with the Saadi Formation and is often characterized by conglomerate basal layers (Jassim and Joffe, 2006).

The real distribution of petrophysical properties in reservoir units Is the result of various processes such as diagenesis and facies change. It is possible to interpret and capture the extent of these processes within the reservoir, but how petrophysical properties are distributed remains unknown, so geological model constructions that simulate features of physical Interest explain to some extent how these properties are distributed.

According to Aqrawi, et al., 2010, the Hartha Formation is divided into upper and lower Members, in central Iraq, with eight lithofacies based on petrographic and petrophysical characteristics. The Hartha Formation is within the Khleisia High and Stable Shelf and is overlain by the Shiranish Formation.

Al-Zaidy, et al., 2013. The present study aims to describe the diagenesis processes and evaluation of the petrophysical properties that affected the Hartha Formation in selected wells from Balad and East Baghdad oil fields Ismail et al. in 2022 in describing its porosity. A study by Ali Daoud Kyar and others in 2016 on porosity: and water saturation are among the Important parameters used to evaluate reservoir Quality. According to a study by Muhammad Sattam and others In 2022, the Hartha Formation was divided into shipments

Chapter Two

Materials and Methods

2.1Materials and Methods

Collect all information regarding Hartha reservoir formation, its literature review, , definitions of petrophysical properties, and articles which help us to build a create a scientific view of our research, -The analysis of petrophysical properties using result from the available in this research and analyzed this result.

Methodology For correction and interpretation, Interactive Petrophysics software (IP V3.5, 2009) was utilized,and Petrel software. Potential spontaneous recordings (SP), gamma rays, density, sonic, neutrons, and resistivity logs were utilized from four well log records in the form of LAS-files. These selected wells are EB-1, EB-2, EB-4, and EB-30(Figure2. 1b). The environment corrections were performed using the Interactive Petrophysics software's environment correction module. Schlumberger Log Interpretation Charts (2000 Edition) was used, whereas Schlumberger oil field services provided the well log data. When gamma-ray measurements are corrected for mud characteristics i.e., mud kind and weight, and borehole condition, the findings show a considerable rise in gamma-ray readings. Whilst the well had no cavities, as shown by the caliper log, mud properties were the determining factor in this shift. Since induction resistivity showed no change in readings, the raw log data were not impacted by drilling mud in the invention zone. Because of the drilling mud and logging techniques utilized, the readings on the micro resistivity and density logs have changed slightly .Neutron density log shifted significantly between readings, and the corrected readings were increased; the neutron log is influenced by various factors, including drilling mud, formation properties, and lithology contrast. Figure2 .2,2.3 displays log plots with corrections for the well EB-30, Southern the study area

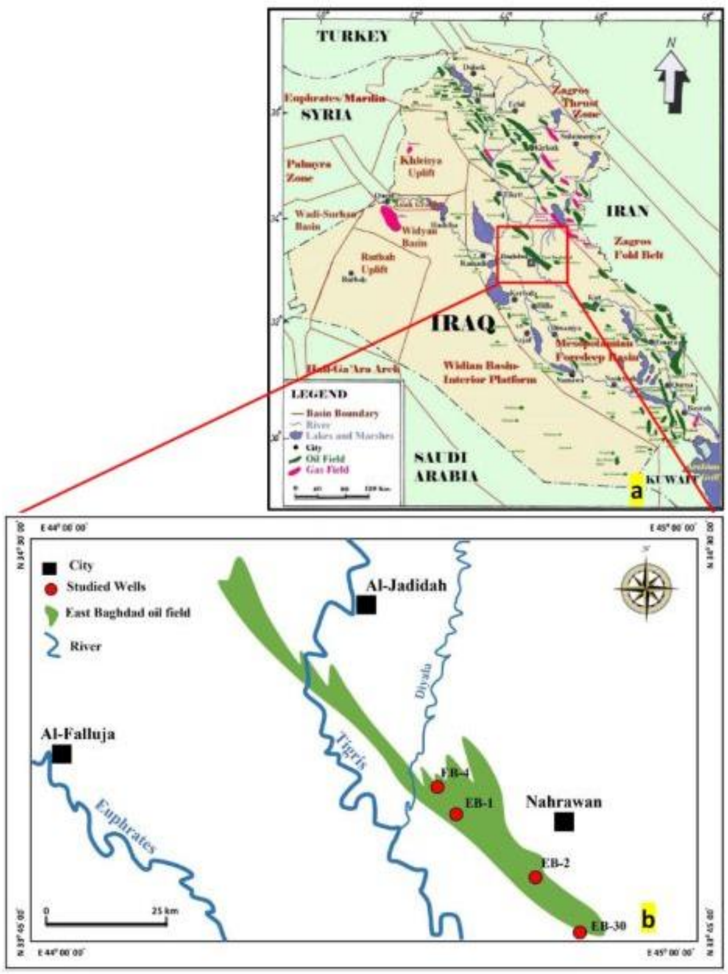

Fig.2.1:a)Map of Iraq showing the location of the East Baghdad oil field highlighted by red rectangle ,b) Locations of four Wells used in the current study within the study areaofEast Baghdad oil

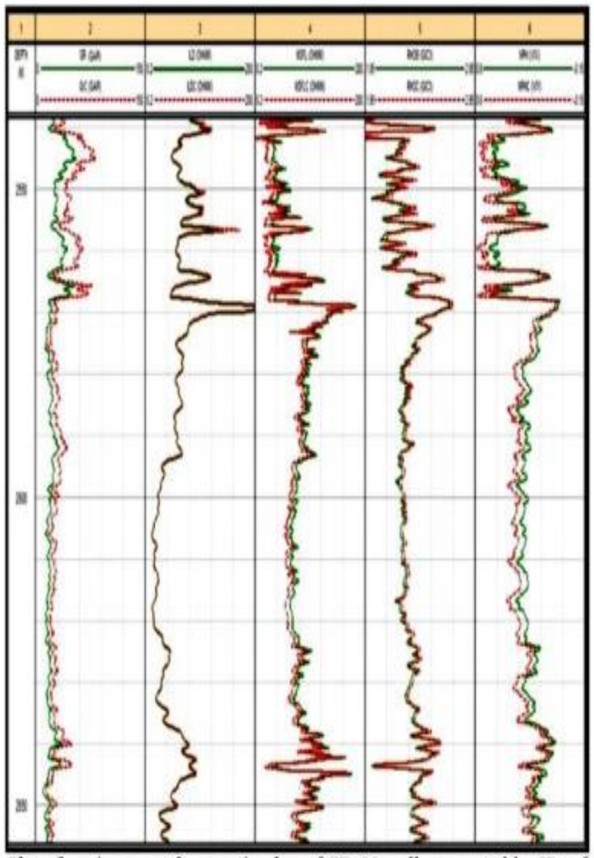

Fig2.2 -Plot of environmental correction log ofEB-30 well,generated by IP software. The solid green lines reflect the well logs reading, while the dotted red lines represent the corrected readings

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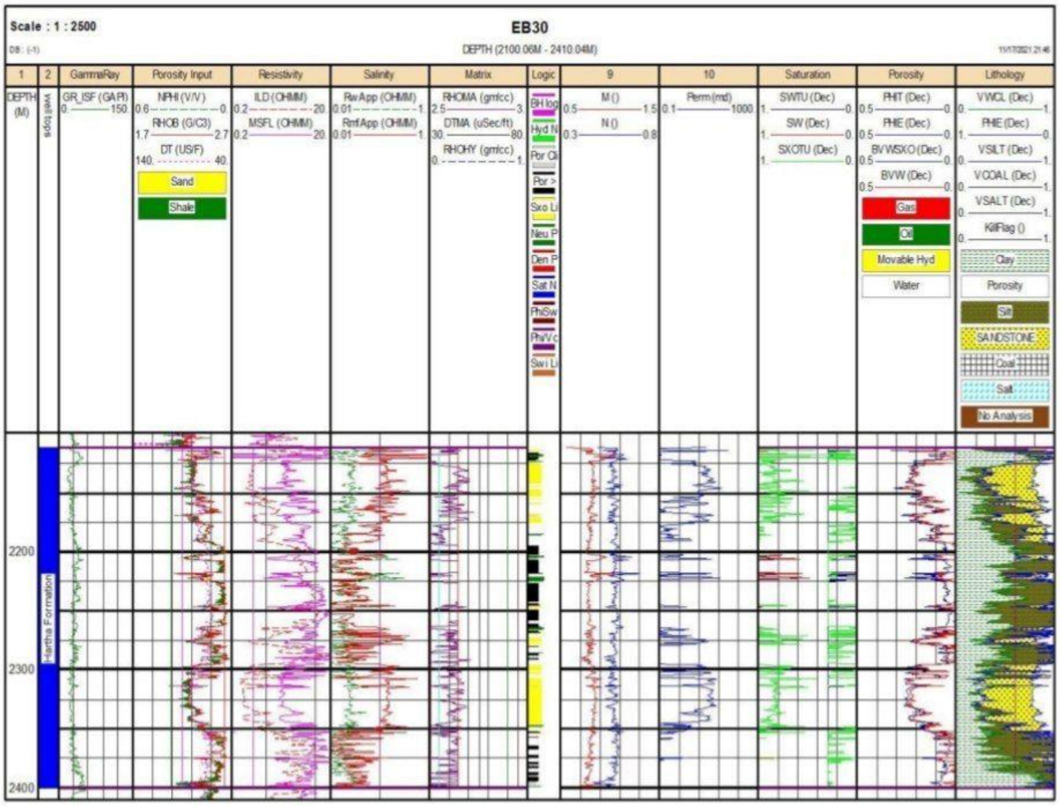

Figure 2.3- The Computer P processing Interpretation (CPI) of the Hartha formation in well EB- 30

Chapter Three

Results

3. Results

3.1. Petrography and Diagenesis

3.1.1. .Petrographic Components

Several petrographic components is recognized in the samples from the Hartha Formation. The main skeletal components include several different kinds of benthonic foraminifera: arenaceous (Monolepedorbis sp., Textularia), rotalids (Rotalia cf. reicheli), and milliolids (Quinqueloculina sp., Spiroloculina). They form the most abundant petrographic constituents in the Hartha Formation, forming up to 40% of the skeletal material (Fig. 4b– c). There are also a few species of planktonic foraminifera (Globogerinids and Globotruncana sp.) represented, along with Calcispheres (Fig. 4d–e). Rudist remains, which occur as broken fragments, form about 20% of the skeletal material. All of these are distributed sporadically throughout the Hartha succession (Fig. 4f).

Some echinoderms were found; they are generally affected by cementation and dolomitization (Fig. 4g). Additionally, corals (Fig. 4h), algae, and few bioclasts also occur, forming up to 20% of the total skeletal components (Fig. 4b, c, f–h). The non-skeletal components are represented by pellets, forming about 20% of the total petrographic constituents. There are also coated grains which represent the transitional stage from skeletal grains to periods as a result of micritization (Fig. 5a). The mineralogical composition of selected samples is indicated in Fig. 3.2.

The main constituents are calcite, quartz, pyrite, and clay minerals represented mainly by kaolinite.

3.1.2. Diagenetic Processes

The rock successions of the Hartha Formation have been affected by several diagenetic processes resulting from variable mineralogical composition and texture. The degree of diagenesis varies from one well to another. Dolomitization is the main and the most important one, affecting the rock succession to various degrees. Some rock constituents suffer partial replacement with fossils appearing as ghosts, whereas others are completely replaced by dolomite.

Four dolomitic textures are recognized, following the Randazzo and Zachos (1984) classification: floating dolomite rhombs, contact dolomite rhombs, sieve mosaic, drusy mosaic, and saddle dolomites. In addition, the inversion of echinoid fragments into dolomite rhombs as single dolomite crystals occur (Fig. 3.1b–g). The variation in dolomite textures indicates that dolomitization took place during both early and late stages.

Early dolomitization is reflected by the presence of floated rhombs and contact rhombs with homogenous texture and similar sizes of the dolomite crystals. Late-stage dolomitization is represented by pervasive dolomitization with various sizes of dolomite crystals and sutured-mosaic and saddle dolomite textures (Bhatt 1976). The inversion of echinoid fragments into dolomite rhombs as euhedral–subhedral crystals with intercrystalline porosity was mentioned by Sibley (1982) as being formed by pseudomorphic replacement of single dolomite crystals because the echinoid fragment is composed of one crystal with a single optical orientation.

The presence of floating, contact rhombs, and dissolved dolomite rhombs may indicate a mixed origin of the dolomite. On the other hand, textures such as saddle dolomite and coarse suture mosaic dolomite associated with stylolites all suggest deep burial dolomitization. Cementation is the second diagenetic process; there are three main types of cement: blocky calcite cement within nudists (Fig. 4.1f), drusy calcite cement within foraminiferal chambers (Fig. 4.1c), and syntaxial calcite overgrowths around echinoid fragment (Fig. 4.1g).

The variation in cement types may reflect different diagenetic environments. Drusy cement formed in the phreatic and vadose zone, while blocky cement formed under vadose zones in meteoric and marine water, whereas syntaxial rim cement indicates deposition in a freshwater phreatic zone (Longman 1980). Other digenetic processes include:

(1) silicification, where silica replaces dolomite and bioclasts (Figs. 3.1h, 3.3a).

(2) compaction, which is manifested by three types of stylolites according to Logan and Semeniak (Flu¨gel 1982). These include irregular anastomosing sets, low amplitude peak stylolites, and hummocky stylolites (Fig. 3.2b).

(3) Formation of evaporitic minerals replacing dolomite (Fig. 3.3c).

(4) Dissolution in the form of various porosity types: moldic (Fig. 3.3d), vuggy (Fig. 3.1b), intercrystallite (Fig. 3.1e, d), interparticle, and fracture (Fig. 3.3e) porosities. In addition, micritization was recorded in two forms, as micritic rims

around skeletal grains (micrite envelope) and as micritized grains to form peloids (Bathurst 1975) (Fig. 3.3f)

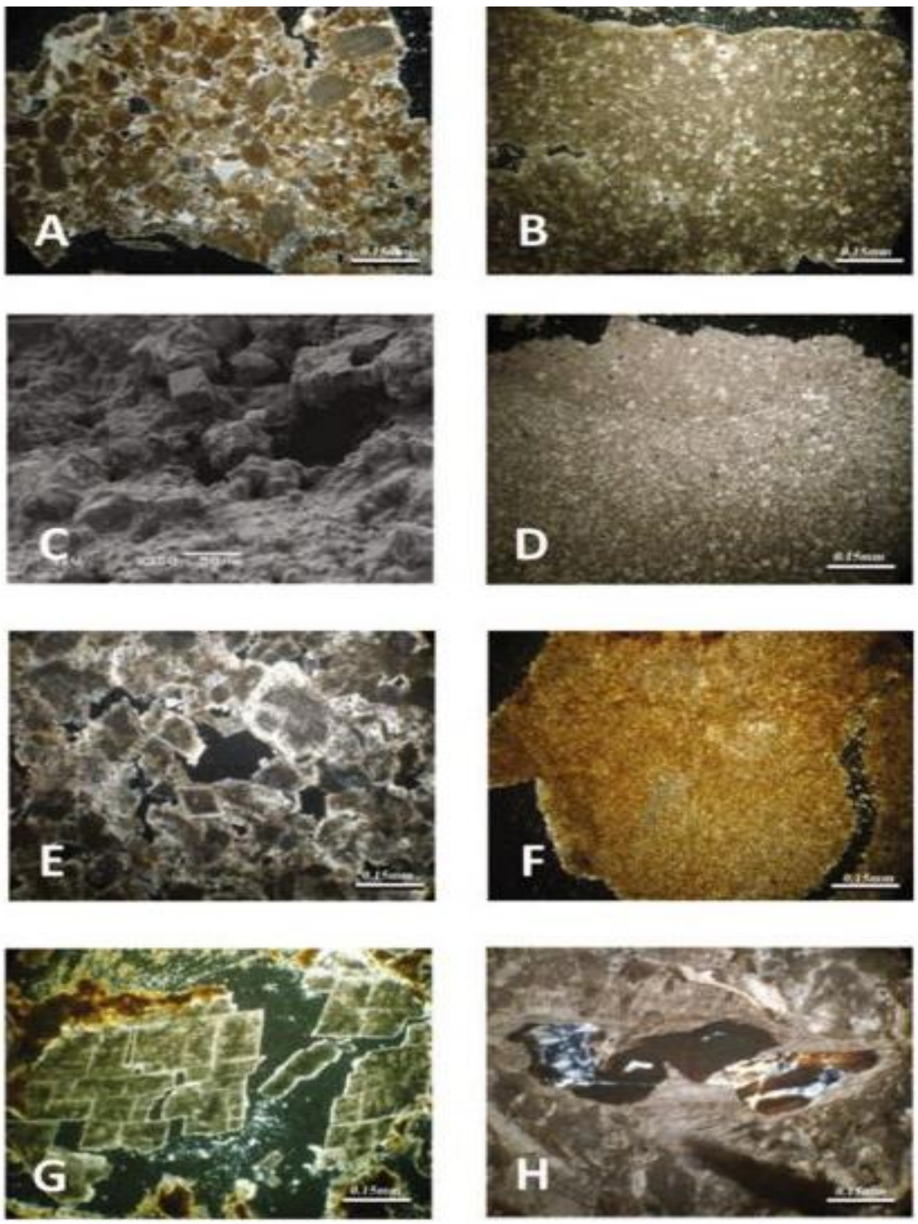

Fig. 3.1: **a** Peloids and coated grains in peloid grainstone microfacies, Mr-1 (1027–1028 m). **b** Floating rhombs fabric in dolomitic limestone and vuggy porosity, Qs-11 (851–852 m). **c** SEM shows dolomite rhomb in dolomitic limestone in sieve mosaic fabric, Qs-11 (772 m). **d** Contact rhombs fabric in dolomitic limestone, Qs-11 (839–840 m). **i**nversion of echinoderms into dolomite with the cloudy center and clear rims of dolomite rhombs in sieve mosaic fabric, Ib-1 (1343–1344 m). **f** Sutured mosaic fabric in dolomite, Qs11 (843–844 m). **g** Saddle dolomite crystals, Qy-56 (726–727 m). **h** Replacement of silica (chalcedony), Ib-1 (1286–1288

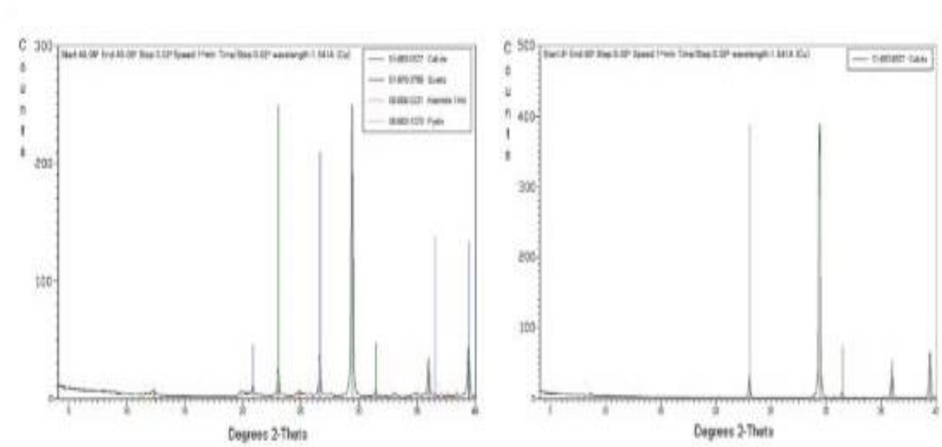

Fig. 3.2 XRD diffractograms for selected samples of the Hartha Formation

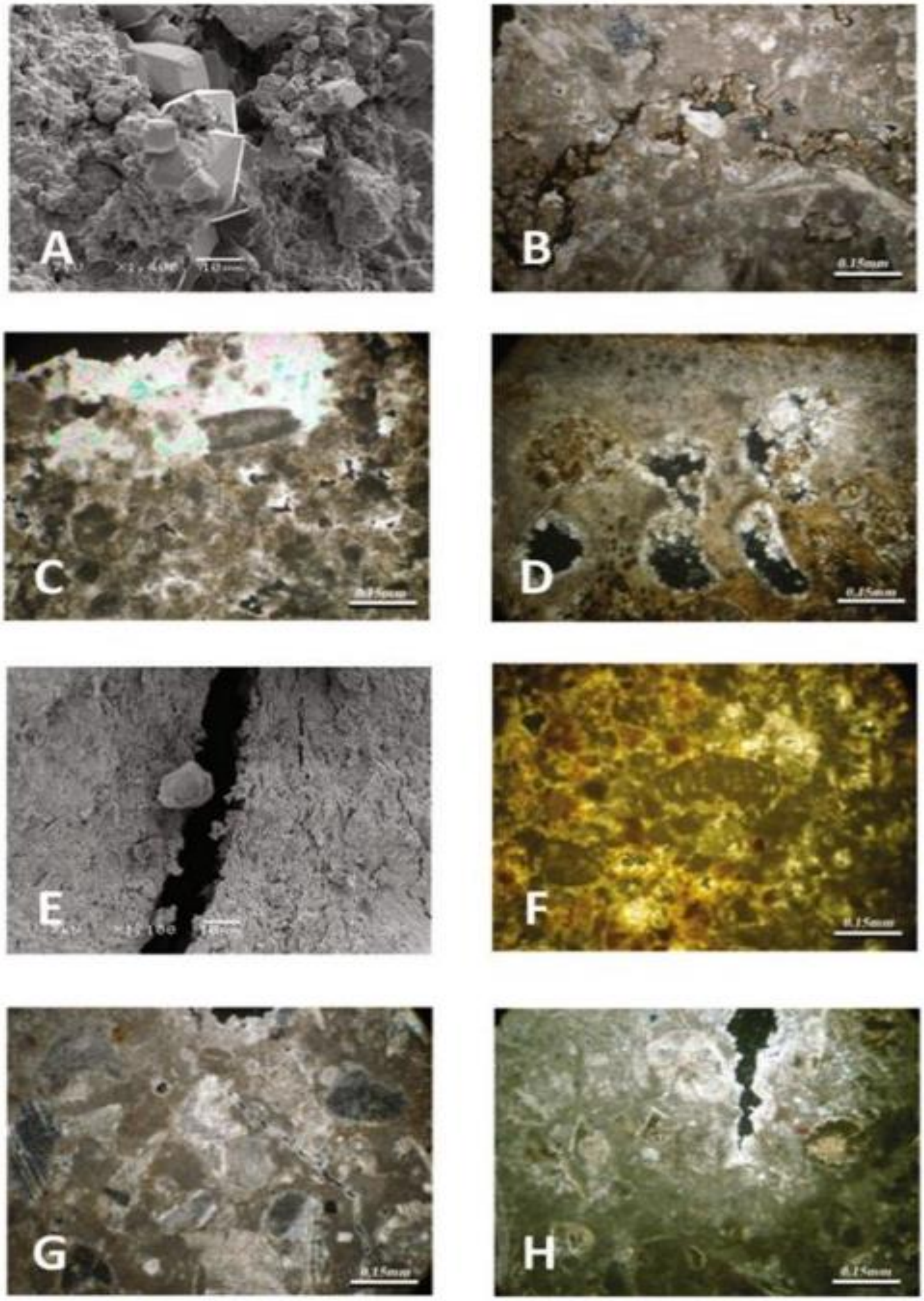
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Fig.3.2. a SEM shows large quartz grains filling pores in carbonate groundmass, Qs11(732 m). b Chemical compaction (stylolite) in bioclaste wackstone–packstone microfacies, Ib-1 (1280–1282 m). c Anhydrite replacing dolomite in sieve mosaic fabric, Ib-1 (1370–1371 m) d Selective dissolution in fossils chamber and dolomite rhomb cement around the pores (moldic porosity). e SEM image showing microfracture with common clay minerals, Qs-11 (775 m). f Peloidal Monolepidorbis packstone microfacies, Qy-56 (739–740 m). g Echinoderm wackestone microfacies, Ib-1 (1300–1302 m). h Monolepidorbis-bioclast wackestone microfacies, B h-86 (1667–1668 m).

Chapter Four

Discussion& Depositional Model

4. Discussion

4.1Microfacies Analysis and Depositional Environments

The vast diverse petrographic constituents of the Hartha Formation have led to the recognition of a wide range of microfacies that have environmental and paleogeographic importance. They reflect the uneven depositional conditions of the Hartha Formation. This instability is common in the depositional environments of the late Cretaceous sediments in northern Iraq resulting from alpine tectonic movements in the region (Ilhan 1967).

4.1.1Eleven microfacies types occur in the deposits of the Artha Formation:

4.1.1Bioclast wackestone– packstone microfacies. Bioclasts (mainly molluskan debris) are the most abundant components of this microfacies in addition

to some benthonic foraminifera in a micritic groundmass. It is commonly affected by several diagenetic processes: dolomitization, recrystallization, and micritization (Fig. 2.3b). They resemble the standard microfacies of Wilson (1975) and Flu¨gel (2004) and indicate a shelf lagoonal environment.

4.1.2.1Milliolid wackestone microfacies. Milliolids (Quinqueloculina sp., Spiroloculina) form the main components, with few gastropods and echinoid fragments in micritic groundmass. Cementation and micritization are the main diagenetic processes (Fig. 1.4c). These microfacies correlate well with those recognized by Okhravi and Amini (1998) and indicate lagoonal environments where porcellaneous foraminifera suggest hypersaline conditions.

4.1.3Planktonic foraminiferal wackestone microfacies. This microfacies is characterized by abundant planktonic foraminifera (Globogerinids and Globotruncana sp) in addition to few calcispheres. It is highly affected by dolomitization, recrystallization, and compaction (Fig. 1.4d). The predominance of planktonic foraminifera may indicate a quiet and deep marine environment. This microfacies corresponds to the standard microfacies 3 of Wilson (1975) and Flu¨gel (2004), which represent an open marine shelf environment.

4.1.3Calcisphere wackestone microfacies. Spherical and ovate calcispheres dominate over other skeletal grains such as planktonic foraminifera in this mirofacies (Fig. 1.4e). This microfacies is generally muddominated and is rare in shallow marine environments. It may indicate shelf margin and slope environments. It is similar to standard microfacies of the facies zone 13 of Wilson (1975) and Flu¨gel (2004).

4.1.4Bafflestone microfacies. This is a common and important microfacies in the Hartha Formation. It consists mainly of rudist bioherms as autochthonous deposits. Rudists form 80 to 90% of the total petrographic constituents with a little infiltrated mud between skeletal grains (Fig. 1.4f). It is affected by calcite cementation in the pores and indicates a reef environment (James 1979).

4.1.5Rudstone microfacies. Rudist fragments [2 mm in size and other biogenic debris (from echinoderms and mollusks) are the main components of this microfacies, in addition to few benthonic foraminifera (Fig..1 4h). This microfacies is grain-supported and is similar to standard microfacies 6 of Flu¨gel (2004), indicating deposition in a fore reef environment.

4.1..6Echinoderm wackestone microfacies. This microfacies consists mainly of echinoid fragments in addition to bioclasts. The echinoid fragments are large to medium-sized calcite crystals altered mainly by cementation in the form of syntaxial rim cement and dolomitization (Fig. 2.3g). Echinoid fragments are the dominant constituents of the carbonate platform deposits (Tucker 1985).

4.1.7Monolepedorbis—bioclast wackestone microfacies. Benthonic foraminifera (Monolepedorbis spp.) form the main constituents of this microfacies in addition to bioclasts, echinoderm fragments and few planktonic foraminifera (Fig. 2.3h). This microfacies has been affected by dolomitization and compaction. Association of the few planktonic foraminifera with orbitods that are commonly present in shallow settings suggests deposition of this microfacies in shoal, fore reef settings (Al-Haj 2011).

4.1.8Monolepedorbis packstone microfacies. This microfacies is characterized by the abundance of benthonic foraminifera (Monolepedorbis spp.) of different size with few bioclasts (Fig. 1.4b). Monolepedorbis was common in fore reef depositional settings Boudagher

(2008), and Flu¨gel (2004) mentioned that benthonicforaminifera may be found in shoal and fore reefsettings.

4.1.9Peloidal—Monolepedorbis packstone microfacies.Pellets are the common constituents of this microfacies, along with some benthic foraminifera (Monolepedorbis) and bioclasts (Fig. 2.3f). Micritization and recrystallization are the main diagenetic processes affecting these microfacies. These microfacies correlate with the standard microfacies of facies zone 7 and represent an open lagoon depositing setting (Wilson 1975; Flu¨gel 2004).

4.1.10Peloidal packstone—grainstone microfacies. Medium- to large-sized pellets are the main constituents of these microfacies. They are commonly generated by the micritization of skeletal grains. The groundmass normally consists of micrite and sometimes calcite(Fig. 2.1a). Al-Haj (2011) mentioned that large-sized pellets indicate shallow, high-energy environments.

These microfacies can be grouped into four major facies associations as follows:

1. Outer Shelf Facies Association (I)

This association is composed mainly of calcisphere wackestone and planktonic foraminiferal wackestone with a low percentage of benthonic foraminifera and bioclasts. Itis mostly confined to the lower parts of the Hartha Formation in the wells Mk-1, Qy-56, Ib-1, and does not occurin Bh-86 and Qs-11 wells (Fig. 3.1). The predominance of planktonic foraminifera and calcispheres reflect deposition in a deep marine environment (Masters and Scott 1978).

2. Fore Reef and Shoal Facies Association (II)

This is the most abundant and widespread facies association of the Hartha Formation. It occurs in the lower and middle parts of the Hartha Formation in all of the wells studied (Fig. 4.1). It includes a wide range of microfacies which are as follows:

(a) Rudestone microfacies. This is the main microfacies and is composed of rudist bioclasts with some echinoderms. It indicates a fore reef setting (Simmons et al. 2000).

(b) Bioclast packstone. This consists of coral and mollusk fragments, in addition to benthonic foraminifera.

(c) Monolepidorbis-bioclast wackestone. Benthonic foraminifera (Monolepidorbis spp) constitute the dominant skeletal components of this MF. These last two microfacies reflect the deposition in the forereef environment (Laviano et al. 1998; Carannante et al. 1999; Pomar et al. 2005).

The other microfacies of this association are relatively rare. They include the peloidal grainstone-packstone microfacies, echinoderm wackestone, peloidal-Monolepidorbis packstone microfacies, and Monolepidorbis packstone microfacies. The benthonic foraminifer Monolepidorbis indicates shallow shoals in a fore setting (Boudagher 2008). The peloidal accumulations also reflect shoaling and shallow waters in a reef setting.

3. Rudist Reef Facies Association (III).

This facies association consists predominantly of thebafflestone microfacies, mainly representing a rudist reefenvironment. It occurs in the upper parts of the

Hartha Formation in three wells, Ib-1, Qs-1, and Bh-86 (Fig. 4.1). Rudists have long been considered the most important constituents of reefs during the late Cretaceous Coogan(1977).

4. Restricted Platform and Lagoon Facies Association(IV).

This association consists of two microfacies: bioclast wackestone and molliolid wackestone. It occurs in the upper part of the formation in the wells Mk-1, Qs-1, and Ib1 (Fig. 4.1). The common occurrence of milliolids, rotalids, and bioclasts indicates deposition in lagoonal and lacustrine settings (Polsak 1981; Antoshkina 1998).

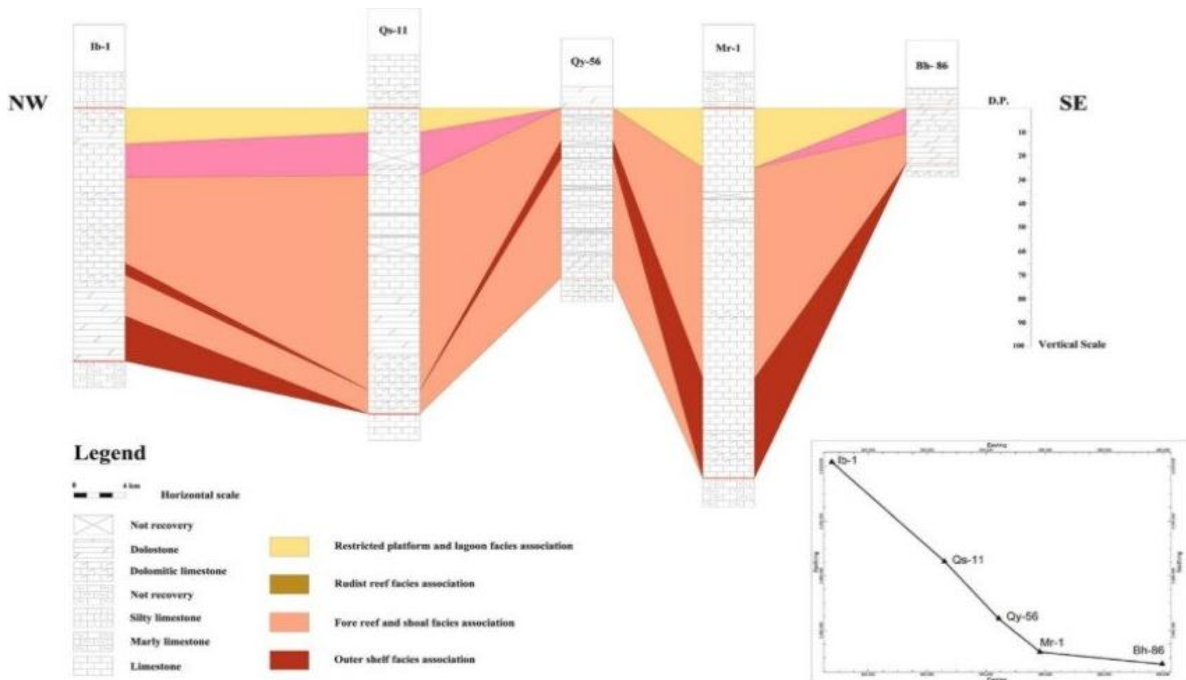

Fig. 4.1 Lateral correlation of the Hartha facies association

4.2Depositional Model

The Hartha sediments accumulated in four main depositional environments: lagoon, rudist reef, fore reef, and shoal into open shelf. The lagoonal environment (Facies Association IV) is characterized by common but low-diversity milioids and abundant bioclasts in wackestone microfacies. This indicates open marine circulation in a shelf lagoon. The rudist reef environment (Facies Association III) was developed in shallow water or in an open lagoon characterized by the predominance of nudists and few corals.

The fore reef environment (Facies Association II) is characterized by common nudists, other mollusks, coral bioclasts, and echinoderm fragments. The nudists of the Hartha Formation developed in areas of moderate- to high-energy conditions as indicated by the presence of angular, unsorted bioclasts with moderate to high fragmentation. The shoal environment is characterized by accumulations of large foraminifera (Monolepidorbis spp.) in wackestone–packstone and peloids in grainstone. Basinward, planktonic foraminifera and calcispheres embedded in a wackestone that may represent quiet water conditions (open shelf Facies Association I).

These four depositional environments of the Hartha Formation in Iraq are very similar to the ramp-type carbonate platform depositional model described by Read(1985). The overall depositional system on the Arabian plate during the Late Cretaceous corresponds to a marine shelf (or ramp) under humid equatorial climatic conditions(Alsharhan and Nairn 1997; Hay 2008; Rahimpour-Bonabet al. 2012).

The gradual vertical stacking of these environments from the deep outer shelf, fore reef, reef, and finally into a lagoon reflects a regressive shallowing-upward sequence ofthe studied wells. The fore reef and shoal environments are common in the northern parts of the study area. The deeper marine environment (outer shelf) is mostly confined to the northeastern oilfields (Qy-Qayara, Mr-Makhmour, and BhBai Hassan), whereas the shallow lagoonal environments are restricted to the northwestern parts of Iraq (Fig. 4.1).

Lateral and vertical variations of these environments rhythmically follow their paleogeographic distribution during late Campanian–Maastrichtian where the Hartha Formation intertongues with the deep basinal Shiranish Formation in northeastern part of Iraq, the Saadi Formation in central and southern part of Iraq, and the shallow AqraFormation and the shallower Tayarat Formation in thenorthwestern and western part of Iraq, respectively(Fig. 4.2)

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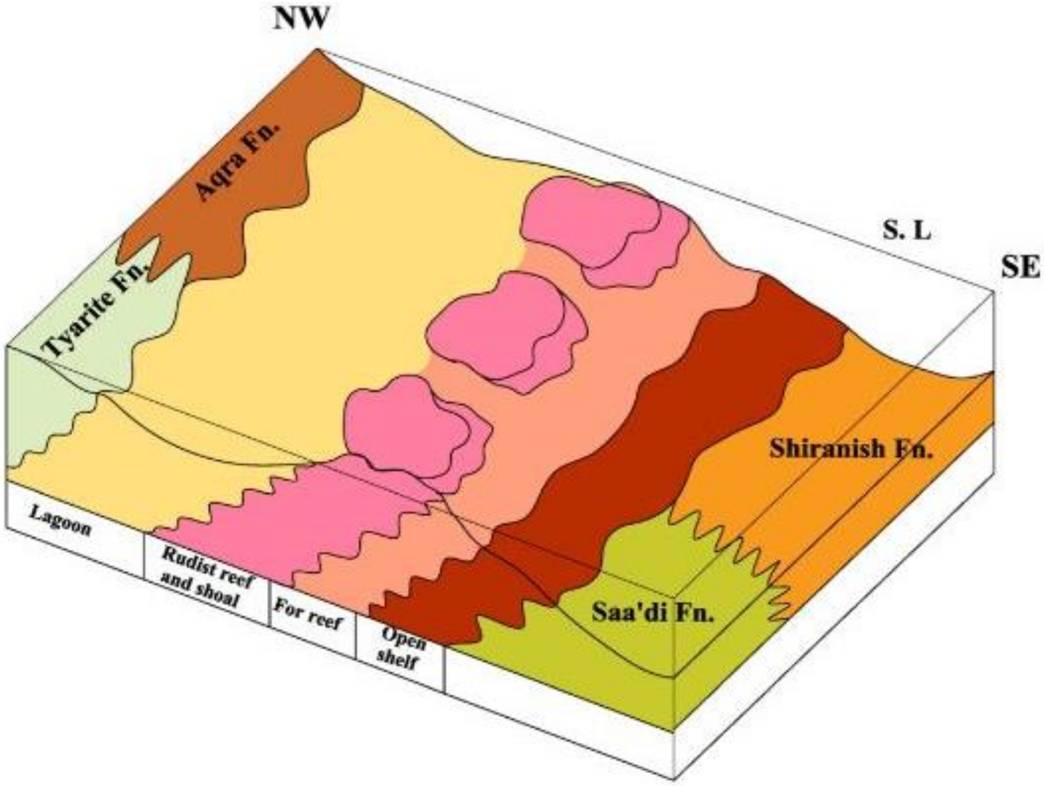

Fig. 4.2 Depositional model of Hartha Formation

Chapter Five

Conclusion& References

5.1Conclusion

The Hartha Formation of late Campanian–Maastrichtian represents the upper part of a late Turonian–Danian megasequence which also includes the Tayarat, Digma, Aqra, Bekhme, Shiranish, Tanjero, and Hadiena formations.

The thickness variations of the Hartha Formation in the studied wells may reflect the topography of the depositional basin as a result of tectonic movements on the area during the late Cretaceous. Eleven microfacies types are recognized in the deposits of the Hartha Formation, organized into four distinct groups of facies assemblages reflecting the unstable depositional settings at the time of deposition.

The outer shelf facies assemblage (I) is comprised mainly of calcisphere wackestone and planktonic foraminiferal wackestone. The fore reef and shoal facies assemblage (II) includes a wide range of microfacies represented mainly by rudestone, bioclast packstone, and Monolepidorbis-bioclast wackestone. It dominates the Hartha succession in the lower and middle parts of the formation in all of the wells studied. The rudist reef facies assemblage (III) consists predominantly of bafflestone microfacies composed mainly of rudist bivalves and occurs in the upper parts of the Hartha Formation in wells Ib-1 and Qs-1 and Bh-86. The restricted platform and lagoon facies assemblage (IV) comprises bioclast wackestone and mullioned wackestone. It occurs in the upper parts of the formation in the wells Mk-1, Qs-1, and Ib-1.

The facies assemblages of the Hartha Formation represent a diverse suite of depositional sedimentary environments that accumulated in four main distinct domains: lagoon, rudist reef, fore reef, shoal, and open shelf environments. These four depositional environments are very similar to those of ramp-type carbonate platform depositional models.

Gradual vertical stacking of these environments from the deep outer shelf, fore reef, reef, and finally into lagoon reflects a regressive shallowing-upward sequence in the wells studied. Lateral variations of these environments show that the deep marine environments (outer shelf) are mostly confined to the northeastern part of the oilfields, whereas the shallow lagoonal environments are restricted to the northwestern part of the oilfields.

Lateral and vertical variations of these environments rhythmically follow the paleogeography during late Campanian–Maastrichtian, where the Hartha Formation inter-tongues with the deep basinal Shiranish Formation in northeastern Iraq, the shallower Tayarat Formation in western Iraq, and the Saadi Formation in southern Iraq

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