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Microfacies Evaluation of Mauddud Formation in Ratawi Field, South Iraq

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Abstruct

This paper includes studying the microfacies evalution of Mauddud Formaion in four wells(Rt-2, Rt-5, Rt17 and Rt-19). Seventy-seven(77) sampels were collected of above mentioned wells. Based on fossil content of the samples under study, four main microfacies were identified: packstone , wakestone , grainstone and lime mudstone microfacies ,which deposited in shallow open marine and restricted marine environments. Petrographic examination of thin section indicated that diagenesis vary in intensity from one site to another, such as dissolution, cementation, compaction, dolomitization and micritization, which led to the improvement and deterioration of porosity. The dominant pore types are vuggy, interparticle and intercrystal.The lithology, mineralogy and the matrix were determined by using crossplot method, which showed that the predominant lithology of the formation is limestone with the presence of dolomite in very few percentages and the mineralogy is calcite. Based on the relationship between porosity and permeability the resevoir performance of the microfacies classified into four types: bad, fair, good and very good. Based on petrophysical properties and core description of well study Mauddud Formation was divided into four rock units A,B,C and D , in terms of reservoir, units A and C are considered good ,while B and D are bad.

Keywords: Mauddud Formation, diagenesis, microfacies performance

تقييم السحنات الدقيقة لتكوين المودود في حقل رطاوي، جنوب العراق

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الخلاصه

يشتمل هذا البحث على تقيم السحنات الدقيقة لتكوين المودود في اربعة ابارلحقل الرطاوي(Rt-2, Rt-5, Rt-17, Rt19). تم جمع سبع وسبعون نموذجا للابار المذكوره اعلاه. اعتمادا على المحتوى الاحيائي للنماذج قيد الدراسة تم تشخيص اربعة سحنات رئيسة هي سحنة الحجر الجير المرصوص وسحنة الحجر الجيري الواكي وسحنة الحجر الجيري الحبيبي وسحنة الحجر الجيري الطيني والتي ترسبت في بيئات بحرية ضحلة مفتوحة ومحصورة .ومن خلال فحص الشرائح الرقيقة تبين وجودعمليات تحويرية تتغاير في شدتها من موقع الى اخرى مثل الاذابة والسمنته والاحكام والدلمته والمكرته التي أدت الى تحسن وتدهور المسامية. المسامية السائده هي بين الحبيبات وبين البلورات . تم تحديد الصخارية والمعدنية والملاط باستخدام مرتسامات التقاطع التي بينت ان الصخارية السائدة للتكوين هو الحجر الجيري مع وجود دولومايت بنسب قليلة جدا والمعدنية هي الكلسايت. اعتمادا على العلاقة بين المسامية والنفاذية صنفت ادائية السحنات المكمنية الى اربعة انواع هي ردئية ومتوسطة وجيده

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وجيدة جدا. وإعتمادا على الصفات البتروفيزيائية ووصف اللباب لآبار الدراسة تم تقسيم تكوين المودود الى أربعة وحدات صخارية هي A و B و C و D ، تعتبر الوحدتين A و C وحدتين مكمنيتين جيدتين ، بينما الوحدتان B و D تعتبران وحدتان رديئتان مكمنيا.

1- Inrtoduction

Several studies have been carried out on the Mauddud Formation ,especially in south and south-east Iraq ,because it has huge oil reserves. For the importance of the relationship between the microfacies and the diagenesis and the depositional environments and their effect on reservoir properties, this research is discussed , study the microfacies through the examination thin sections via microscope and related it with the diagenesis and depositional environments , and their effect on reservoir facies : In addition, the study examines the relationship between porosity and permeability to evaluate the performance of the reservoir facies.

2- Geology of study area

Ratawi field in Basrah province(South Iraq), is located at 70km northwest of Basrah city and in parallel with the North Rumaila field and away about 20 km to the west of it, between latitudes(E705000.4–696000.36m) and(N3394000.183-3373000.8m) Figure-1, on stable shelf in Mesopotamian zone at zubair subzone. It contains prominent N-S trending structures which their amplitudes increase with depth and reach 300m at lower cretaceous level. The most prominent narrow shorter antiforms include Ratawi structure [1] .The results of the seismic surveys interpretation indicated that the structure is ovoid convexity, extends toward North-South with almost symmetrical flanks, and its plunge increases with depth[2] . The lower contact of Mauddud Formation with the Nahr Umr Formation may result from stratigraphic discontinuity developed during flooding of clastic-dominated shelf, resulting in the deposition of shallow-water carbonates. The upper contact of the formation with Ahmadi Formation suggest that clastics dominated the shelf again[3]. [4] indicated the presence of a regional unconformity at the top of the Mauddud Formation in both Kuwait and southern Iraq. It was observed through the core description of the wells of study area, the Mauddud Formation consists of fairly highly, porous limestone, interveined by thin layers of argillaceous and tight limestone and terminated at bottom by dense and compact limestone. They have been compared with the petrophysical properties (porosity and permeability) and according to that, Mauddud formation was divided into four rock units(A, B, C and D) (Table- 1), (Figure- 2).

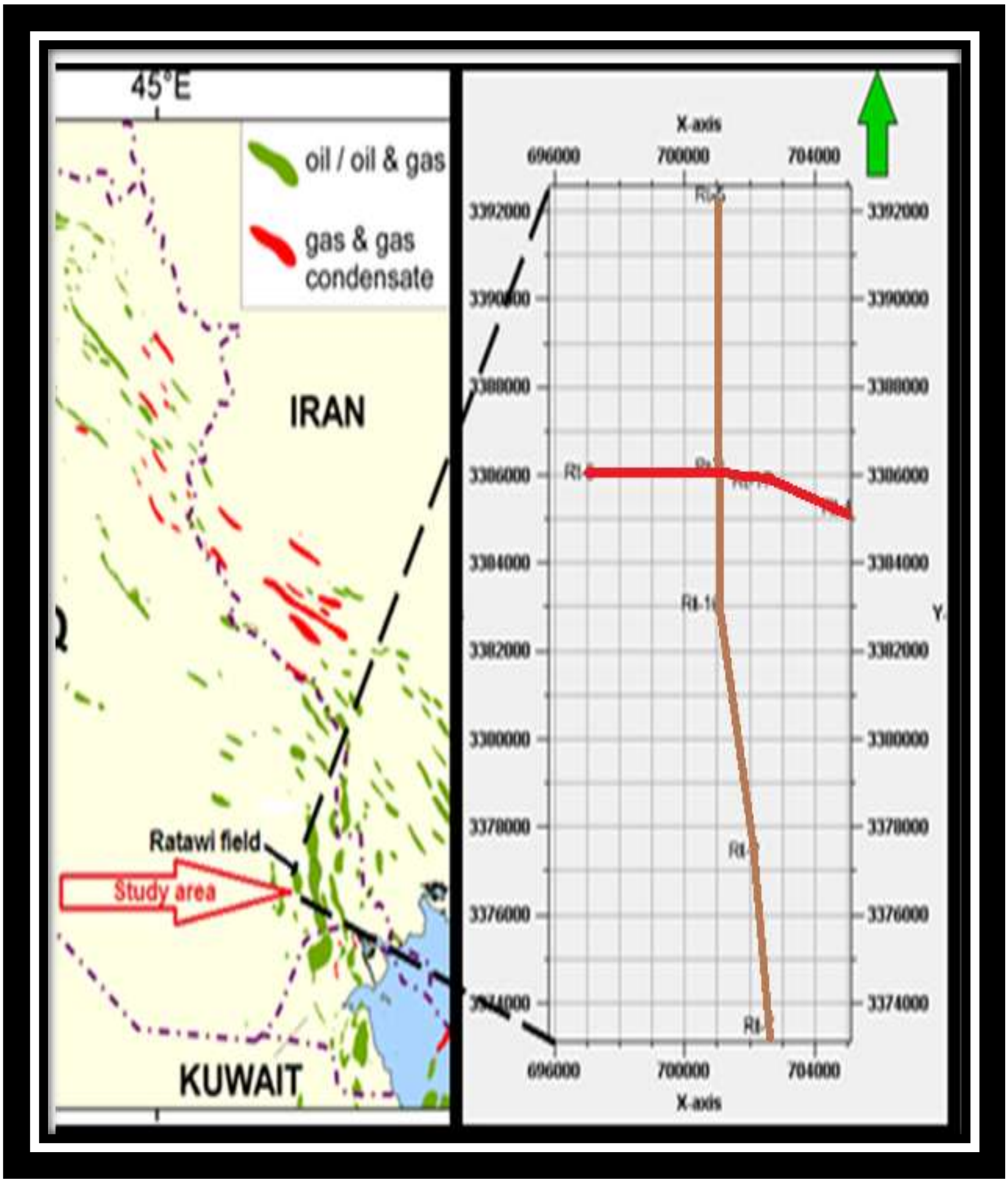

Figure 1- Location map of studied area (Ratawi field).

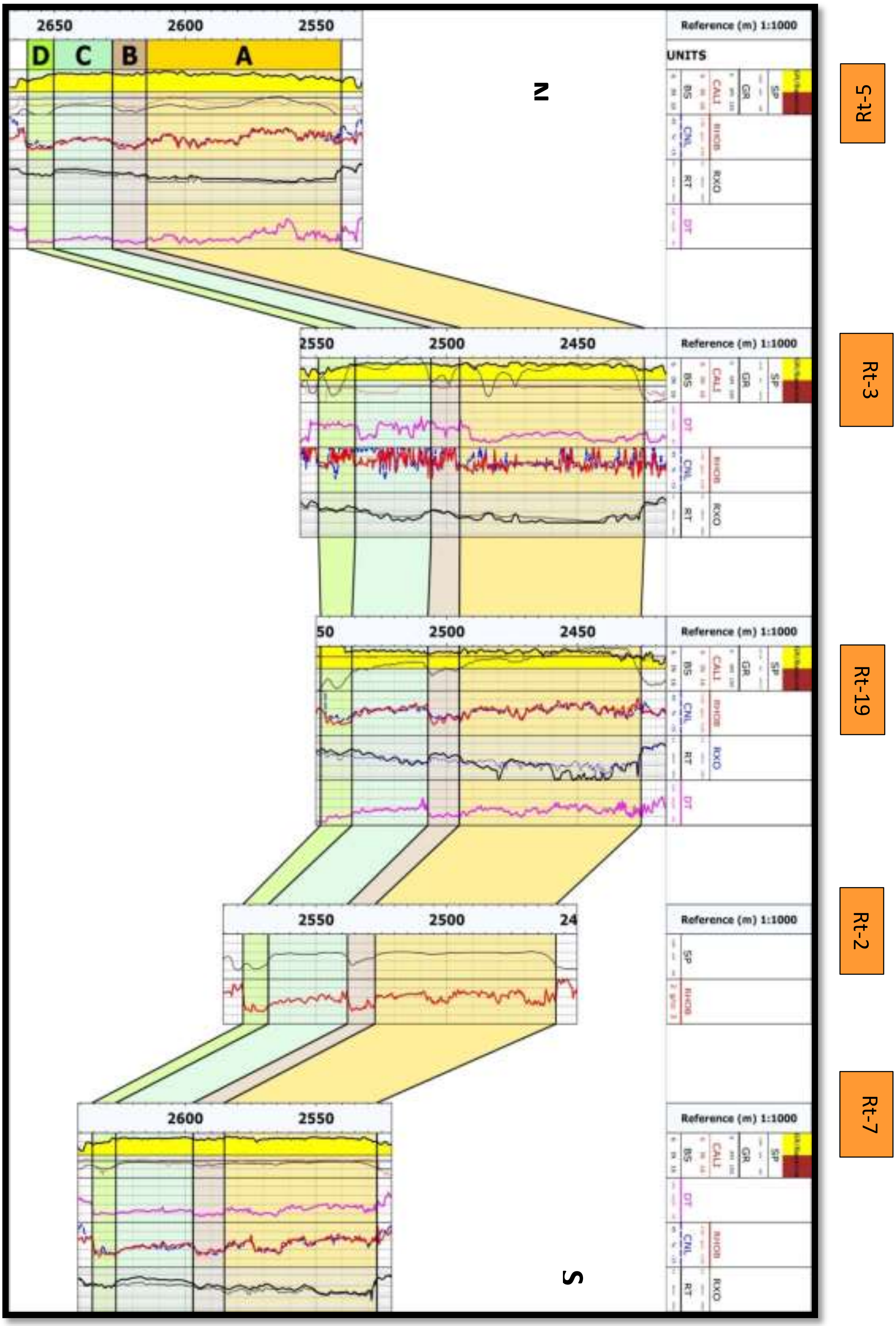

Figure2- Structural cross section showing the correlation of study wells.

Table 1-The tops of Mauddud Formation reservoir units (below sea level).

Well No.	Mauddud Formation				Top of Nahr Umar Formation
	Top of unit(A)	Top of unit(B)	Top of unit(C)	Top of unit(D)	
Rt-2	8065.40ft 2458.20m	8392.40ft 2527.40m	8326.40ft 2537.90m	8426.40ft 2568.20m	8458.40ft 2577.90m
Rt-3	2424.50m	2495.00m	2506.00m	2535.00m	2549.00m
Rt-4	2518.80m	2591.80m	2601.30m	2632.20m	2644.80m
Rt-5	2541.40m	2615.00m	2628.80m	2644.20m	2661.10m
Rt-6	2552.60m	2619.10m	2632.60m	2658.60m	2668.6m
Rt-7	2526.70m	2585.00m	2597.00m	2626.50m	2635.50m
Rt-17	2419.20m	2490.27m	2500.27m	2532.27m	2544.27m
Rt-19	2426.00m	2494.10m	2506.10m	2536.40m	2548.20m

3- Microfacies

Facies is defined as a lithic body has certain properties describe according to the color, bedding and sedimentary structures, mineralogical composition, particle size, main constituents, texture and biological remains, and each facies represent certain geological event[5] .The microfacies defined as a whole sedimentological and paleontological standards that can be study and classified in thin-sections for environmental analysis and correlation[6] .

The important facies of Mauddud Formation was determined in this study through the description of core and thin sections that were available for the wells of study area. The expanded classification of [7] was used to describe the limestone microfacies of Mauddud Formation. After the determination of the microfacies, it was compared with the standard microfacies of [8] and then the environment according to environmental facies zones for [6].

Microscopic examination of thin sections results in to recognition of four major microfacies (Plates 1 and 2) . These are :

- Lime Mudstone Microfacies

Lime mudstone was defined by [7] as a kind of limestone that its infrastructure composed of microcrystalline calcite which corresponds to the term micrite that was launched by [9]. Micrite composed more than 90% of this microfacies, and it also consists of Allochems by ratio ranging from(2-10) % and represented by Bioclasts or lithoclasts , such kind of facies deposited in low-energy environment [10] . In many of the study wells, these microfacies have been subjected to a range of diagenesis processes, depending on their intensity and effect, namely the compaction and dolomitization process. By comparing this microfacies with standard Wilson microfacies[8] showed a similarity with the standard microfacies(SMF-19) located within the facies zone(FZ-8) , within bays and beach lakes with limited movement.

- Wackestone Microfacies

Skeletal and non-skeletal particles form between(10 -15) % of this microfacies. It is considered as the main common microfacies of Mauddud Formation in the wells(Rt-2; Rt-17). This microfacies mainly composed of benthonic foraminifera represented primarily by genus Orbitolina which their structures have been observed intact and their parts are clear , buried in micritic matrix as well as fragments of red algae represented by Permocalculus fragements, fragments and debris of Echinodermata , besides some bioclastic and Mollusc shells. This main microfacies was subjected to a range of diagenesis processes which were observed in it, (1)neomorphism through the growth of micirite crystals and converted it into micro and Pseudo sparite, (2)compaction, (3)dissolution, (4)cementation which represented by several types such as granular and blocky cement and (5)dolomitization which it had partial effect and appearance of small dolomite crystals without facets.

- Packstone Microfacies

This microfacies consist mainly of grains, which represent a ratio between 70-90% when it comparing with the micritic matrix which it is partially or totally converted into micro and pseudo sparite. This microfacies has widespread in Mauddud Formation.The most common skeletal constituents of this microfacies is the benthonic foraminifera represented by *Orbitolina, Trocholina, Textularia*, in addition to presence of bioclast represented by fragments and debris of Echinodermata and fragments of red algae represented by Permocalculus fragements, while the nonskeletal grains occur in large proportions including Peloids and Pellets .The most important digenesis processes which are observed in this microfacies are (1)cementation and the appearance of granular and blocky cement, (2)dolomitization through the appearance of dolomite crystals without facets and with semi-full faceted and (3)the micritization is relatively little.

- Grainstone Microfacies

The grains whether skeletal or non skeletal form about 90% of the basic structure of this microfacies, it contains only about 10% or less of matrix which consist of microsparite texture and Pseudo sparite texture. There is no or less presence of micrite, which means that this submicrofacies has been deposited in a high-energy sedimentary environment where the high currents led to the removal of lime mud and the retention of grains components. The presence of this microfacies is small compared to the other microfacies, and spread in some parts of the middle and upper of Mauddud formation.

The most important skeletal components of this microfaies are the benthonic foraminifera represented by Orbitolina , as well as the presence of Echinodermata fragments,while the non skeletal - components are peloids. The most important digenesis processes that affected this microfacies are the cementation through the appearance of granular and blocky cement.

4 - Diagenetic Processes

Diagenetic processes are defined as all the physical and chemical changes that occur to sediments before and after the burial process[6] . Carbonate rocks are one of the most affected rocks by diagenesis processes, due to the large changes that occur as most carbonate minerals are less stable in environmental conditions near the surface, such as dissolution calcium carbonate in wide range of surface and subsurface environmental conditions, so the effect of diagenesis processes is large in Mauddud Formation. The most important diagenetic processes observed in the Mauddud Formation are dolomitization, dissolution, cementation, neomorphism and to a lesser degree compaction and micritization. The following is a brief summary of these operations Plate(3):

- Dolomitization

It is a process by which the dolomite is formed When magnesium ions replace calcium ions in calcite. This process is described by the equivalent equation:

$$2\ CaCO_{3(calcite)} + Mg^{2+} \leftrightarrow CaMg(CO_3)_{2(dolomite)} + Ca^{2}$$

Dolomitization occurs either early or late. The early dolomitization occurs by the replacement of precipitated micrite from sea water rich in magnesium ions and contact sediments before their lithification , where calcium ion replaces by magnesium ion that existed in the sea water, or through the mixing of interstitial water between the particles with fresh water after the exposure of sediment to the air, resulting in increased magnesium ion and decreasing of calcium ion, thus dolomite is formed, this corresponds to the dolomite formed at the bottom of the Mauddud Formation, which reflects the shallow conditions which is formed due to the mixing of the cosmic fresh water and the marine water found in the pores of the rocks causing the process of complete dolomitization. While the late dolomitization occurs after the separation of sea from the sediments and their lithification,where the source of the magnesium ions needed for the replacement is pore fluids that are rich in magnesium which existed within rocks and Echinodermata available in the rocks of the Mauddud Formation, where dolomite crystals form as a result of the burial pressure, which expels water between grains, thus suitable conditions are available to form dolomite crystals(temperature, pressure, source of magnesium ions) this is supported by the accompanying dolomite crystals with the stylolite veins formed at some depths of the Mauddud Formation.

- Dissolution

It is a process of dissolving the skeletal and non skeletal components that exist in the tissue of carbonate rocks due to their mixing with fresh water or may be with sea water[6]. The moldic and vugy pores form as a result of dissolution which occurs in low stability mineral such as aragonite and high magnesium calcite. As the size of the crystal small, the dissolution increase[6] . The a-dissolution occurs within vadose environment and the upper part of fresh-phraetic environment[11] , that is to say it occurs in shallow environments due to the increase of carbon dioxide which results in the formation of weak acid solutions that dissolve the carbonate components during the passage of this water through the fadose zone. Some researchers[12] have reported that this process can occur in deep burial environments due to the concentration of CO_2 which is produced as a result of decay and decomposition of organic materials in clay-rich facies , in addition to the increase of hydrostatic pressure. Thus, the dissolution process can occur in shallow environments during early diagenesis processes and in deep burial environments. Dissolution was observed in Mauddud Formation, where occurred mainly in the upper part of this formation through the dissolving the fossils skeleton forming moldic porosity.

- Cementation

It was observed in Mauddud Formation the prevalence of the granular mosaic cement, this type of cement is characterized by crystals of high transparency and large size with straight edges to semi-zigzag. With continuous sedimentation and increased mechanical pressure as a result of increased sedimentation load ,another generation of cement is generated which is the block mosaic cement characterized by large size euhedral – subhedral crystals[6] , the latter also indicated that these two types of cement could be occurred in deep and shallow environments during late diagenesis processes. It should be noted that all types of cement in the Mauddud Formation are calcareous, silica cement is absent due to water saturated in the cavities with sea water that saturated with calcite and aragonite.

- Neomorphism

The term “neomorphism” embraces all transformations which occur on the mineral without a change in its chemical composition either by increasing the size of the resulting crystals larger or smaller or different in shape than the original This process is regarded as of physical origin which effect in the crystalline form of the rock, without effect in its chemical composition and its effect may be partially or completely[9]. The most significant secondary growth observed in the Mauddud Formation is the recrystallization process and the growth of micrite crystals, which are less than 4 microns in size and converted into microsparites which are less than 4 μm in size and converted to microsparite which range in size between(30-50 microns), whenever the recrystallization process continues, the microsparite turns into a pseudsparite, which is more than 30 microns in size. The intensity of this process is inversely proportional to the ratio of the presence of the muds , whenever the proportion of the muds increase, the recrystallization process decreased, where the muds impede the recrystallization process[13] .

- Compaction

The compaction regard as of the late diagenesis processes of physical origin. In the initial stages, the process of compaction involves the expulsion of liquids that occupy the pores between the grains and therefore reduce the primary porosity of the sediments and the size of the rocks. There is another type of compaction called compaction of solutions , dissolution of lime-materials may be occur in or along with grains edges or crystals forming dissolution surfaces (stylolite) which represent the late stage of the diagenetic processes[14] , this process occurs after the end of compaction process and the lithification of rocks and as a result of impressed forces on contact surfaces between grains leading to dissolving the calcite mineral which redeposited as cement materials filling the pores space.

- Micritization

Is a process of excavating the surfaces of organisms via algae, bacteria and fungi that have drilled the outer edge of the skeletal of these organismis creates gaps filled with fine grains of micrite matrix gaining dark or black color and lead to the distortion of the external structures of fossils that may occur to the bioclasts also .This process occurs especially in shallow environments[6 and in this study it appeared in definite depths.

5 - Depositional environments

Through the microscopic examination of thin sections and the results of log analysis, it has been possible to identify sedimentary environments characterized by a number of microfacies accompaniment. The most important fossils that have been observed in these microfacies are the benthonic foraminifera represented by *Orbitolina*, *Trocholina*, *Milliolida*, each of these fossils has its own environmental evidence, The presence of large benthonic foraminifera confirms the shallow sedimentary basin and that the *Orbitolina* fossils are present in environments with shallow water. They represent marine life, semi-static, low motion and a guide of warm tropical waters, while the presence of *Milliolida* indicates shallow water environments that do not exceed a few tens of meters and high temperature. The Mauddud Formation can therefore be considered as deposition in a generally shallow and warm marine environment and includes the following environments:

- Restricted Marine Environment

The inner shelf water is limited because there is a barrier in front of it , either to be on the margin of the reef or oolitic barrier[15]. This environment has been observed in the lower part of the Mauddud formation, it is represented by dolomitic lime mudstone which indicating that the sedimentation energy is calm and close to the coast.

- Shallow Open Marine Environment

It is one of the inner shelf environments, where there is a large diversity of life groups because of the shallow water and the fact that it is open to the basin where the water circulation that helps to continuity of the water occurs. This environment was observed through the wakestone microfacies and the wakestone- packstone microfacies. While packstone and garinstone microfacies are deposited in a high-energy environment that shallowing conditions of this environment and resulted from the regression in the sea level [16].

Table 2-Petrographic description, and the distribution of microfacies and diagenesis for Mauddud Formation in the well (Rt-2)

Well	Depth(m)	Facies	Fossils																			Diagenesis					porosity					Oil show
			miliolids	Bryozoa	Bivalve	pseudolitunella	Ovalveolina	Rudists	peloids	iraqia	orbitolina	Trocholina	Coral	Spiroplectammina	stromatolite	Echinoids	Pseudotextularia	pellet	Hedbergella	Qataria dukhani	Nezzazata	cementation	recrystilaization	compaction	Dissolution	dolomitization	intrapartical	interparticle	vuggy	moldic	fracture	
Rt-2	2495.14	Grainstone		●	●		●		●	●	●	●								●		●			●		●	●	●	●		●
	2497.14	Lime mudstone	●		●																										●	
	2513.20	Packstone																●						●	●	●	●	●	●			●
	2516.30	Packstone							●				●	●	●		●			●		●			●		●	●				●
	2525.80	Packstone						●	●	●	●				●										●		●			●	●	●
	2533.80	Packstone							●	●	●														●		●	●	●	●		●
	2535.75	Grainstone							●													●			●		●	●		●		●
	2537.45	Grainstone						●	●	●															●	●		●	●			●
	2541.30	Packstone						●			●														●	●	●		●	●		●
	2541.85	Packstone						●	●	●						●	●					●			●						●	●
	2541.90	Packstone							●														●		●		●		●			●
	2557.70	Grainstone						●	●	●	●				●										●		●	●				●
	2562.20	Grainstone	●			●			●	●	●														●		●		●	●		●
	2563.20	Packstone								●	●	●				●								●								●
	2573.90	Packstone			●			●		●		●										●			●		●					●
	2575.20	Packstone							●	●												●			●	●	●	●				●
	2580.00	Packstone						●	●	●											●				●		●	●	●			●
	2589.67	Packstone			●					●												●			●	●			●		●	●
	2596.77	Packstone			●			●	●	●		●			●	●				●		●			●		●	●		●		●
	2600.57	Dolostone							●				●			●							●		●	●					●	●
	2603.27	Packstone			●			●	●				●			●			●	●		●			●				●			
	2607.27	Packstone						●							●				●			●	●		●		●					●
	2612.07	Packstone								●					●	●			●			●		●	●	●		●	●			

Table3-Petrographic description, and the distribution of microfacies and diagenesis for Mauddud

Well	Depth(m)	Facies	Fossils																		Diagenesis				porosity					Oil show
			miliolids	Textularia	bivalve	cisalveolina	transversal	rudist	peloids	iraqia	orbitolina	algae	coral	praeveolina	stromatolitic	echinoid	dicycluna	pellet	planktonic	gastropods	cementation	compaction	Dissolution	dolomitization	intrapartical	interpartical	vuggy	moldic	fracture	
Rt-5	2570.00	Packstone	●	●	●	●	●	●	●												●		●		●	●				●
	2572.90	Wackestone	●	●	●				●					●			●				●		●		●			●	●	●
	2590.10	Grainstone		●				●	●		●	●	●			●		●			●		●		●	●		●		●
	2602.30	Packstone						●				●			●	●					●			●					●	●
	2603.00	Packstone						●	●		●		●										●		●	●	●		●	●
	2604.80	Packstone			●			●			●				●						●	●	●			●		●		
	2609.00	Wackestone						●			●											●	●			●			●	
	2616.00	Packstone			●			●			●		●			●					●	●	●	●			●	●	●	●
	2616.90	Packstone			●			●				●	●			●					●		●		●	●		●	●	●
	2618.00	Packstone			●			●			●					●					●	●	●		●	●		●		●
	2618.90	Packstone																			●		●		●	●		●	●	●
	2619.00	Grainstone			●						●		●			●		●			●		●		●	●		●	●	
	2624.60	Lime mudstone																				●	●							●
	2624.90	Lime mudstone							●																					
	2630.80	Grainstone	●			●		●			●					●					●		●		●	●		●	●	
	2636.90	Grainstone		●	●	●		●	●		●					●					●		●			●		●		●
	2638.70	Packstone			●			●			●				●	●					●	●	●		●					
	2641.95	Wackestone			●						●		●										●	●		●			●	
	2643.90	Wackestone			●			●			●					●					●		●			●			●	●
	2647.50	Packstone			●			●			●	●	●			●			●		●		●		●	●		●	●	●
	2650.50	Packstone			●			●	●				●			●					●		●	●		●		●	●	●
	2652.00	Grainstone						●			●					●				●	●		●	●	●	●		●		●

Table 4-Petrographic description, and the distribution of microfacies and diagenesis for Mauddud Formation in the well (Rt-17)

Well	*Depth (m)*	Facies	Fossils											Diagenesis					porosity					Oil show
			Cycledomia	hedbergella	bivalve	Pseudolituonell	Qataria dukhani	Rudist	peloids	iraqia	trocholina	Echinoid	Coral	cementation	recrystallization	compaction	dissolution	Dolomitization	moldic	fracture	intrapartical	interparticle	vuggy	
RT-17	2495.65	Packstone			●			●	●	●		●	●	●	●		●			●				●
	2498.70	Packstone			●				●	●	●			●										●
	2505.70	Grainstone							●	●	●			●			●				●	●		●
	2509.60	Wackestone							●					●			●			●				
	2513.70	Packstone	●		●			●						●			●			●	●	●		
	2519.50	Packstone				●		●	●	●		●	●	●			●			●	●	●	●	●
	2527.65	Packstone			●			●		●		●	●				●						●	●
	2532.98	Wackestone						●		●		●	●		●	●	●	●			●	●		
	2536.95	Grainstone	●				●			●							●		●		●	●	●	
	2541.00	Packstone				●		●	●	●			●	●			●				●			●
	2543.50	Wackestone								●							●	●					●	●
	2551.50	Wackestone								●							●	●				●	●	●
	2558.05	Wackestone								●								●						●
	2561.30	Wackestone	●		●			●	●	●		●				●	●			●	●	●		●
	2565.80	Wackestone										●		●			●						●	●
	2568.70	Wackestone			●			●		●				●			●	●		●	●	●	●	●
	2570.25	Packstone		●	●		●	●		●		●												

Table 5-Petrographic description, and the distribution of microfacies and diagenesis for Mauddud Formation in the well (Rt-19)

Well	Depth(m)	Facies	fossils																		Diagenesis					Porosity					Oil show
			miliolids	cisalveolina	Bivalve	Pseudolituonella	Planktonic fossil	rudist	peloids	iraqia	orbitolina	trocholina	coral	trocholina	stromatolitic	echinoid	pseudocyclammina	gastropods	Qataria dukhani	nezzazata	cementation	recrystilaization	compaction	Dissolution	dolomitization	intrapartical	intraparticle	vuggy	moldic	fracture	
Rt-19	2460.50	Packstone	●	●		●		●	●								●			●	●			●		●	●				
	2464.40	Packstone			●			●							●						●				●						●
	2482.95	Packstone						●	●	●			●				●				●			●		●	●				●
	2486.70	Packstone							●	●	●										●			●		●	●			●	●
	2489.00	Wackestone							●												●	●		●				●			●
	2497.25	Packstone			●	●		●	●	●							●				●			●		●		●			
	2499.50	Packstone			●	●		●		●	●		●		●	●					●		●	●		●	●	●		●	●
	2503.70	Packstone							●	●			●							●	●			●		●	●				●
	2523.00	Packstone						●		●			●			●			●		●			●	●	●	●	●			●
	2526.00	Packstone						●		●	●		●						●		●		●	●	●	●	●	●		●	●
	2529.00	Wackestone			●		●																●	●	●	●	●	●		●	●
	2530.00	Packstone			●			●		●		●	●								●			●		●	●		●	●	
	2532.00	Wackestone																						●	●			●		●	●
	2537.70	Packstone			●					●	●								●					●	●	●		●			
	2541.25	Wackestone			●			●	●	●								●			●			●		●		●		●	●

6- Determination of lithology and Porosity by using crossplots

Crossplots are a convenient graphical way to solve complex relationships using two or(three) porosity measurements . Below are the main types of crossplots used to determine the lithology and porosity:

Density-Neutron plot

In the study wells Figure-3 indicate that the the Mauddud Formation data cluster on the lithology line of limestone.

M-N plot

This crossplot requires sonic log, density log and neutron log to calculate the lithology-dependent variables M and N Figure-4. M and N values are largely independent of matrix porosity. (M) and (N) values are calculated by the following equations[17] :

$$M = \frac{\Delta tfl - \Delta t}{\rho b - \rho fl} \quad \ldots\ldots\ldots (1)$$

$$\mathbf{N} = \frac{\mathbf{\emptyset Nfl - \emptyset N}}{\mathbf{\rho b - \rho fl}} \quad \ldots\ldots\ldots (\mathbf{2})$$

Where :

Δ_t= interval transit time in the formation (from the log)

Δtfl = interval transit time in the fluid in the formation

ρb = formation bulk density(from the log)

$\emptyset N$ = neutron porosity (in limestone units, from the log)

$\emptyset Nfl$ = neutron porosity of the fluid of the formation (usually = 1.0)

MID plot

Mineral –identification(**MID)** plot Figure-5 helps identify lithology and secondary porosity, but it created to emphasize matrix values rather than porosity[17] depend on the calculation of apparent matrix values as a crossplot parameters as follows:

$$\rho maa = \frac{\rho b - \emptyset ND \times \rho fl}{1 - \emptyset ND} \ldots\ldots\ldots (3)$$

$$\Delta tmaa = \frac{\Delta t - \emptyset NS \times \Delta tfl}{1 - \emptyset NS} \ldots\ldots\ldots (4)$$

$\rho b = bulk\ density\ (\ from\ the$ log)
$\rho fl = fluid\ density$
$\emptyset ND = neutron - density\ crossplot\ porosity$
$\Delta t = interval\ transit\ time\ (from\ the$ log)
$\Delta tfl = fluid\ transit\ time$
$\emptyset NS = neutron - sonic\ crossplot\ porosity$

7- Porosity & permeability relationship

Permeability is the ability of a rock to transmit fluids[17], or it is a measure of the rock`s ability to flow fluids (oil, gas, water) [18]The permeability of a rock rely on its effective porosity, so, it is affected by the rock grain shape, grain packing, sorting,grain size, type of clay, cementation and the degree of consolidation[19]. Permeability is important because it is a rock property that relates to the rate at which hydrocarbons can be recovered[20] .

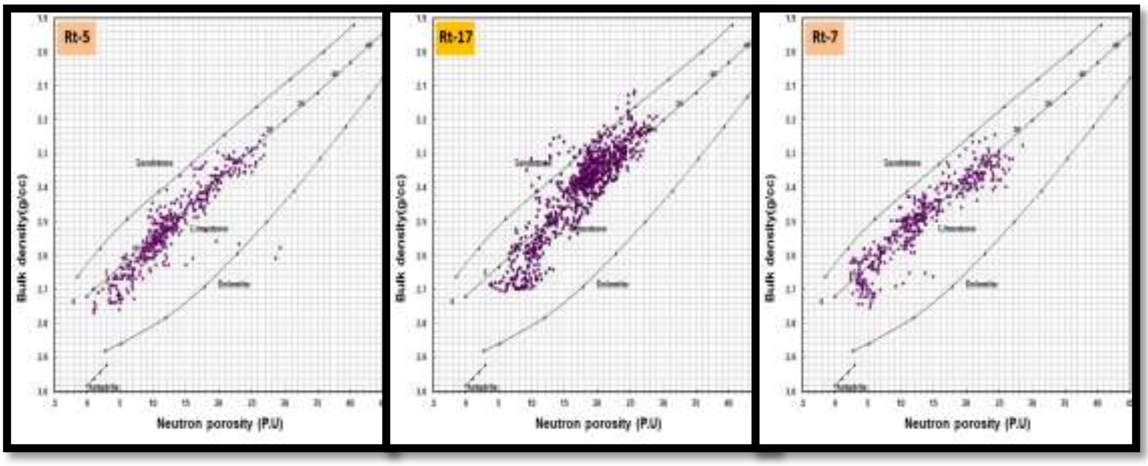

Figure 3- Density -porosity cross plots for the study wells(Rt-5, 17and 19)

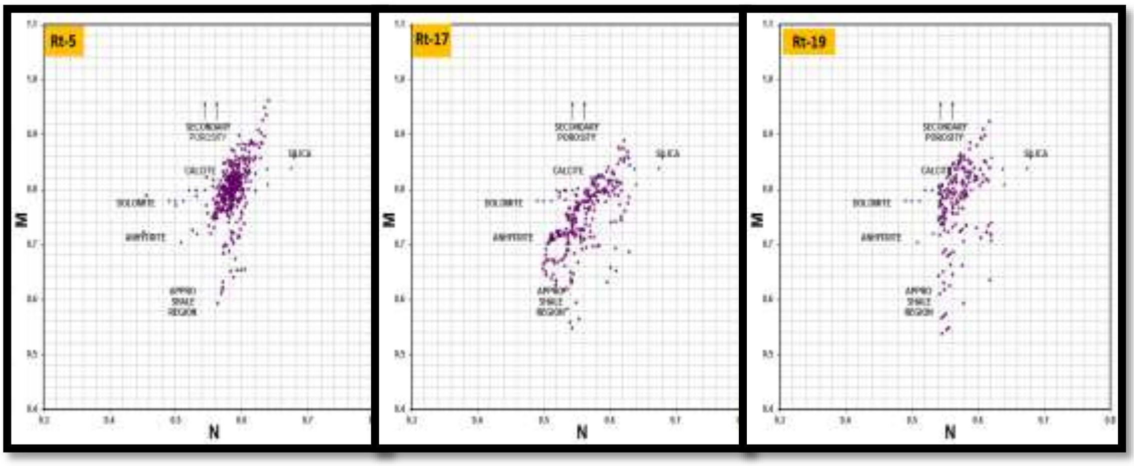

Figure 4- M-N Plot to determine complex mineral mixtures for study wells(Rt-5, 17and 19)

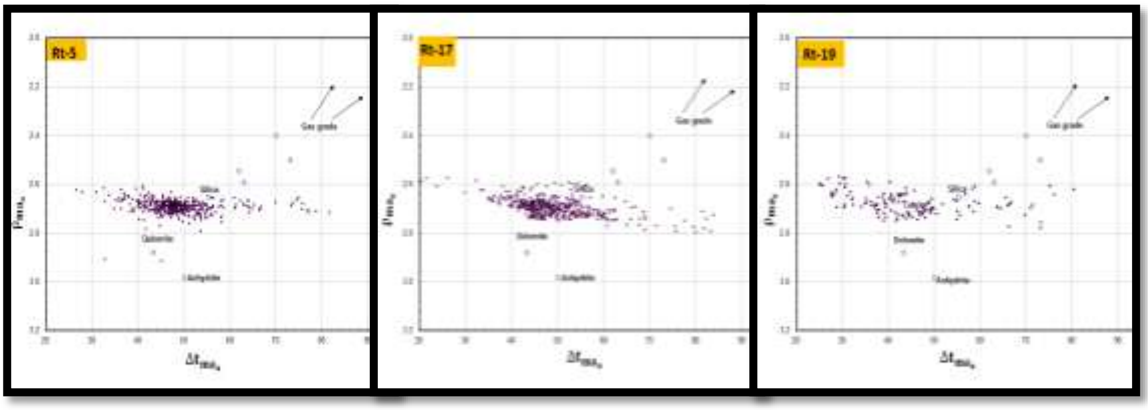

Figure 5- MID Plot to determine matrix values for study wells(Rt-5, 17and 19)

The fluid saturation and number of mobile fluids have a great effect on permeability, thus single fluid is needed to estimate permeability from log and this occurs when the zone at irreducible water saturation(i.e.,the values of BVW=S_wØ are constant or very close to constant) [21].

- Method to estimate permeability from logs

In this study, the equation of Wyllie and Rose(1950) used for estimating permeability, the permeability values which are gotten in this step plotted versus the porosity values by using the Empirical model and used the relationship between porosity and permeability in evaluation the performance of reservoir facies, for the units(A) and(C).

In this study the units(A) and(C) Figures-(6 and 7) which indicated that the dominated performance reservoir flow unit is fair to good for the unit(A) of(Rt-5) and produces little oil without water, while the performance reservoir flow unit of unit(C) is bad (i.e., non-reservoir unit). For(Rt-17) the performance reservoir flow unit is good to very good for unit(A),producing high oil with little water, while the performance reservoir flow unit of unit(C) is fair ,good to very good and producing high oil with little water. For(Rt-19) the performance reservoir flow unit is good to very good for the unit(A),producing high oil with little water, while the the performance reservoir flow unit is fair, good to very good, some depth interval produce high oil and the other little with very little water.

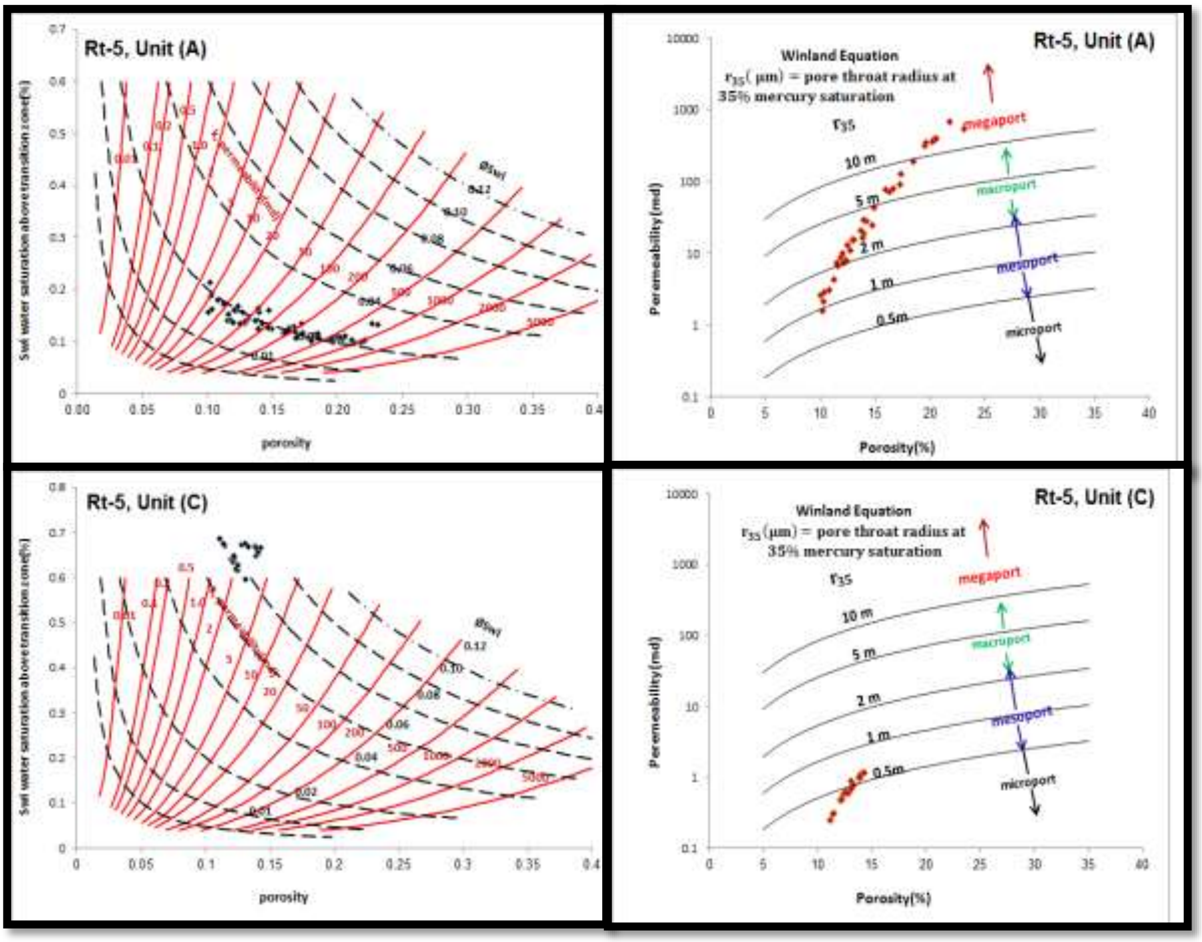

Figure 6- Charts of(Ø) versus (S_{wirr}) for estimating permeability and determining(BVW) and Empirical model for four ranges of r_{35} for reservoir units of well (Rt-5)

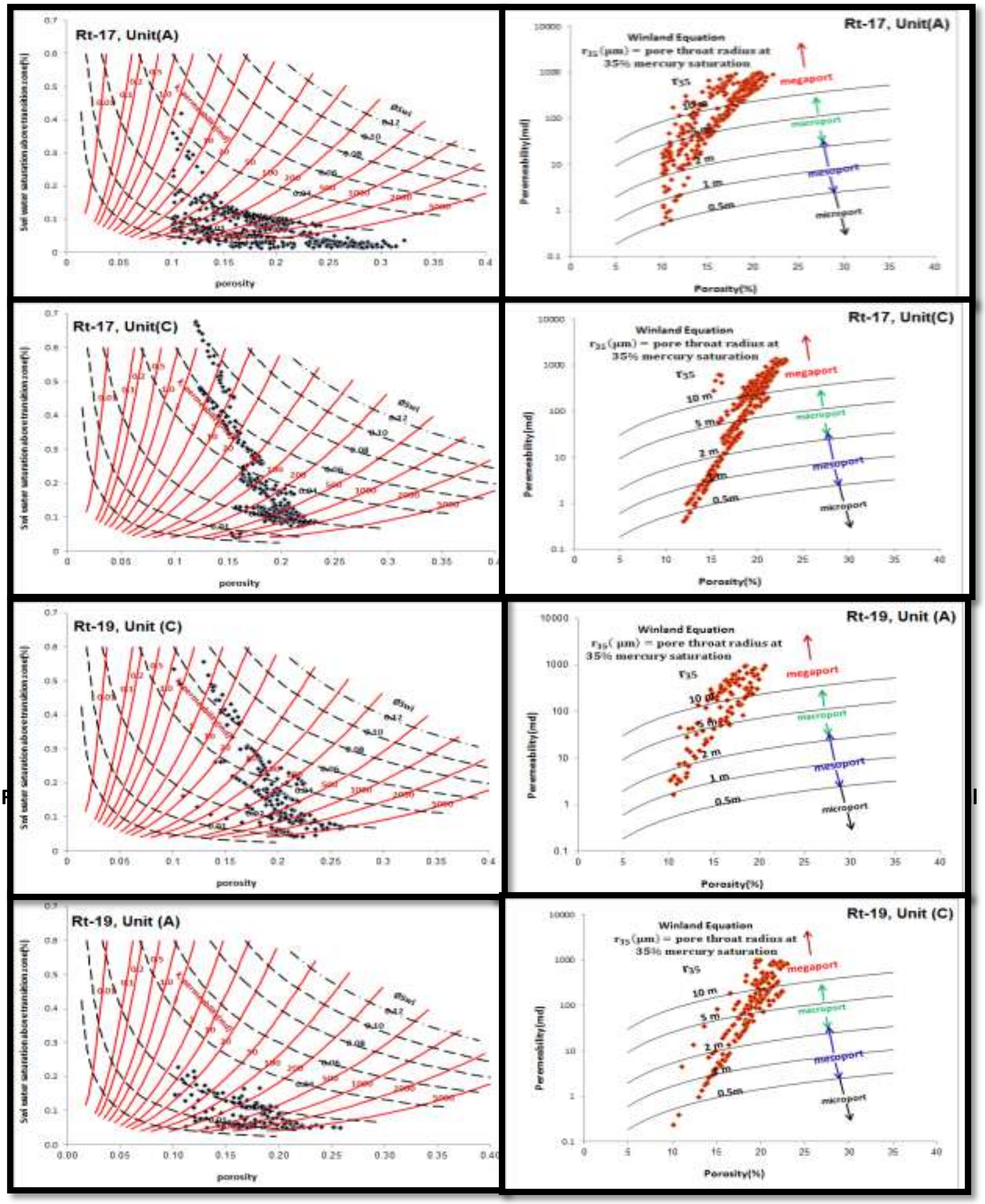

Figure 7- Charts of(Ø) versus (S_{wirr}) for estimating permeability and determining(BVW) and Empirical model for four ranges of r_{35} for resovoir units of wells(Rt-17 and 19).

8- Conclusions

1-The examination of thin sections showed the existence of limited diagenesis which include cementation, compaction and dolomitization and micritization, led to deterioration of porosity, while the dissolution led to the improvement of porosity.

2- Based on the interpretation of well logs and the description of cores in addition to the relationships between porosity and permeability, Mauddud Formation was divided into four rock units (A, B, C,

D). In terms of the reservoir, units A and C are considered good units (dominant size of pore throat between2.0μm and > 10.0μm i.e.,macroport and megaport) ,while units B and D are bad [22].
3-The environment of the Mauddud Formation includes shallow open marine and restricted marine environments depending on fossils observed in number of microfacies.

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