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Diagenetic History and Porosity Evaluation of the Albian-Aptian Succession in BaladOil Field, Central of Iraq

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ABSTRACT

Carbonate-clastic succession which includes the Shu'aiba, Nahr Umr and Mauddud formations are representing a part of Barremian-Aptian Sequence (Wasi'a Group). The present study includes three boreholes; Balad-1, Balad-4 and Balad-8within the Balad Oil Field. The most common diagenetic features observed in the studied sections include micritization, cementation, leaching (dissolution), dolomitization and compaction fabrics in carbonate rocks. While the calstic rocks effected by cementation, compaction, dissolution processes. The Albian-Aptian succession in the study area is affected by many types of diagenetic processes during and post deposition. There are three diagenetic zones in this succession; the first within Shuaiba Formation which characterized by high compacted limestone and dolomitization in all studied wells with low porosity values. The second within Nahr Umr Formation is characterized by different diagenetic patterns in the studied area, where appeared in Ba-1 three late diagenetic subzone within sandstone units. These zones are affected by dissolution process to product an affective porous unit, and separated them by cemented and compacted zones. To the south of study area (Ba-4) these subzones became less porosity values and the early and moderate diagenetic stages (cemented and compacted) were common. To the north the clastic succession was characterized by one affective porous unit and dominantly by cemented and compacted zones. The third upper zone within Mauddud succession is characterized by two high effective porous units with dominance of dissolution process in the upper part of Mauddud Formation in Ba-1. While the lower part of this formation is affected by cementation and dolomitization (early and moderate diagenetic stage) with a breakdown for primary and secondary porosities. To the south of study area (Ba-4), the effective porous was become weaker because of dominance the dolomitization effect. In addition to developed a new effective porous zone in the middle part of Mauddud Formation. In the northern part of the region (Ba-8), the dissolution and early dolomitized processes were the dominance effects in this unit. Therefore, the effective porous zones were becoming more prevalent and influential. Accordingly, three effective porous have been distinguished in the upper part of Maudud Formation and three others in the lower part.

KEYWORDS: *Diagenetic history, Porosity evaluation, Albian-Aptian succession, Balad oil field*

INTRODUCTION

Carbonate-clastic succession which includes the Shu'aiba, Nahr Umr and Mauddud formations are representing a part of Barremian-Aptian Sequence (Wasi'a Group). The present study focused on identifying diagenetic effectson the mentioned sequence in the Balad oil field by using three boreholes (Ba-1, 4 and 8), and determinate the important porous zone. The study area is located in the central Iraq within the Mesopotamian Zone according to tectonic subdivisions of Fouad 2014 (Figure 1).

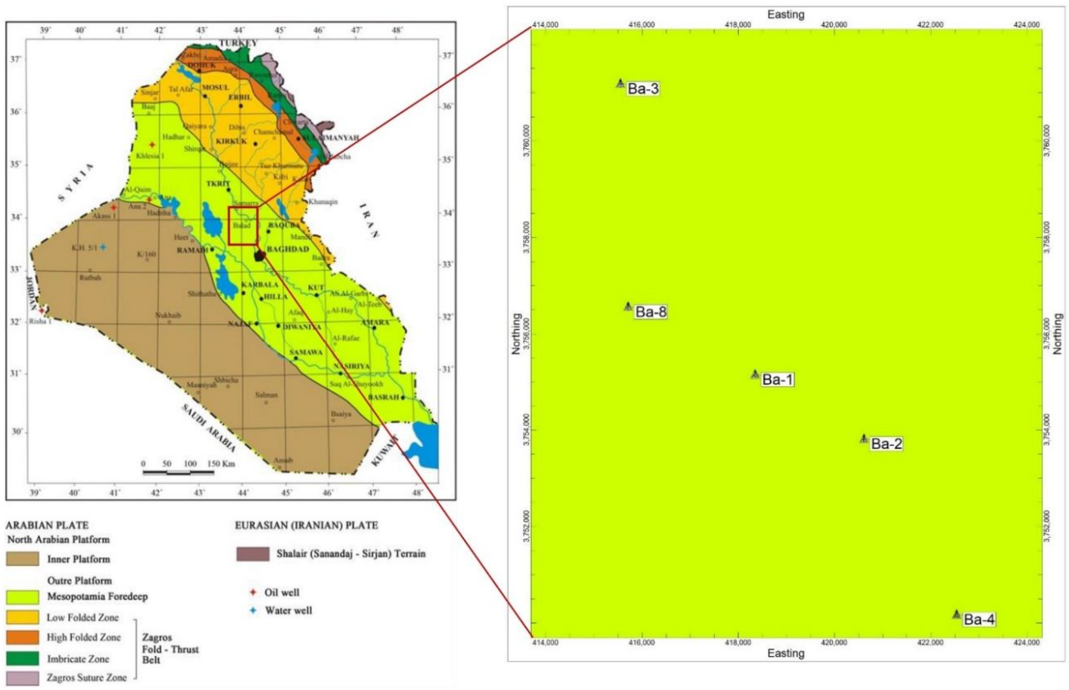

Figure 1: Location map shows distribution of studied boreholes.

The Shu'aiba Formation was first defined by Owen and Nasr (1958 in Bellen *et al*., 1959) from well Zubair-3 in S Iraq. It comprises 62 m of pseudo-oolitic limestone, sometimes sandy, fine-grained organodetrital limestone grading into the chalky limestone and limestone with shale streaks near the top. It contains *Orbitolina cf. discoidea* GRAS, *Choffatelladecipiens* SCHLUMBERGER (at the base only) and globigerinids which (together with the stratigraphic position of the formation) indicate an Aptian age (Bellen *et al*., 1959). The formation overlies and passes laterally into the Zubair Formation with a conformable and gradational contact. The upper contact is associated with a 6 Ma break in Kuwait (Douban and Medhadi, 1999).

The Nahr Umr Formation was defined by Glynn Jones (1948 in Bellen et al., 1959) from the NahrUmr structure in South Iraq. The two major depocenters in Central and Southern Iraq correspond to areas which received clastics from the Rutba Uplift and the Arabian Shield. In its type area in Southern Iraq, the NahrUmr Formation comprises black shale bedded with medium to fine grained sandstones with lignite, amber, and pyrite. The proportion of sand in the formation increases towards the Salman Zone (Jassim and Buday, 2006). Nahr Umr Formation was divided in to three main rock units by Al-Garbawi and Al-Shahwan (2019), these are upper Nahr Umr unit (NRA), middle Nahr-

Umr unit (NRB) and lower Nahr-Umr unit (NRB).

The Mauddud Formation includes the Upper part of Qamchuqa Formation and is the most widespread Lower Cretaceous formation in Iraq. Its thickness varies due to lateral facies changes and erosional truncation. At outcrop in NE Iraq, the Qamchuqa Formation comprises organodetrital, detrital and locally argillaceous limestones with variable degrees of dolomitization. In some areas fresh- or brackish-water limestone beds were reported (Bellen *et al*., 1959). In Southern Iraq, the Mauddud Formation comprises frequently dolomitized organodetrital limestone (Buday, 1980).

MATERIAL AND METHODS

The current study was completed in three stages:

1. Sampling and description stage; this stage is represented by going to the North Oil Company (NOC) where the samples are collected.
2. Laboratory stage; during this stage the samples were chosen and made thin sections. The petrographic study and diagenetic features tetermination are based on the study of thin sections of cuttings and core from the selected boreholes from Balad Oil Field.
3. In this stage, study and process the available well logs were utilized in calculated the volume of shale and porosity. The following equations and steps were used in calculating the volume of shale, total porosity and effective porosity (Figure 2).

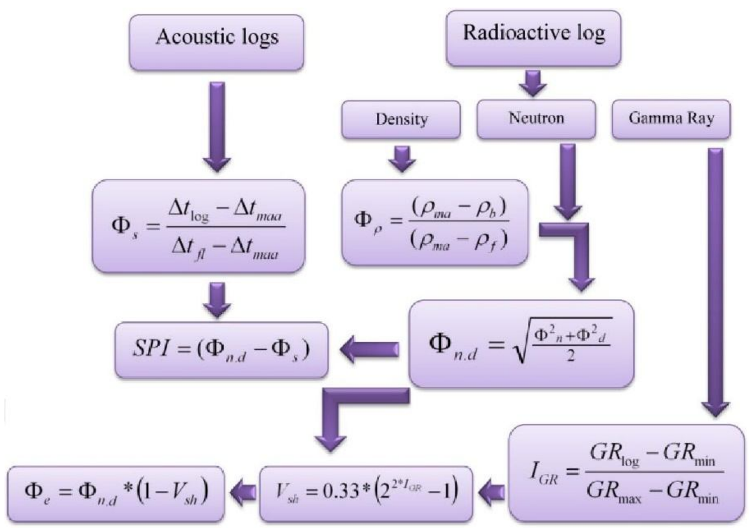

Figure 2: Diagram showing steps and equations which used in the present study (Al-Zaidy et al., 2013).

Diagenetic Features

Diagenesis includes any physical or chemical changes in sediments or sedimentary rocks that occur after deposition (Scholle-Ulmer, 2003). Digenesis provides information about the history post-depositional settings, Pore water composition, and temperature (Flugel, 2010). Diagenesis begins at the depositional site, from the time of their initial deposition and continues during burial and uplift. When carbonates are brought into contact with waters of varying chemical composition or with burial, they are extremely susceptible to mineralogical and textural changes, cementation and dissolution. These alterations can occur at any time from initial deposition to deep burial. Most diagenetic changes affect porosity and thus must be considered in the exploration for carbonate (Bathurst, 1975 & Longman, 1980).

The three major digenetic environments in which carbonate porosity are formed or modified are meteoric, marine, and subsurface (Figure3). The understanding of these processes and their products is important, because diagenetic criteria account for many of the physical properties of carbonate rocks and determines their value as reservoir rocks (Flugel, 2004). In carbonate rocks, diagenesis has a far greater effect on ultimate reservoir quality because of the greater potential for chemical reactions during burial (Roger, 2006).

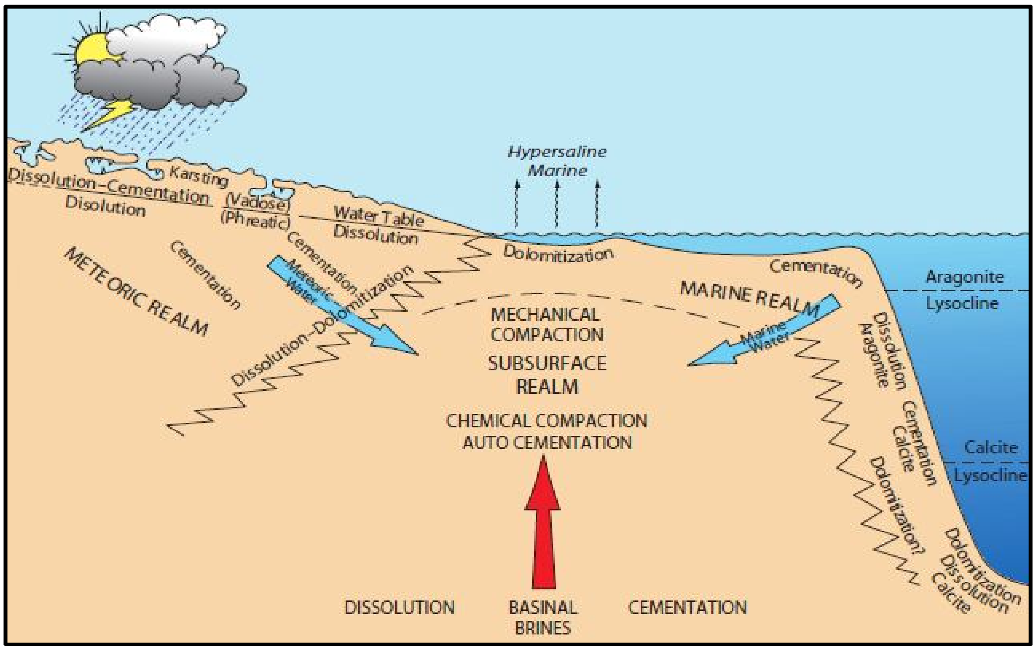

Figure 3: Schematic diagram illustrate the three major environments within which diagenetic porosity modification and evolution occur. After (Moore, 2004).

The most common diagenetic features observed in the studied sections include micritization, cementation, leaching (dissolution), dolomitization and compaction fabrics in carbonate rocks. While the calstic rocks effected by cementation, compaction, dissolution processes.

Nahr Umr Formation (digenetic processes)

The effects of diagenesis on sandstone reservoirs include the destruction of porosity by compaction and cementation, and enhancement of porosity by solution for that it is control regional variations of reservoir quality the main processes include: -

Cementation

Cement is a chemical precipitate from solution; it grows in pores, and requires super saturation of the pore fluid with respect to the cement mineral (Flugel, 2010). Several types of cement were recognized in Nahr Umr Formation.

1-Silica cement

- ***Quartz overgrowths***

Quartz overgrowths developed by the precipitation of silica directly from aqueous solution well-ordered, low (alpha) quartz. The most common form of quartz cement is an overgrowth a syntaxial rim with the same crystal ographic orientation and optical continuity as that of the detrital grain. Overgrowths are one variety of (Folk, 1965) sedimentary (low-temperature) quartz. This type of cement is abundant in the sandstones of Nahrumr Formation in the studied sections (Plate1. A).

- ***Micro-crystals quartz cement***

Other polymorphs of silica that occur as cements in sandstones are fibrous microcrystalline quartz. Almost all occurrences of these polymorphs are in silcretes, indurated products of surface silica diagenesis (Summerfield, 1983) (Plate1.B).

2-Clay cement

The Percentage of this cement is less than 1% (Plate 1.C). The source of this cement is partly from dissolution to rock fragment and feldspar. This cement has an important effect on Porosity (Burley, 1984).

Dissolution

Rock fragments and low stability silicate minerals dissolved because of increasing burial temperatures. There are two type of dissolution; the first is the pressure solution (see compaction) and the second is the dissolution which leads to increase in secondary porosity (Boggs, 2009) (Plate1. D).

Plate 1

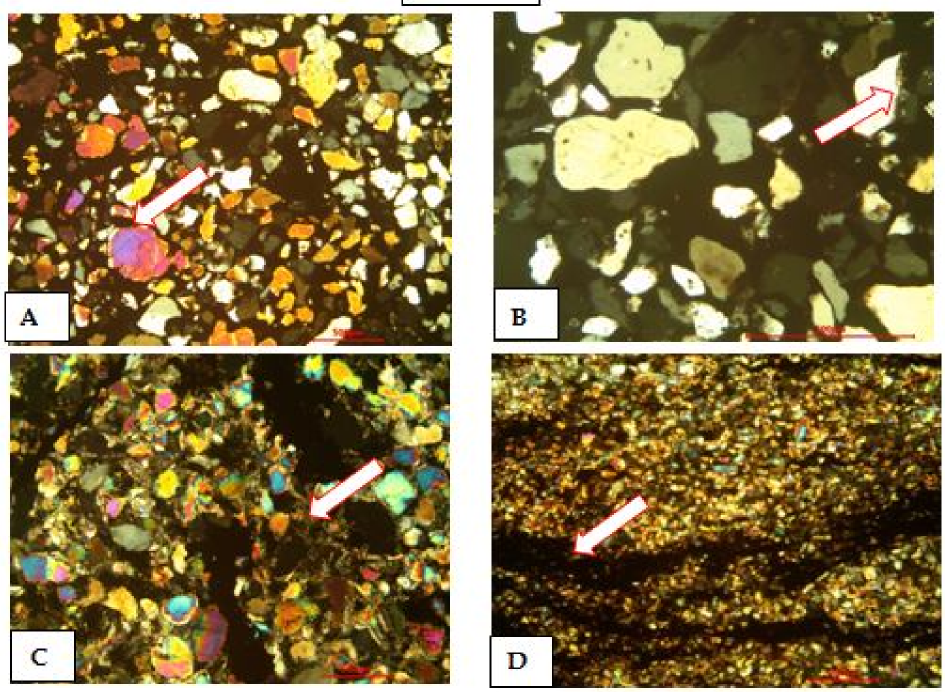

Plate 1:
A-Quratz overgrowth in Nahr Umr Formation in Ba-4 depth (3064m)
B- Micro Crystalline Quartz cement in Nahr Umr Formation in Ba-4 depth (3064m)
C- Clay cementin Zubair Formation in Ba-1 depth (3168m)
D- Dissolution in Nah rUmr Formation in Ba-1depth ((3160m)

Maudud and Shuaiba formations (diagenetic processes)

These formations were affected by several genetic processes such as the Nahr Umr Formation that affected porosity, as explained below: -

Micritization

The main volume of any limestone is usually composed of carbonate mudor micrite. Because of the small size of the grains or crystals in the micrite, identification of their origin is difficult to impossible. The grain size boundary between sand and mud that is used by geologists for carbonates varies: for instance, Dunham (1962) puts it at 0.02 mm and Folk (1962) 0.004 mm. The micritization is represented by micrite envelope surrounding the skeletal whole organisms or the skeletal bioclast especially in wacke stone and packstone texture (Ginsburg, 1957). This type of daigenesis processes is common in most study carbonate rocks (Plate2.A).

Plate 2

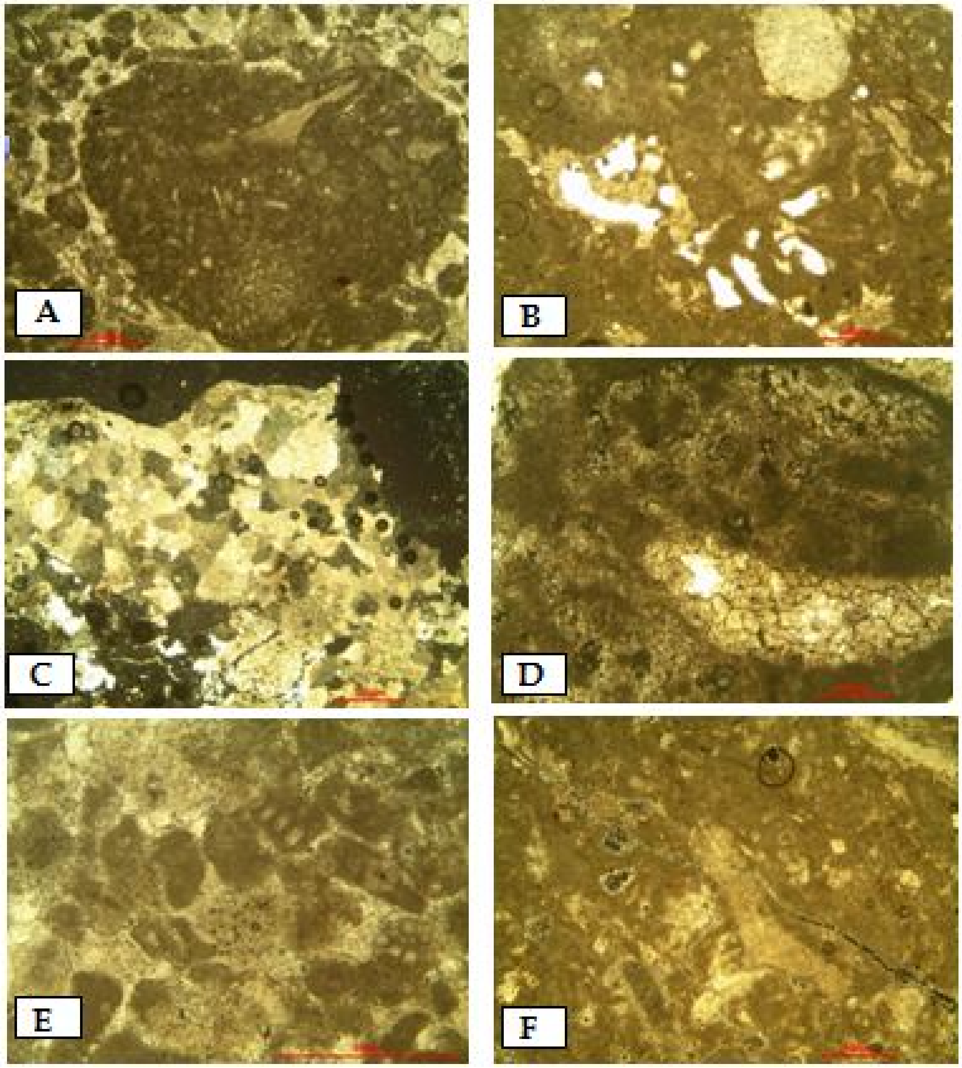

Plate 2:

- **A. Micritization of *Orbitiolina* skeletal fragments**
- **B. Dissolution in shale unit of Maudud Formation in Ba-1depth (2900)m**
- **C. Blocky cement Ba-1(3297b)**
- **D. Drusy mosaics cement Ba-1(3283e)**
- **E. Granular cement Ba-1 (2900)**
- **F. Syntaxial rim cement Ba-1 (2905)**

Dissolution

Dissolution maybe occurs in any point in the burial history of the carbonate sequence after mineral stabilization (Moore, 1989). The dissolution is an important process which is shown in most shells of fossils. It is the result of solution conditions of unstable minerals (aragonite or high – mg calcite) and the chemistry of the pore water. Carbonate solubility increases with decreasing temperate and increasing acidity (decreasing PH) (Nichols, 2009). This process is very important affecting the porosity and reservoir quality, it is related to meteoric water (fresh water under saturated in calcite and high pressure of CO_2) (Longman, 1980) (Plate 2.B).

Cementation

Cementation is the precipitation and growth of new carbonate crystals in thevoid space, thus leading to lithification (Einsele, 2000). The important cement types in the studied formations include: Granular cement, Blocky cement, Drusy cement, Syntaxial rim cement.

- ***Blocky cement***
  This type of cement can be formed from medium to coarse – grained crystals without preferred orientation this cement type represent a late stage of diagenetic history, and represents freshwater phreatic zone (Longman, 1980) (Plate 2.C).
- ***Drusy mosaics cement***
  Drusy mosaic calcite cement is represented by anhedral crystals filling vugs and moldic pores in different sizes and represented by crystals showing an increase in sizes toward the center of the pores (Plate 2.D). Drusy mosaic cement was observed mainly in wackestones and packestones. It forms as late diagenetic process indicating meteoric phreatic zone (Longman, 1980).
- ***Granular cement***
  The Granular cement is represented by anhedral or subhedral calcite crystals 10-60 mm in size and usually with a preferred orientation of crystals, (Longman, 1980) formed in meteoric-vadose, meteoric-phreatic and burial environments (Flugel, 2004) (Plate 2.E).
- ***Syntaxial rim cement***
  Optical continuity with skeletal (low Mg calcite skeletal grains such as echinoderm) fabric and the origin of Syntaxial fabric cement is meteoric vadose zone cementation (Longman, 1980; Kaufman *et al*. 1988), However, overgrowth cements on echinoderms are common in Mauddudcarbonate, and overgrowth of quartz in of Nahr Umr Formation. This type of cementation is identified in most part of the succession (Plate 2.F).

Compaction

Compaction is both physical and chemical process resulting from theincreased overburden pressure due to burial. Textural effects include the loss ofporosity, reduction of pore-size, grain penetration, grain deformation, grainbreaking and fracturing (Lucia, 2007).

Compaction fabrics are related to burial diagenesis when the carbonate rock is buried under a thick sediment overburden, and it is one of the principal diagenetic mechanisms for porosity destruction. The force of compaction varies from being weak, moderate or strong depending on the depth of burial; shallow or deep. This results in different compaction fabrics.

The compaction includes mechanical and chemical compaction, where: -

- The mechanical compaction causes rearrangement of the grain packing, fracturing or deformation of carbonate grains and reduction of the porosity. It is particularly important in mud-dominated sediments as pelagic oozes, chalk and shelf lime mud such as Shattered micrite (Scholle, 1977) (Plate 3.A).
- The chemical compaction (Pressure Solution) is the dissolution of carbonate rocks along planes as a result of the compaction (pressure) of overburden or tectonism such as stylolite. During deep burial, pressure-solution is more sustained than at shallow depths and is important in reducing both porosity and permeability. (Moore, 1989)(Plate 3.B).

Plate 3

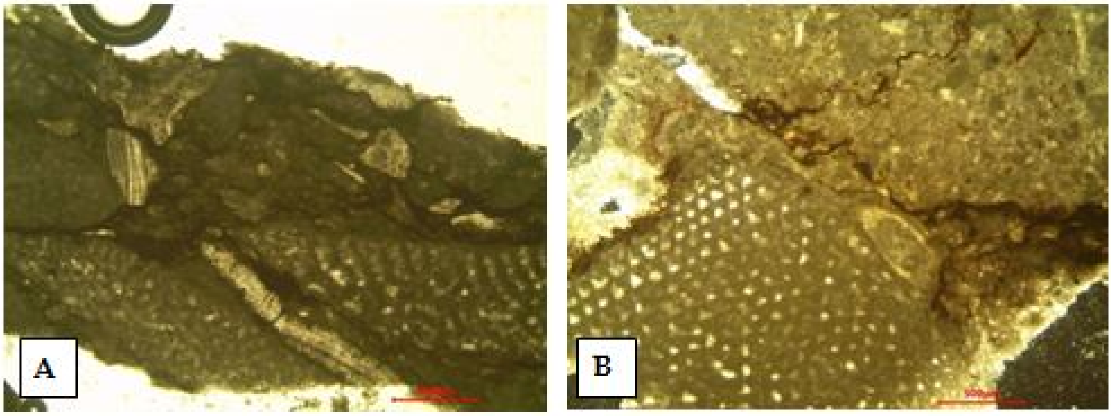

Plate 3:

A. **Physical compaction, Ba-8(3172).**
B. **Chemical compaction (Stylolite), Ba-4(2978).**

Dolomitizaition

Dolomitization is a process whereby limestone or its precursor sediments completely or partly converted to dolomite by the replacement of original $CaCO_3$ by magnesium carbonate, through the action of Mg bearing water. Porosity tends to increase slightly in the initial stages of dolomitization of limestone, but increase abruptly with higher amounts of dolomite. At this stage, the dolomite is characterized a sucrosic texture, composed of equally- sized rhombohedra with intercrystalline porosity originating by dissolution of associate calcite (Flugel, 2004).

According to Moore (1989) we can describe three general dolomite types in studied sections:-

- Scattered, coarse, euhedral dolomite rhombs with strong, often light crystal zone, generally associated with stylolites and pressure solution (Plate 4.A, B).
- Pervasive coarsely zoned crystalline dolomite (cloudy center clear rim) that may exhibit fabric selectivity and well-developed porosity, or may form dense interlocking mosaics and floating dolomite crystal (Plate 4.C, D).
- Saddle dolomite, which is common, as mentioned above, and generally occurs as very late pore-fill cement and characterized by cloudy coarse crystals (Plate 4.E, F).

The scattered late burial dolomites associated with pressure solution generally have little effect on reservoir porosity. However, pervasive subsurface dolomites can be economically important in certain situations, and both types are represented by the mixing zone dolomite. If the dolomitization event only partially dolomitizes a sequence, and the remaining $CaCO_3$ is not removed by dissolution, the tendency is for no enhancement of porosity (Murray, 1960; Anderson, 1985). If a muddy sequence is totally dolomitized in a non-fabric-selective manner, an interlocking dolomite mosaic may form, with actual porosity destruction (Mattes and Mountjoy, 1980). Pervasive burial dolomitization of porous grainstones, or other porous facies, however, will generally lead to porosity enhancement, and porosity preservation under deep burial conditions. Fabric selective dolomitization, accompanied with $CaCO_3$, dissolution, can also lead to the formation of exceptionally favorable reservoir characteristics (Anderson, 1985). The cloudy cores have been interpreted to reflect mixing zone conditions in which metastable, inclusion-rich dolomite formed.

The Saddle dolomite occurs in moldic and vuggy pores, less commonly as a massive replacement of carbonates, and often in sulfate bearing carbonate host rocks associated with hydrocarbons and epigenetic sulfides (Flugel, 2004). Saddle dolomite is commonly interpreted as having formed under deep burial or hydrothermal conditions from high-saline brines and under high temperatures, or as a by-product of thermochemical sulfate reduction (Scholle, 2003).

Plate 4

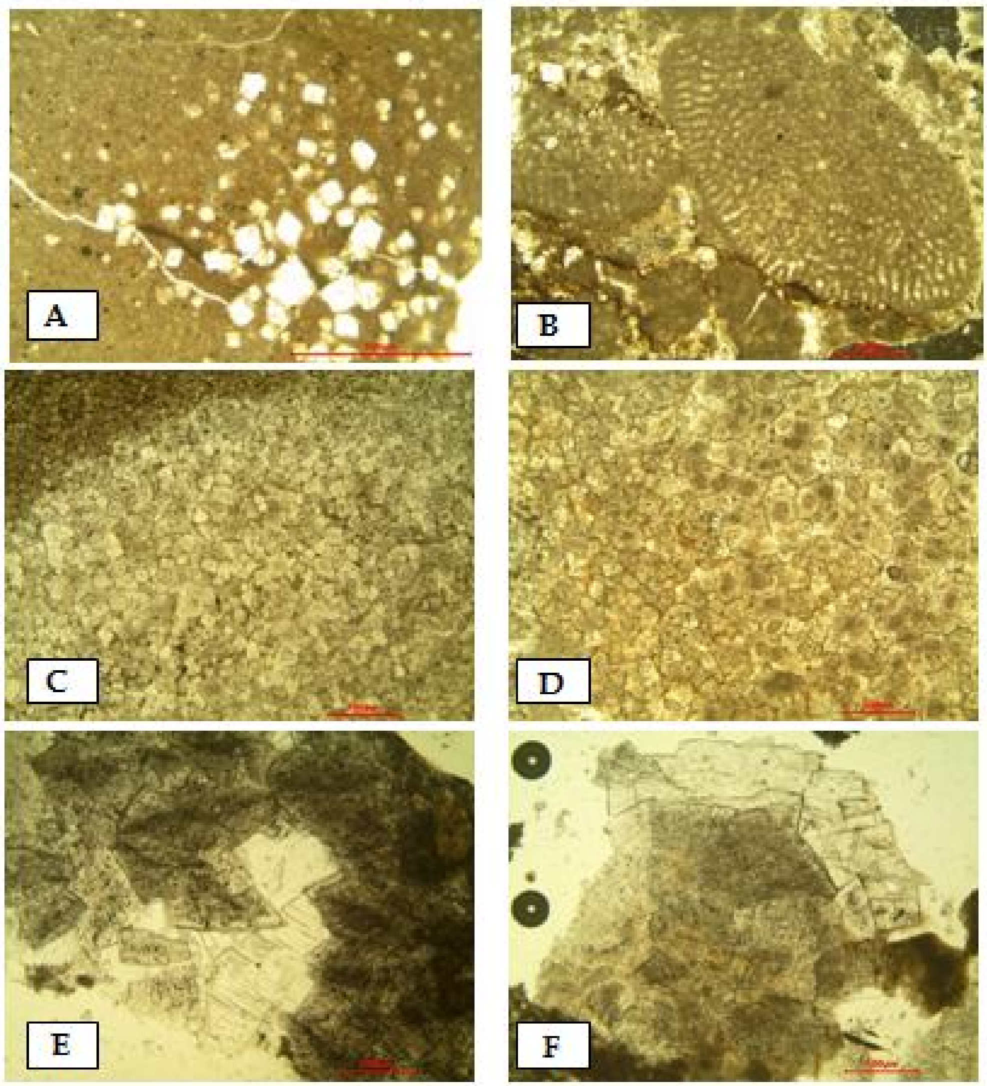

Plate 4:

- **A. Scattered fine crystal dolomiteinBa-1depth(3118)m**
- **B. Scattered dolomite associated with stylolite in Ba-4depth(2983)m**
- **C. pervasive zoned dolomite (cloudy center) in Ba-4 depth (2860a))m**
- **D. pervasive zoned dolomite (cloudy center) in Ba-1 depth (3024)m**
- **E. Saddle dolomite inBa-8 depth (2870)**
- **F. Saddle dolomite in Ba-8 depth (3180)**

DIAGENETIC HISTORY

The concept of diagenetic regimes is a broad framework that relates diagenetic processes to the evolution of sedimentary basins. Three conceptual regimes are commonly recognized: early diagenesis (eogenesis), burial diagenesis (mesogenesis) and uplift-related diagenesis (telogenesis). This terminology was adopted from a scheme developed initially by Choquette & Pray (1970) to describe limestone diagenetic processes, but is now more generally applied: correctly so, as the same fundamental processes and controls operate in clastic diagenesis and in carbonate diagenesis. Alternative schemes (e.g. the Russian system including such terms as catagenesis and epigenesis have been used but are less commonly applied now. Because of the maximum temperature of burial, the effect of variable long time is difficult to affect by the kinetic control as diagenetic reactions.

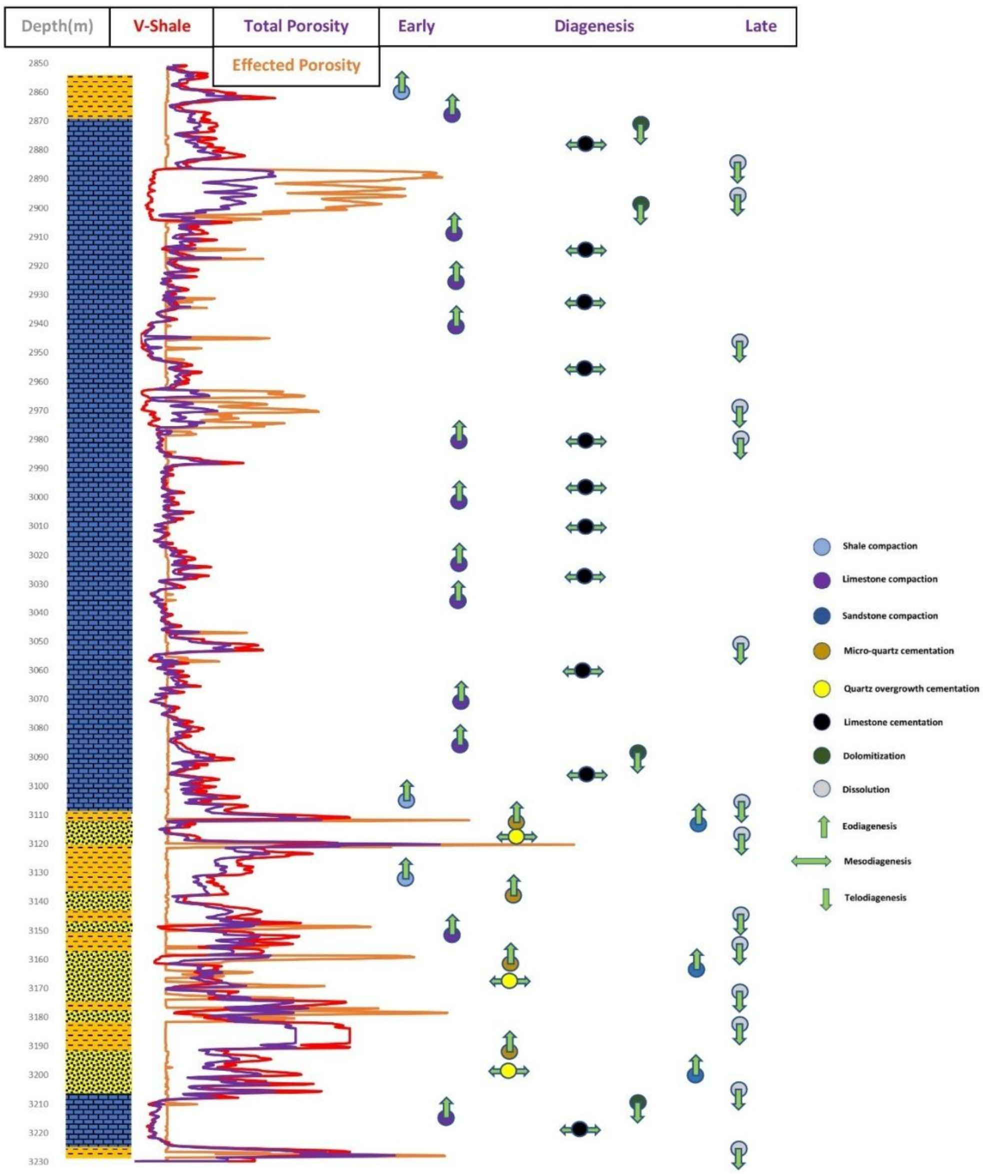

Figure 4: Columnar section shows diagenetic history and porosity types and values in Ba-1

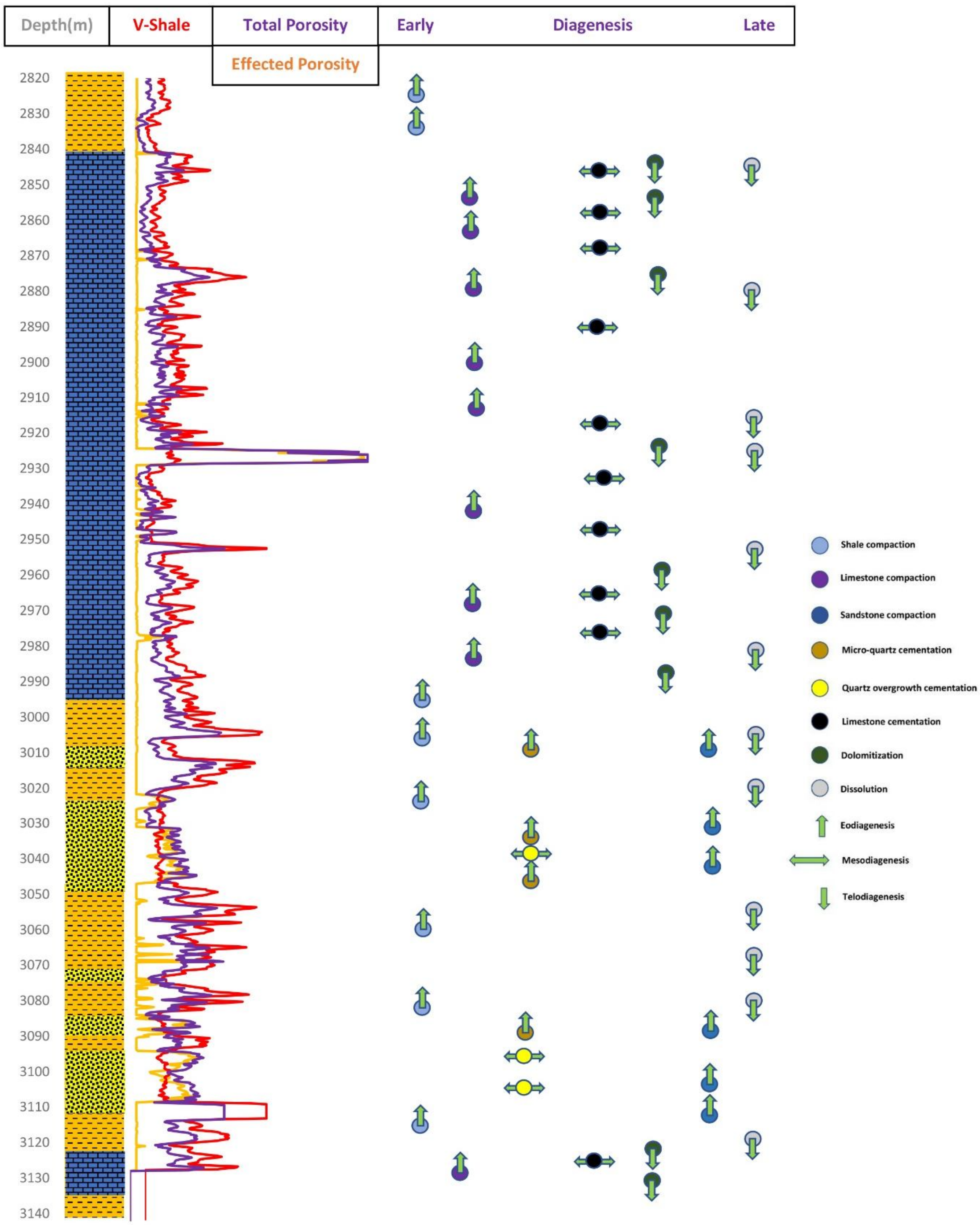

Figure 5: Columnar section shows diagenetic history and porosity types and values in Ba-4

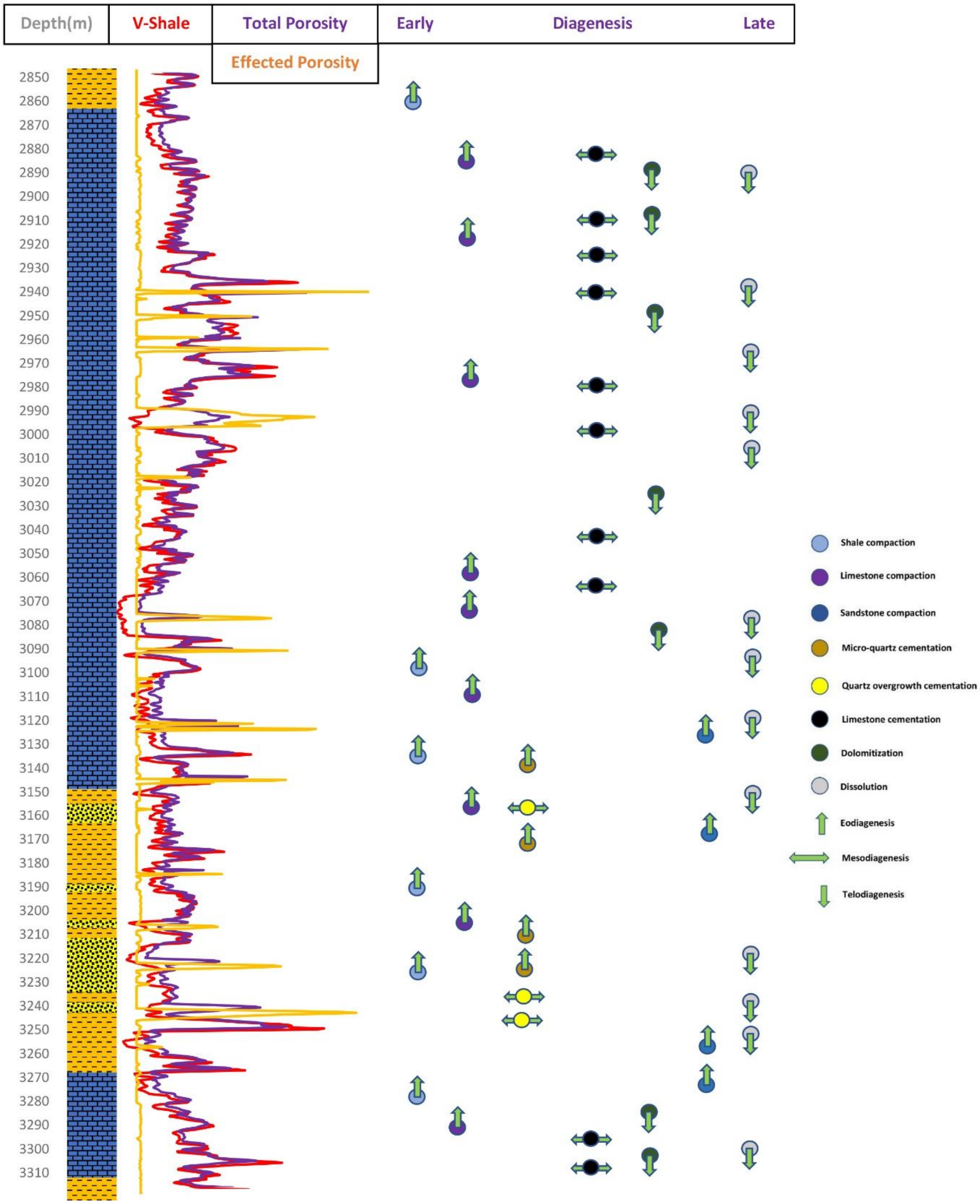

Figure 6: Columnar section shows diagenetic history and porosity types and values in Ba-8

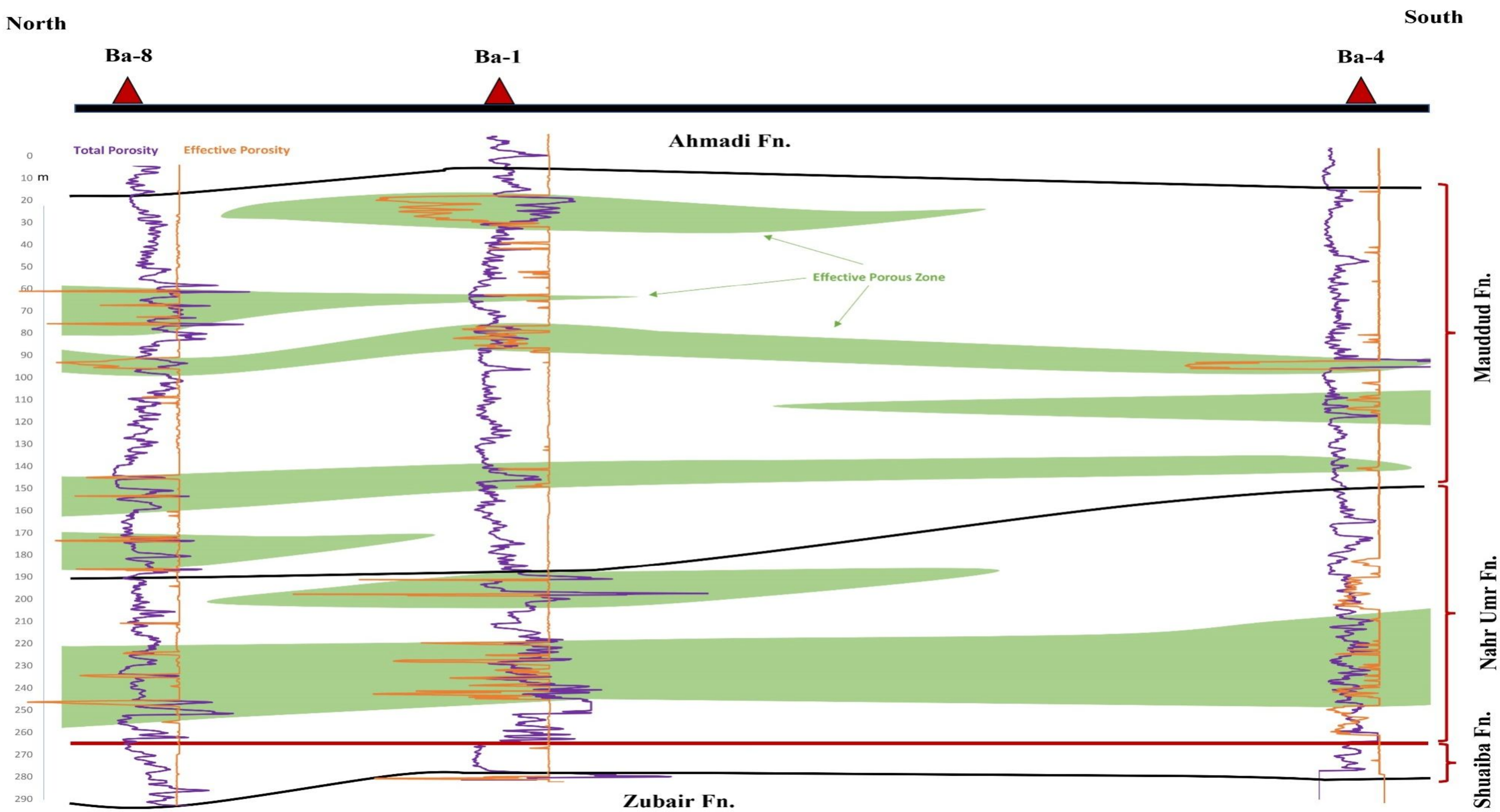

Figure 7: Cross section shows the effective porous zones in studied boreholes within Balad oil field.

The Albian-Aptian succession in the study area is affected by many types of diagenetic processes during and post deposition which represented by figures 4, 5, 6 and 7. There are three diagenetic zones in this succession; the lower part of the Albian-Aptian succession (Shuaiba Formation) is characterized by high compacted limestone and dolomitization in all studied wells. The clastic middle part of this succession (Nahr Umr Formation) is characterized by different digenetic patterns in the studied area, where appeared in Ba-1 three late diagenetic zone within sandstone units (Figure 4 and 7). These zones are affected by dissolution process to product an affective porous unit, and separated them by cemented and compacted zones. To the south of study area (Ba-4) these zones became less porosity values and the early and moderate diagenetic zone (cemented and compacted) were common. To the north the clastic succession was characterized by one affective pours unit and dominantly by cemented and compacted zones.

The upper part of the Albian-Aptian succession (Mauddud Formation) is characterized by two high effective porous zones as dissolution zones within the upper part of Mauddud Formation in Ba-1. While the lower part of this formation is affected by cementation and dolomitization (early and moderate diagenetic stage) with a breakdown for primary and secondary porosities. To the south of study area (Ba-4), the effective porous was become weaker because of dolomitization, addition to develop a new effective porous zone in the middle part of Maudud Formation (Figure 5 and 7). In the northern part (Ba-8) was dominated by dissolution and early dolomitized process where the effective porous zones were becoming more prevalent and influential in this part (Fig.6 and 7). Where it appeared that there are three effective porous zones in the upper part of Maudud Formation and three others in the lower part.

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