

Lithofacies Characterization of the Early – Middle Miocene Succession, Case-Study, South Iraq.

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ABSTRACT

The Early – Middle Miocene Ghar and Lower Fars sedimentary succession at the representative oil-well Nu-18 of the Nahr Umr oil field south Iraq; is taken by this study to investigate the sedimentological to reservoir rock facies buildups and related reservoir zonation; as first rock-typing attempt for the both formations.

The sedimentological characterization of the Early Miocene Ghar formation is mainly comprised by successive buildups of sands-gravels and sandstones, *whereas*; the Middle Miocene Lower Fars formation is started by limestone, limestone-marly/marl anhydritic, upgraded into interbedded-series of marl and anhydrite facies, with less-common occurrences of thin-sandstone interlayers, terminated by marl-sandy-section at the upper part of the Formation.

A successive depositional succession has established of 2 litho-units for Ghar Formation & 4 members for Lower Fars Formation, with related sedimentary intervals. The composite micro-to-mega pores/multi-fractures system of the carbonate – anhydrite lithofacies buildups, of the Lower Fars Formation reflects a good pore – reservoir characterization framework. *Accordingly; the* Lower Fars Formation members and the Ghar Formation litho-units has passed into reservoir-layering-scheme, and a *reservoir layering system* has submitted of: 7 and 2 reservoir-units for Lower Fars and Ghar formations respectively, and *symbolized* as: LF-B1, LF-B21, LF-B22, LF-B23, LF-C1, LF-D1, LF-D2, and GH-A, GH-B.

Keywords: Sedimentological & Reservoir Rocks Characterization, Rock-typing, Sedimentary Interval, Reservoir Unit.

الخلاصة:

ان التتابع الرسوبي لتكوين الغار والفارس الاسفل ذات عمر المايوسين المبكر – المتوسط، في البئر نهر عمر 18- حقل نهر عمر النفطى جنوب العراق، تم اختيارها في الدراسة لمعرفة البناء السحني المكني وعلاقتها بالانطقة المكنية.

ان التوصيف الرسوبي لتكوين الغار ذات العمر المايوسين المبكر يتكون بشكل رئيسي من بناء متعاقب من رمل- حصي وحجر رملي، بينما تتالف تكوين الفارس الاسفل ذات العمر المايوسين المتوسط ابتداءً من الحجر الجيري، حجر جيرى - صلصالي/ متبخرات صلصالية تعلوها وحدات متداخلة من سحنات المتبخرات والصلصال مع تواجد قليل - كثير من طبقات الحجر الرملي الرقيق، وتنتهي بمقطع صلصال رملي في الجزء العلوي من التكوين.

المقطع الرسوبي المتعاقب تتكون من وحدتين صخرية لتكوين الغار واربعة وحدات لتكوين الفارس الاسفل، مرتبطة بالفترات الترسيبية. يعكس نظام المسامات (الدقيق – الكبير) في الحجر الجيري – المتبخرات من تكوين الفارس الاسفل نظام مسامي جيد وذات خواص مكنية. وفقاً لذلك فإن وحدات الفارس الاسفل والغار تعد طبقات مكنية وهذه الطبقات تتمثل من 2-7 وحدات مكنية لكل من تكوين الفارس الاسفل والغار على التوالي ويرمز لها بـ : LF-B1, LF-B21, LF-B22, LF-B23, LF-C1, LF-D1, LF-D2, and GH-A, GH-B

Introduction:

The Early-Middle Miocene succession was described and forwarded as a stratigraphic nomenclature represented as a rock unit for the Lower Fars formation of green marl, limestone marly, with anhydrite and sandstone interlayers, identified this formation in south-west Iran [1]. This succession at the well Zubair number-3 Zubair oil field, Basra, south Iraq [2]. In the Iraqi the Middle-Miocene Lower Fars formation stratigraphy as lagoonal to evaporate sequence, composed mainly of anhydrite–gypsum & salt, interbedded with limestone, marl, fine-grained plastics [3][4].

Four informal units defined from bottom to top: a/ transition-beds of anhydrites-facies, separated by common thin limestone & mudstone beds, b/ saliferous beds of anhydrite/rock-salt with some siltstones/mudstones & fair limestone intercalations, c/ seepage-beds of anhydrite, interbedded with siltstones, mudstone and limestone-beds, d/ upper-reddish-mudstones/siltstones, with frequent limestones and some anhydrites [3, 5]. The Ghar formation comprises mainly of successive-buildups of sands-gravels and sandstones interlayers. The field is around 35Km north of the Basra city as shown in Figure (1).

Eighteen-drilled-wells; differently crossed the Tertiary–Cretaceous succession. The Lower Fars and Ghar Formations at the represented oil-well Nu-18; are encountered within the depths 336 to 675m and 675 to 780m respectively, with good core recovery and cuttings prevalence. The succession was drilled between the depths 336 to 780m, of 444m thickness. The sedimentary intervals have been well-examined in this work through the cored-sections: (C1; 418 –430.5m), (C2; 603 – 612m, 615 – 617m), (C3; 621 – 627.5m), (C4; 630 – 647m), (C5; 648 – 654.8m), and (C6; 661m – 669m). Drill-cuttings from the different intervals of the both formations have undergone into petrologic analysis. Tens of rock-thin-sections from cores & drill-cuttings have studied petro-graphically as well.

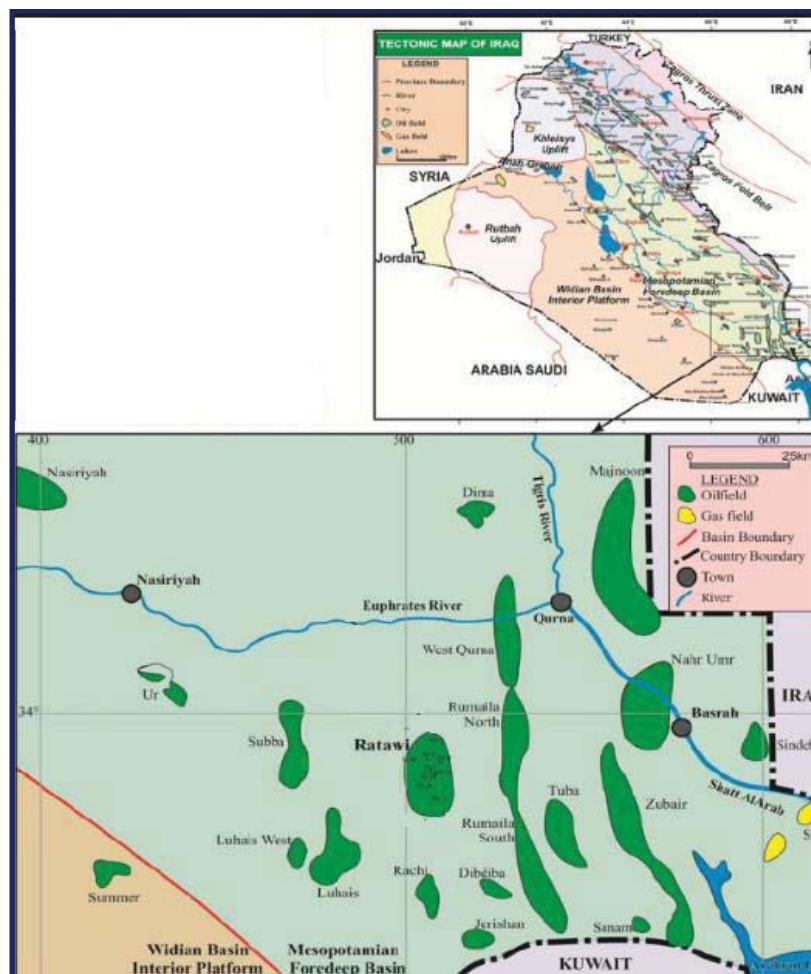


Fig. (1) Location Map of Nahr Umr Filed

The main purpose of this work:

The aim of this investigation is to construct the first rock-typing system of the studied succession; from stand point of sedimentary litho-facies to related reservoir zonation buildups and accompanied concludes pore-system characterization. The first part covers the sedimentologic succession in the Nahr Umr oil-well Nu-18 via the good rock (core to drill cuttings) availability, the second part covers the reservoir rocks characterization, and to evaluate the rock-potentiality of the both formations in the Nahr Umr oil field.

Discussion:

Part One: Sedimentology

The Lower Fars formation top is described in this study as marl greenish-grey, soft/plastic-texture, calcareous, and limestone marly pale-green, plastic to semi-plastic, anhydritic, partly sandy of very-fine/fine-grained-texture, corresponds to (336m) as equivalent-log-depth at this studied oil-well. Generally, it represents lagoonal/evaporate depositional setting. The formation conformably underlies the Upper-Miocene/Pliocene Dibdibba formation, of fluvial to deltaic sands-gravels and pebbles of multi-colors, and sandstone-interlayers. The sedimentary-interval bounded between 336 to 675m represents; marl-sandy, interbedded by marl to anhydrite, and carbonate succession representing the Lower Fars formation.

The Lower Miocene siliciclastic buildups of fluvial/deltaic sands-gravels and pebbles of Ghar formation is encountered from 675 to 780m (total-depth at this well), it is unconformably superimpose the Late Eocene Dammam lagoonal carbonates Formation. The litho-data; has been extrapolated into log-facies as presented in the Figures (2-1) and (2-2).

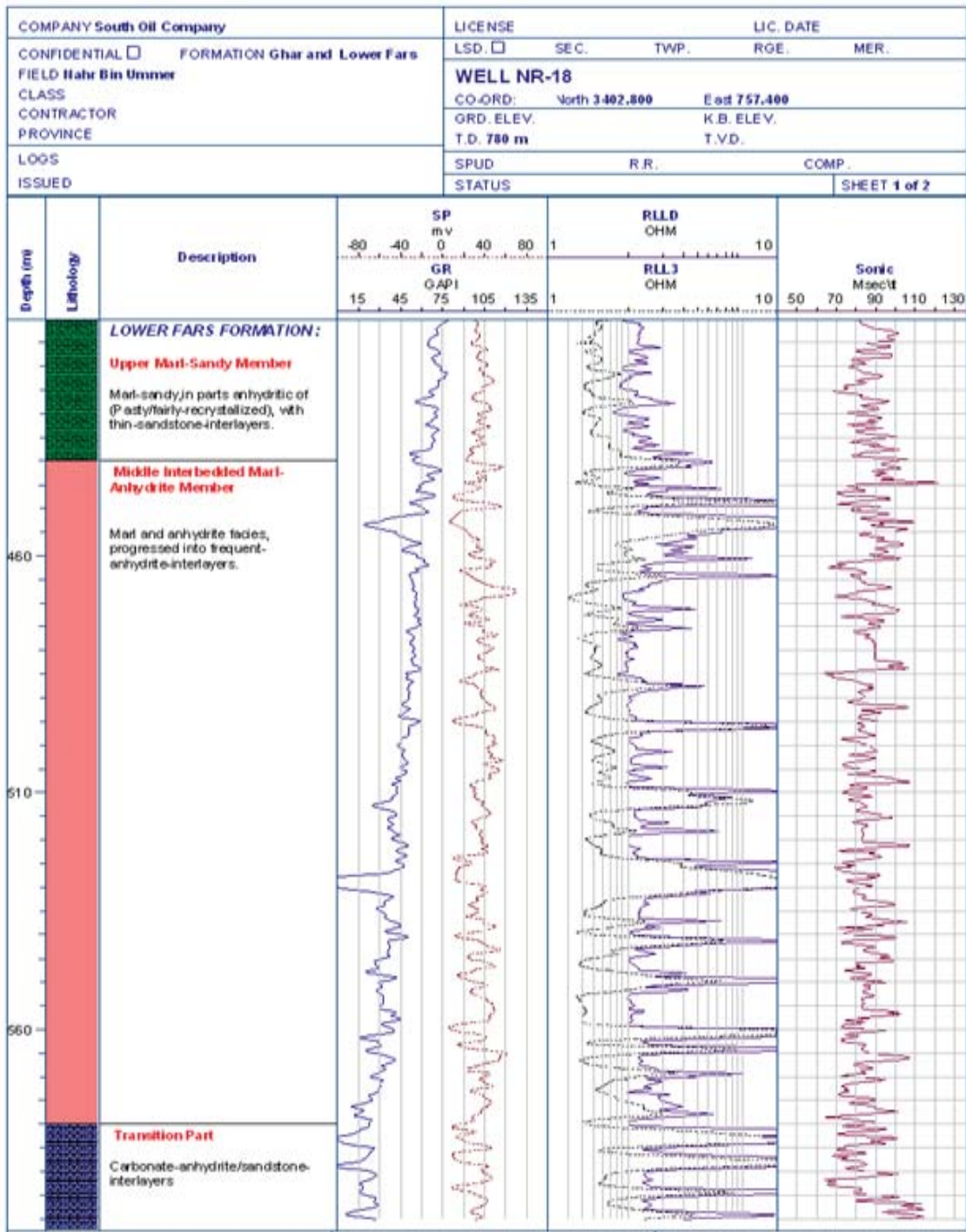


Fig. (2-1) Lithostratigraphic Construction of the Early-Middle Miocene Succession illustrates: Lithological members of the Lower Fars & Ghar formations at the well Nu-18, Nahr Nahr Umr Oil Filed.

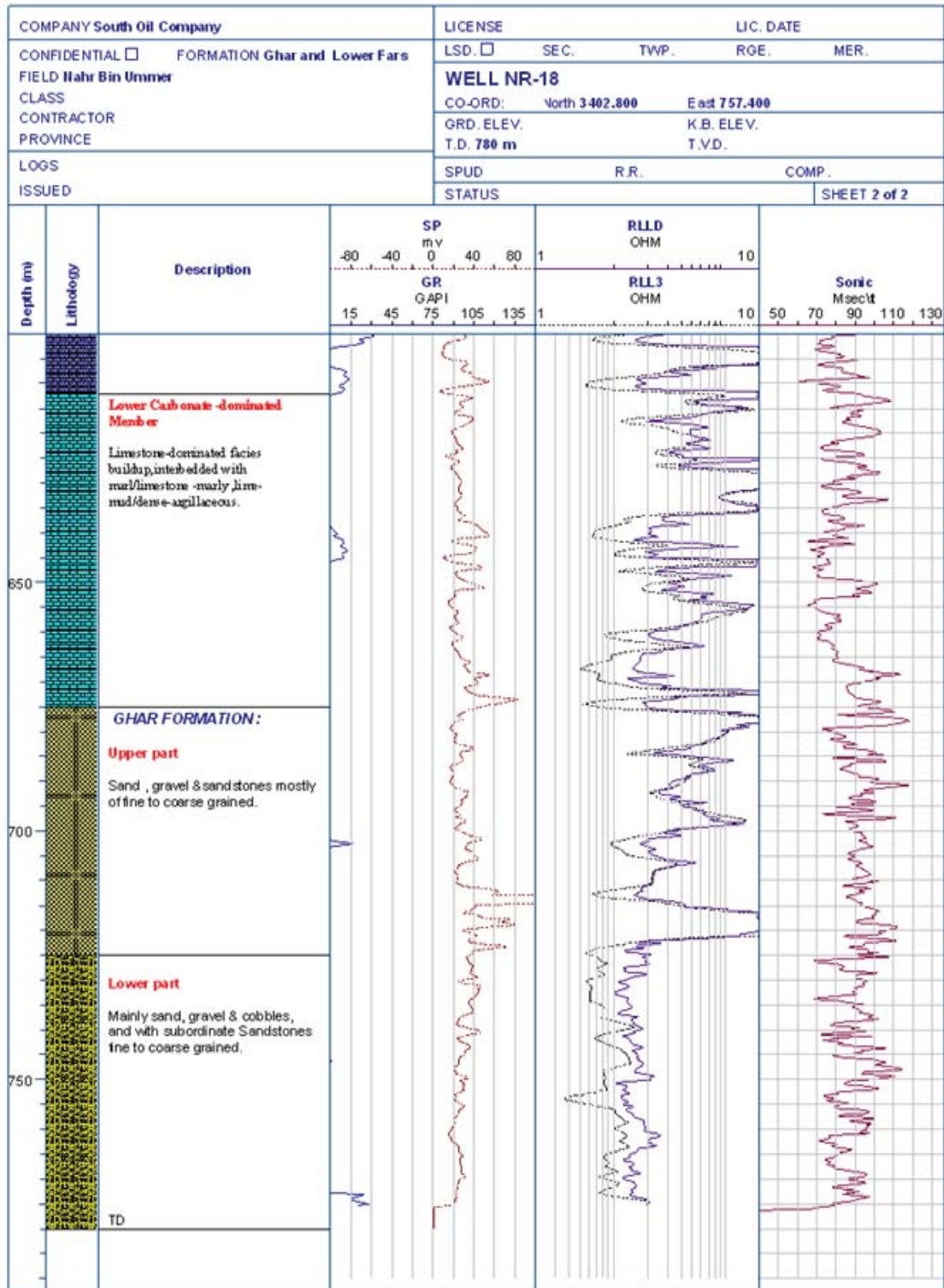


Fig. (2-2) Lithostratigraphic Construction; Continued, the Lower Fars Formation

The petrologic/petrographic analysis of the Lower Fars formation based on core and cutting examinations of tens of rock-thin-sections has issued; the following depositional members & related sedimentary intervals, in descending-order:

1. The Upper Marl-sandy Member: represent a depositional member from **336m to 440m (104m) thickness**. The member is comprised the following sedimentary intervals (sed-intervals):

Sed-interval 1-1: marl, greenish-grey, sandy, fine-medium grained, partly anhydritic pasty to slightly recrystallized with thin sandstone in-layers of fine-medium grained, vary-color, differently sorted, between **336 to 418m**.

Sed-interval 1-2: marl greenish-grey, plastic, calcareous, anhydritic, sandy, fine-grained, pyritic, and limestone-marly, pale-green, and semi-plastic, dense, with micro/mesovugs bituminous, between **418 to 425.5m**. Lime-mudstone facies, fine crystalline, with moldic pyrite, sandy of fine grained, argillaceous, anhydritic, plate (1), Figure (1). Sandstone facies between 424.5 to 425.5m, light-brown, fine to medium grained, sub-angular to sub-rounded, well-sorted, slightly calcareous, moderately packed, oily impregnated, plate (1), Figure (2).

Sed-interval 1-3: marl, greenish-grey, calcareous, plastic, sandy, and limestone-marly, pale-green, dense, semi-plastic, anhydritic, plates-1/1 and 2/1, between **425.5 to 440m**. Intercalated with; Lime-mudstone facies, sandy, fine/medium grained, sub-angular to rounded, rarely-sorted, pyritic, anhydritic, white, fine to medium grained, anhedral to subhedral anhydrite crystals, elongated-aggregates to fibrous texture.

2. The Middle Interbedded Marl – Anhydrite Member: a depositional member from **440m to 580m (140m) thickness**; interbedded marl-sandy and anhydrite facies. The marl-facies progressed into frequent-anhydrite-interlayers of well-developed anhydrite facies comprised mainly anhedral to subhedral crystals, elongated-aggregates/fibrous-texture. Subordinate anhydrite-gypsiferous facies.

Sed-interval 2-1: limestone marly, pale-green, soft/semi-plastic, slightly-argillaceous, anhydritic, with marl, green to greenish-grey, soft-plastic, calcareous, partly-sandy very-fine/fine-grained, with limestone, light-brown, fine-crystalline anhydritic between *440 to 465m*. *As well as*; anhydrite layers of white-colorless to light brown, pasty/crystalline-fabric, and elongated-aggregates to fibrous-texture. *As well as*; Mud to grain dominated bioclastic wackestone facies from *451 to 455m*, with mollusks, dolomitic, sandy, fine-grained, and argillaceous.

Sed-interval 2-2: intercalation of Marl, greenish-grey, soft-plastic, calcareous, anhydritic, sandy of fine-grained texture, and limestone light-grey, argillaceous, dense, partly pyritic between *465 to 476m*. Anhydrite bed, brown, of elongated-aggregates to fibrous-texture, partly pasty, between *471 to 476m*, intercalated with dolomite fine-crystalline, light-brown to brown, dense.

Sed-interval 2-3: series of marl, greenish-grey, soft-plastic, calcareous, sandy of fine to medium grained texture, and limestone marly, pale-green, dense, slightly argillaceous, with lime-mudstone facies, brown, fine-crystalline, dense-compact, argillaceous and bituminous, between *476 to 486m*.

Sed-interval 2-4: anhydrite bed of light-brown, elongate aggregates to fibrous-texture, partly of pasty-fabric, intercalated with dolomite fine-crystalline, light-brown/brown, dense, partly heavy-oil, between *486 to 488m*.

Sed-interval 2-5: Marl, green/greenish-grey, soft-plastic-fabric, calcareous, sandy of fine/medium-grained, and limestone marly, pale-green, dense, slightly argillaceous, partly-sandy, between *488 to 509m*. Interbedded by; anhydrite facies of light brown, elongated-aggregates, fibrous. Subordinate dolomite, fine-crystalline, brown, partly heavy oil show.

Sed-interval 2-6: limestone dolomitic-anhydritic bed, fine-crystalline-texture, with well-developed elongate anhydrite-crystals, randomly oriented aggregates, created high-

secondary-porosity, between *509 to 513m*. Intercalated with, mud/grain-dominated bioclastic wackestone facies, mollusks debris, micro/meso-vugs, slightly argillaceous, sandy of fine-grained texture.

Sed-interval 2-7: distinctive marl bed from *513 to 524m*, of green/greenish-grey, soft-plastic fabric, calcareous sandy fine/medium-grained texture, anhydritic, and limestone marly, pale-green, dense, argillaceous.

Sed-interval 2-8: specific Anhydrite-gypsiferous bed, between *524 to 531m*, of anhedral/subhedral, medium/coarse anhydrite crystals. Partly exhibits euhedral elongated gypsum crystals, randomly-oriented; good intercrystalline pore-system, and common micro/meso-vugs, plate (3).

Sed-interval 2-9: marl, green/greenish-grey, soft-plastic, calcareous, sandy of fine-grained-texture, and limestone marly, pale green, dense, argillaceous, anhydritic /dolomitic, between *531 to 560m*.

Sed-interval 2-10: intercalation of anhydrite-gypsiferous and limestone dolomitic, anhydritic, with marl, calcareous, sandy, between *560 to 565m*.

Sed-interval 2-11: A Marl bed, green/greenish-grey, calcareous, sandy of fine-grained, and limestone, light-brown, dolomitic-anhydritic, and fine-crystalline, between *565 to 580m*.

3. The Transition Part: a depositional-interval from *580m to 612m*, (32m) **thickness**. This sedimentary section is considered a transitional-zone from the lower-carbonate-dominated part to the middle interbedded part of the formation. A series of carbonate-anhydrite to sandstones-interlayers represents this part.

Sed-interval 3-1: Intercalation of limestone, light-brown/brown, dolomitic-anhydritic, fine-crystalline, micro-pore-system, and mud-to-grain-dominated bioclastic wackestone facies, well-developed composite-pore-system between *580 to 590m*. Interbedded with;

limestone marly, very-fine sands, and lime-mudstone facies, of grey, dense, compact, and argillaceous texture.

Sed-interval 3-2: Marl, green/greenish-grey, calcareous, sandy of mostly fine-grained, and lime-mudstone, grey, dense, argillaceous, encountered between **590 to 603m**. Interbedded with; limestone dolomitic-anhydritic, mud/grain-dominated bioclastic wackestone facies, partly silty.

Sed-interval 3-3: Intercalation of limestone-marly, greenish-grey, semi-plastic, dense, and lime-mudstone, brownish-grey, fine-crystalline, compact, anhydritic, with anhydrite white-colorless, fine to medium grained, anhedral/subhedral crystals, elongated-aggregates, fibrous texture, randomly oriented and slightly to moderately-packed, encountered between **603 to 606.85m**. Plate4.

Intervened with; lime-mudstone facies, pale-green, fine-crystalline, marly, tightly-packed-texture. Characterized by; well-developed mega-fractures and micro-to-megavugs. The interval indicates: local-tectono-sedimentary period/late-diagenetic/subareal-exposure of vadose-zone. At **606.85m** composed of grain-dominated bioclastic wackestone/packstone facies, common to abundant mollusk and gastropod shells. Comprises; composite pore-system of micro/meso-to-mega-vugs, moderately-open network, with common micro-vugs/microfractures, oily.

Sed-interval 3-4: Marl, greenish-grey, plastic to semi-plastic, calcareous, intercalated with limestone marly, pale-green, anhydritic, sandy, fine-medium grained, calcareous, between **606.85 to 612m**. Intercalated with; Lime-mudstone facies, fine-crystalline, anhydritic to anhydrite facies of fine/medium-grained, anhedral to subhedral crystals, elongated-aggregates/fibrous-texture, with megavugs/micro-mega-fractures, bituminous, moldic pyrite, plate4, figs 3 & 4.

4. The Lower Carbonate-dominated Member: a depositional member between **612m to 675m (63m) thickness**. Characterized mainly by; limestone-dominated facies buildup, interbedded by marl/limestone-marly, lime-mudstone/dense-argillaceous, and less frequent thin-anhydrite-&-sandstone-interlayers.

Sed-interval 4-1: Sandstone, brown, fine to medium-grained, subangular/ subrounded to rounded grains, moderately-sorted, friable-character, calcareous.

Intercalated with; lime-mudstone, sandy/silty, anhydritic, microvugs oily-stained, intervened by aggregated-anhydrite-crystals, microvugs bituminous, between **611.80 to 613.50m**. Well-developed mega-vugs and microfractures @ 612.75m and 612.95m, oily impregnated, may reflect emergence-features.

Sed-interval 4-2: Limestone, brown, chalky/granular-texture, loosely-packed to friable-character, common mollusk-shells, sandy of very-fine-to-fine grained, and organic matter, between **613.50 to 616.50m**. Intercalated with; lime-mudstone, dense, partly dolomitic, and sandstone, brown, fine/medium-grained, calcareous, with marl greenish-grey, sandy, calcareous, plate5, figs 1 & 2. A well as; grain-dominated bioclastic wackestone/packstone facies, common to abundant mollusk and gastropods shells with milliolids, abundant composite-vuggy pore system of micro-to-mega types and solution-enlarged-voids partly well-connected by solution-micro-channels.

Sed-interval 4-3: Limestone bed between **621 to 623.80m**: brown, chalky to granular texture, loosely-packed/friable-character, common mollusk-shells, sandy of very-fine-to-fine grained, with oil show. At **621.23m**: mud/grain-dominated bioclastic wackestone facies encountered, with common mollusk, with megavugs of good connectivity-pattern, and solution-channels/microfractures.

Well-developed lime-mudstone facies with composite-pore system and solution-enlarged-voids, oily impregnated.

Sed-interval 4-4: Mud/grain-dominated bioclastic wackestone facies, moderately to packed, intercalated with lime-mudstone facies, of fine-crystalline, clayey, dense, sandy very-fine-grained, in-parts with moldic-pyrite, between **623.80 to 637.60m**. As well as; Limestone, brown, chalky/granular-texture, loosely-packed, common Mollusk-shells, sandy very-fine/fine grained, vuggy, with oil show, intercalated with lime-mudstone, pale-green, fine-crystalline, dolomitic, dense.

Intercalated with limestone, marly, pale-green, plastic, common moldic-pyrite, and

limestone brown, chalky/granular, fairly-packed, sandy, oily-stained, with micro-to-mega-vugs, solution-micro-channels/microfractures, oily-bituminous.

Sed-interval 4-5: Lime-mudstone facies, pale-green, fine-crystalline, dense-compact, moderately-packed, marly, anhydritic, partly sandy of fine-grained, between **637.60 – 649m**. Intercalated with; lime-mudstone, grey to light brown, fine-crystalline, anhydritic, dense, packed, and anhydrite, white/colorless, fine to medium-grained, anhedral to subhedral crystals, elongated-aggregates/fibrous-texture. The white/colorless anhydrites, of fine/medium grained, anhedral to subhedral crystals, of elongate-aggregates/fibrous-texture are randomly-oriented.

The pore characterization is of open-network-character, oily-stained, plate (5), Figure (3).

The interval **645.60 to 649m**: limestone, brown, chalky/granular-texture, loosely character, Mollusk-shells, sandy very-fine/fine grained, and oil show with organic matter, intercalated with lime-mudstone, pale-green, anhydritic/dolomitic, partly the texture shows solution-microchannels, oily-stained.

Sed-interval 4-6: Limestone, brownish-grey, chalky-to-granular-texture, of loosely to moderately-packed character, with common mollusk-shells, sandy fine-grained, oily-stained and/or bituminous, between **649.5 to 654.80m**.

Intercalated with; lime-mudstone, pale-green, fine-crystalline, dense, dolomitic, and marl, pale-green, plastic/semi-plastic, calcareous, & lime-mudstone, marly, dense, plate5, Figures (1) & (2). The interval from **654.8 to 661m** is of no recovery.

Sed-interval 4-7: Limestone, brownish-grey/brown, chalky to granular texture, loosely to moderately-packed, with common mollusk-shells, sandy of fine grained, with organic matter/bituminous, intercalated with lime-mudstone, pale-green, fine-crystalline, dense, between **661 to 669m**. At **661.55m**: characterized by bioclastic-peloidal packstone/grainstone facies with ***Dendritina cf. rangi***, and common rounded mollusk-shells partly micritized. In-parts the facies is moderately-cemented by fine/medium equigranular-mosaics, whereas; at the other parts the facies shows well-developed

inter/intra-granular pores, oily, shoal buildup, plate6, Figures (3) & (4). Between **662.70 to 667m**: limestone, brown, chalky to granular texture, loosely-packed/friable, with common mollusk-shells, sandy of fine-grained, megavugs/microfractures of late-diagenesis, with oil.

Intercalated with; lime-mudstone, green, fine-crystalline, dense, compact and bituminous. The rock-fabric is up-graded into bioclastic-peloidal wackestone to packstone/grainstone facies at 662.70m, with common mollusk/ostracod shells mostly of peloidal-texture, and sandy. The overall facies is of shoal-buildup.

The interval; well intercalated with finely to moderately-recrystallized anhydrites. From **661.55 to 668m**; may represent: the Jeribe equivalent section. *Whereas*; at **668.5 – 669m** composed of sandstone, white/brown, fine/coarse-grained, subrounded/rounded, sub-angular, friable, of variably-sorted, slightly & in-parts of moderately calcareous, and oil show, bituminous at 668.5m. From **669 to 675m**; is considered a transitional section from Ghar formation to Lower Fars formation, composed of sand-gravel/sandstones and limestones/marl.

The Ghar Formation

Ghar Sedimentary Units Construction:

This formation originally described by Owen and Naser 1958, at the type-locality Zubair oil-well 3: consists sands & gravels with sandstones, and interlayers of limestones sandy; deposited in fluvial-deltaic-sedimentation all over south Iraq during early Miocene. The Ghar formation was not cored previously and basically studied by drill-cuttings, the top of the formation at the studied-well has identified at **675m**; as first appearance of sands and gravels with sandstones calcareous.

1. The Upper Part: 675 – 725m: It is made-up mainly of sands, gravels & more sandstones mostly of fine/medium to coarse-grained-texture, almost same aforementioned composite-litho/pore system characteristics of the lower part.

Sed-interval 1-1: sandstones white-brown, of fine to medium-grained, subrounded-to-rounded, moderately-sorted, fairly to moderately-calcareous, well-developed intergranular-pore-system, improved by micro/meso-vugs, oil show, between **675 to 686m**. Intercalated with; sandstones white-grey, fine/coarse-grained, calcareous, argillaceous, compact.

Sed-interval 1-2: This interval resembles the above interval, yet; the sandstones mostly of medium/coarse-grained, subrounded/rounded, moderately-sorted, slightly-moderately calcareous, well-developed intergranular pore-system, more tightly-packed and less oil show, between **686 to 696m**.

Sed-interval 1-3: sands and gravels, white/light-brown color, subrounded to rounded-grains, loosely-packed, of highly-friable-character, in-parts with chert-grains, between **696 to 700m**.

Sed-interval 1-4: sands and gravels, white/light-brown color, subrounded to rounded-grains, loosely-packed, of highly-friable-character, in-parts with chert-nodules, and subordinate facies of sandstone, white-to-light-brown, fine-to-coarse-grained, calcareous, moderately-sorted, oily, between **700 to 716m**, brown/dark-brown bituminous/or heavy oil show; between 711 and 714m.

Sed-interval 1-5: sandstones white-to-light-brown/brown, fine-to-coarse-grained, subrounded/rounded, moderately-sorted, calcareous, and highly-loosed, good intergranular-pores, good oil show, between **716 – 725m**.

2. The Lower Part: 725 – 780m (TD): This part comprises mainly of sands, gravels & cobbles, vary-colors, subrounded to rounded grains, with subordinate sandstones of variable-colors as well, fine-to-coarse-grained-texture, and of moderately sorted fabric, loosely-packed and friable-character. Characterized *by*; sandstones white/light-grey/grey, fine-to-coarse-grained, subrounded/rounded, poorly-to-moderately-sorted, calcareous, and argillaceous, more-dense/compact, in-parts sands, gravels and chert-grains, and

bituminous, between 725 – 745m. From 745 to 765m: coarse-grained sandstone, less friable and of conglomeratic. Whereas; from 775 to 780m comprised by limestones, white-to-light-grey, sandy of fine/medium to coarse-grained, of fine-crystalline-texture, compact, bituminous. At the base of this part contains dolomite and limestone-dolomitic facies, it may reflect the top of the underlying Dammam formation.

Part Two: Reservoir Rocks Characterization

This part has organized to study the rock-facies/pore-system characterization to; delineate reservoir lithofacies layering system. The rock-cuttings and core-depths are corrected to their log-equivalents.

The Lower Fars Formation

According to; the above aforementioned lithological subdivision and composite-lithofacies/pore-system characteristics of this formation with (LF) symbolized items, plates (1) to (6) and Figures (3a & 3b); the following scheme has organized:

1. Lower Fars Part-A (LF-A):

This part represents the upper-member of the formation and does not maintain any reservoir-rock characteristics due to; non-required petrophysical properties. It is ranked under non-reservoir-rocks and classified as a main cap-rock for the underlying reservoir units.

2. Lower Fars Part-B (LF-B):

This part of the formation represents the middle-member consists of; many reservoir-units of varied thicknesses. From stand point of reservoir geology: the important investigated units are as follows:

2.1: Reservoir Unit (LF-B1): intercalation of mud-to-grain-dominated bioclastic wackestone facies, sandy, and lime-mudstone facies partly recrystallized (microsparitic-texture) dolomitic, between 451 to 455m.

The interval between 455 to 510m consists of marl, sandy, anhydritic and lime mudstone facies, dense and argillaceous of non-reservoir characteristics.

2.2: Reservoir Unit (LF-B21): lime-mudstone, microsparitic, dolomitic, anhydritic between *510 to 514m*. The micro-intercrystalline pore-system highly controls the reservoir characteristics, oily impregnated. The interval between *414 to 525m* consists of marl, sandy, anhydritic and lime mudstone facies, dense and argillaceous of non-reservoir characteristics.

2.3: Reservoir Unit (LF-B22): composed of anhydrite-gypsiferous facies of well-developed anhedral/subhedral anhydrite crystals, of elongated-aggregates and fibrous-texture, between *525 to 531m*, plate 3. The anhydrites; commonly transformed into secondary-gypsum of very well-developed subhedral-euhedral fibrous-crystals, confirms fine/medium-acicular-halite-crystals. The randomly oriented crystal network during the very late diagenetic process, highly created good secondary pore system, improved by; micro-to-meso and mega-vugs with solution-enlarged-voids, oily impregnated. The interval *531 to 560m* consists of marl, sandy, anhydritic/dolomitic and lime mudstone facies, dense, argillaceous is of non-reservoir characteristics.

2.4: Reservoir Unit (LF-B23): composed of anhydrite-gypsiferous facies, well-developed anhedral/subhedral anhydrite crystals, elongate aggregates of fibrous-texture, as well between *560 to 565m*. The anhydrite crystals are commonly well-transformed into secondary gypsum of very-well-developed fibrous-texture. The randomly-oriented crystal-network of the anhydrite and gypsum during late-diagenesis; created good-secondary-pore-system, improved by micro to meso and mega vugs. The interval from *565 to 581m* of marl, sandy, anhydritic and dolomitic/lime-mudstone facies, dense and argillaceous is non-reservoir unit.

3. Lower Fars Part-C (LF-C):

This part of the formation represents the depositional transition zone between the lower and middle members, consists of a well-developed single-reservoir-unit; evidently itemized as LF-C1.

Reservoir Unit LF-C1: mud-to-grain-dominated bioclastic wackestone facies, dolomitic, and sandy of fine-grained to silty, slightly-argillaceous between *581 to 589m*, represent good oil-zone, through the composite-pore-system; micro-meso to megavugs/solution-microchannels with intercrystalline-pores. The interval from *589 to 612m* is mud-grain-dominated bioclastic wackestone/lime-mudstone facies, dolomitic/anhydrite & marl/thin-sandstone-beds, of low reservoir character.

From *601 to 607m*; well-developed meso/mega-vugs/micro-to-mega fractures in anhydrite facies, good hydrocarbon-continuity between the underlying carbonate dominated reservoir-units and the overlying anhydrite-carbonate reservoir-units.

4. Lower Fars Part-D (LF-D):

This part is obviously represents the lower-carbonate-dominated member of the Lower Fars formation. The lower-most-section of the member represents well-developed HF-cycles of shoal/lagoonal-buildup of HST-depositional-system. The system occasionally affected by; restricted-lagoonal/evaporitic features of non-reservoir-facies, and subareal-exposures influences of sand-silt-influxes, the part consists of 2-main reservoir-units:

4.1: Reservoir Unit LF-D1: Encountered between *612 – 616m*, characterized by grain-dominated bioclastic wackestone/packstone facies, with common mollusk shells, well-developed composite-micro/megavugs-system and solution-enlarged-voids/solution-micro-channels, oily-impregnated. The peloidal-texture of shoal-tendency is oily-impregnated. The interval between *616 to 627m*; is lime-mudstone facies, dense argillaceous and considered non-reservoir unit.

4.2: Reservoir Unit LF-D2: mud-dominated bioclastic wackestone facies, common mollusk-shells, sandy fine grained, oily-impregnated, and moderately cemented between *627 to 635m*. Intercalated with; lime-mudstone, pale-green, fine-crystalline, dolomitic/anhydritic, micro/mega-vugs/solution-micro-channels to microfractures, oily-impregnated. The Mega-vugs/solution-enlarged-voids at 634.25m may represent late-diagenetic-feature/subareal exposure-effects.

The interval from *635 to 675m* is non-reservoir unit, lime-mudstone to mud/grain-dominated bioclastic wackestone facies, compact, argillaceous, anhydritic and dolomitic, between 645 – 647m & 653 – 657m; with organic matter.

The Ghar Formation

Based on; the sedimentary lithofacies buildup, two-informal lithostratigraphic members of the Ghar formation and related log-facies characteristics; are summarized as in the following scheme, refer to Figures (3a) and (3b):

1. The Upper Part:

It is encountered between *675 – 725m*; made-up mainly of sands, gravels & more sandstones mostly of fine/medium to coarse-grained-texture, almost same aforementioned composite-litho/pore system characteristics of the lower part.

2. The Lower Part:

This part is encountered between *725 – 780m (log-TD)*; comprises mainly of sands, gravels and cobbles, of vary colors, subrounded to rounded grains, with subordinate sandstones of variable-colors as well, fine-to-coarse-grained texture, and of moderately-sorted fabric, loosely-packed and friable character.

The Ghar Reservoir-Layering (**GH-Units**): is established as in their descending order of buildups; refer to Figures (3a) & (3b):

1. Ghar-A (GH-A): reservoir unit between *676 – 681m*; consists mainly of sands and gravels and sandstones white-brown, fine to medium-grained, subrounded-to-rounded, and moderately-sorted, moderately-calcareous, with well-developed intergranular pore-system, enhanced by micro/meso-vugs, oily-impregnated.

2. Ghar-B (GH-B): reservoir unit between *715 – 721m*; consists mainly of sandstones white-to-light-brown/brown, subrounded to rounded, fine/medium to coarse-grained fabric, moderately-to-well-sorted texture, slightly-calcareous, and of highly-loosed

character created very-good intergranular pore-system, made the interval to be of good oily-impregnated unit.

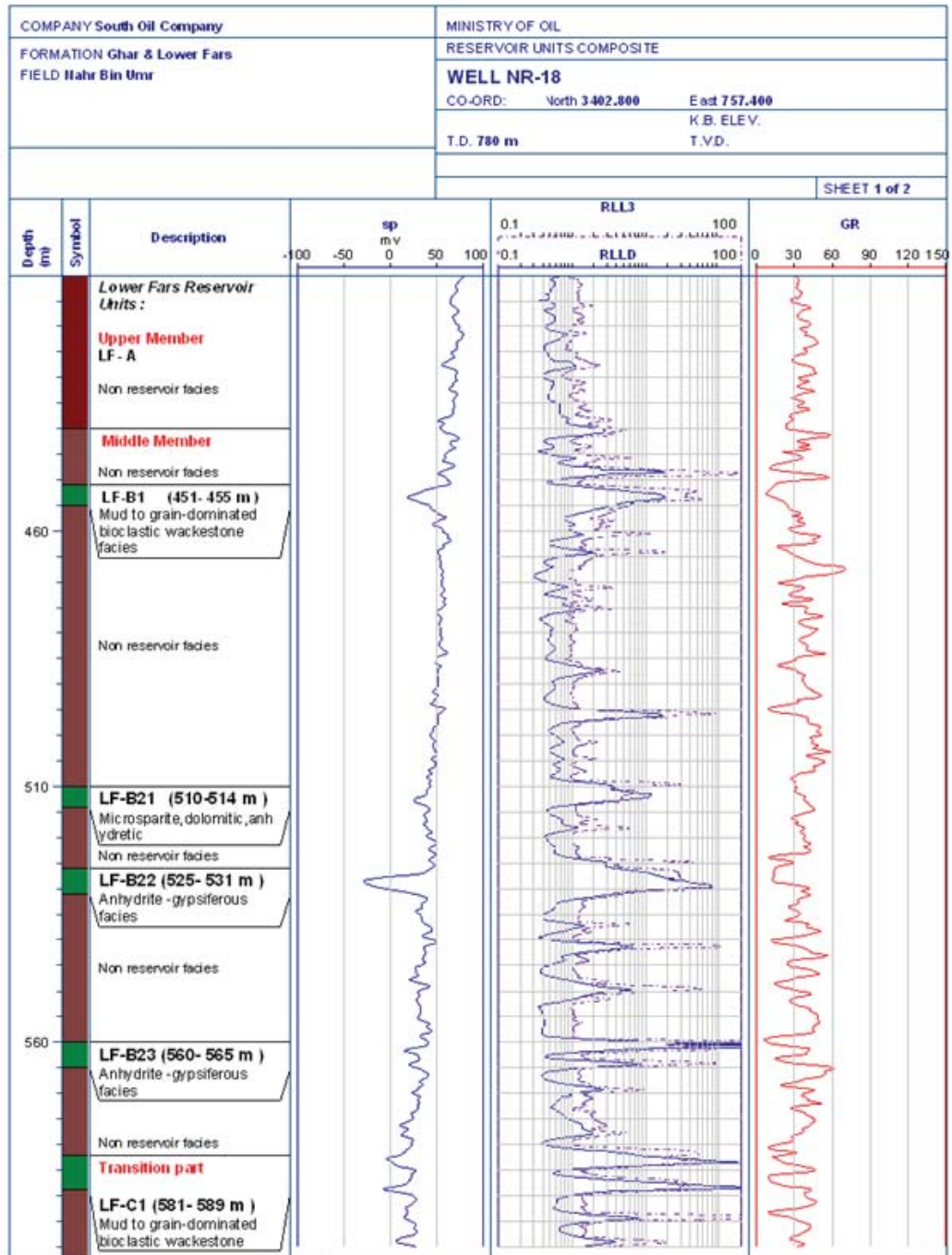


Fig. (3a) Reservoir-Lithofacies-zoning of the Lower Fars and Ghar Formations in the well Nu-18, Nahr Nahr Umr Oil Filed.

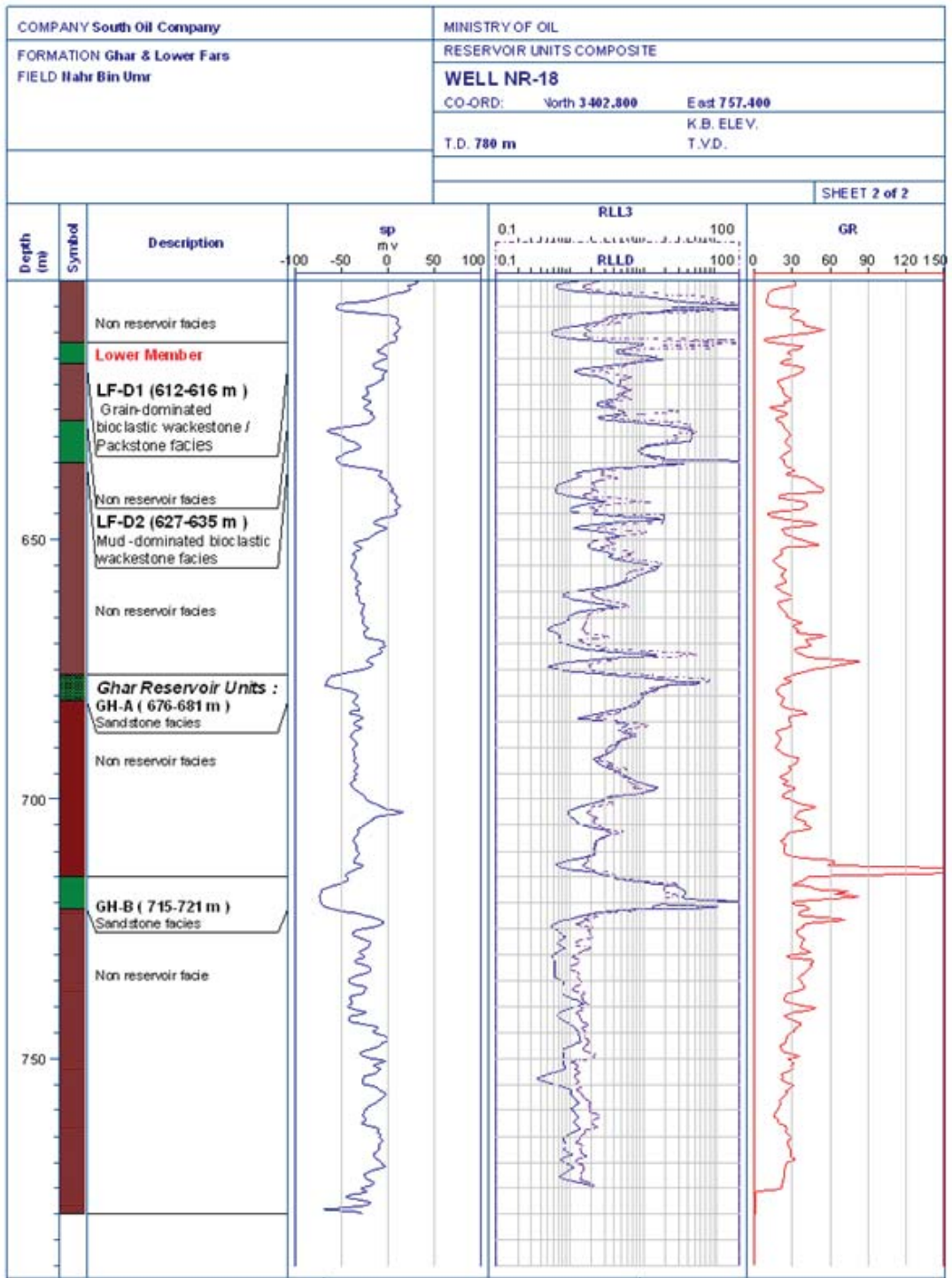


Fig. (3b) Reservoir-Lithofacies-Zoning; continued.

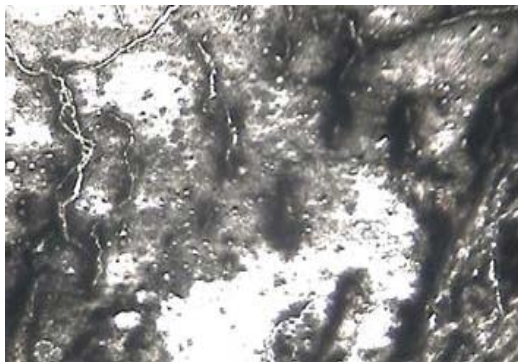
Plate -1-

Figure (1): Marl, greenish-grey, plastic, calcareous, sandy of fine-grained and limestone-marly, pale-green, soft and semi-plastic, anhydritic in-parts, and 423.30m X10.

Figure (2): Sandstone facies, fine-medium/coarse-grained, sub-angular/sub-rounded/rounded, well-sorted, loosely to moderately-packed-texture, good intergranular-pores with common micro/meso-vugs, oily impregnated, 424.75m X20.

Figure (3): Marl, greenish-grey, plastic, calcareous, sandy of (very-fine to fine-grained), and limestone-marly, pale-green, dense, soft and semi-plastic, anhydritic in-parts, 426.30m X10.

Figure (4): Enlarged-view (X45) of fig2, X-nicols, sub-rounded/rounded monocrystalline quartz grains, less polycrystalline-grains, fluvial impact during early/middle lowstand depositional system. It represents the uppermost section of the Lower Fars formation.



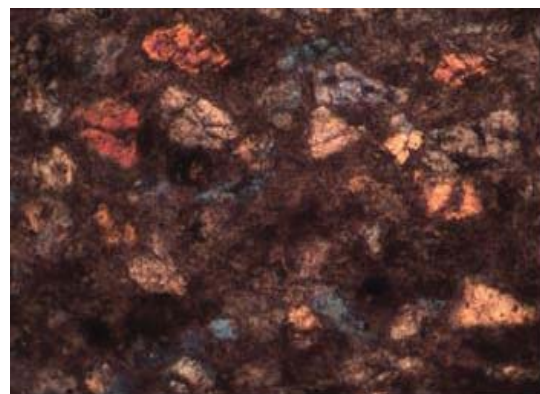
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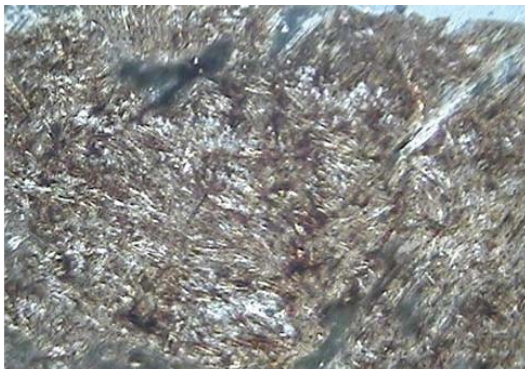
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Plate -2-

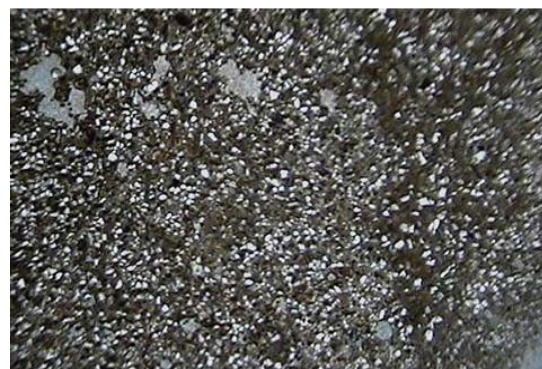
Figure (1): lime-mudstone facies, fine-crystalline, anhydritic with common and well-developed anhydrite crystals, white/colorless, anhedral/subhedral, fine/medium-grained, mostly elongated-aggregates and fibrous-texture, common microvugs oily, 428.70m X10.

Figure (2): Lime-mudstone facies, fine-crystalline, dense, sandy fine to medium-grained, sub-angular/subrounded-rounded, rarely-sorted texture, common micro-vugs oily, randomly-distributed mega-vugs of open-character, with moldic-pyrite, 429.85m X10.

Figures (3) & (4): Represents anhydrite-gypsiferous facies of well-recrystallized, anhedral-subhedral anhydrite/gypsum crystals, white-colorless, fine/medium-to-coarse aggregates/elongated-grains, commonly fibrous texture, rarely of rectangular cleavage. Randomly oriented aggregates with well-developed micro-to-meso/mega pores/solution-microchannels of open-pattern, oil show. X25-45. **Sed-interval 2-8:** 524-531m.



1



2



3

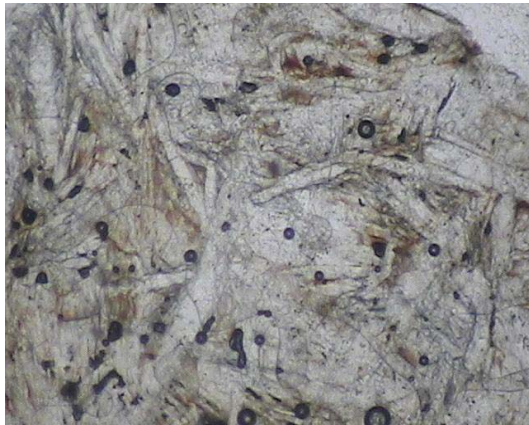


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Plate -3-

Anhydrite-gypsiferous facies; composed of well-recrystallized anhedral-subhedral crystals of anhydrite/gypsum, white to colorless. The overall texture shows fine to medium/coarse & elongated-grains, fibrous-fabric, rarely of rectangular-cleavage.

The randomly oriented aggregates well-improved and well-distributed showing micro-to-meso/mega pores, enhanced by solution-microchannels of open pattern, oily impregnated, X25. Reservoir unit LF-B22, 525-531m.



1



2

Plate -4-

Figures (1) & (2): same anhydrite-gypsiferous facies as plate2 figs 3 & 4, and lime-mudstone transition-to-anhydrite, with anhydritic-gypsiferous texture, with dendroid microfractures, 603.60m X10.

Figures (3) & (4): Anhydrite-gypsiferous facies with more anhedral/subhedral crystals, fine-to-medium-grained, elongated-aggregates, fibrous-texture, randomly-oriented. Well-developed micro/meso-pore system, oily, of good intervening between anhydrite and lime-mudstone facies. Represent mega-fracturing period, probably due to faulting. It shows common coarse-crystalline-anhydrite/gypsum of aggregated/fibrous-grains-texture, less intervened lime-mud. The facies processes well-developed composite-pore-system, oily impregnated in parts, 609.85-611.80m X10.

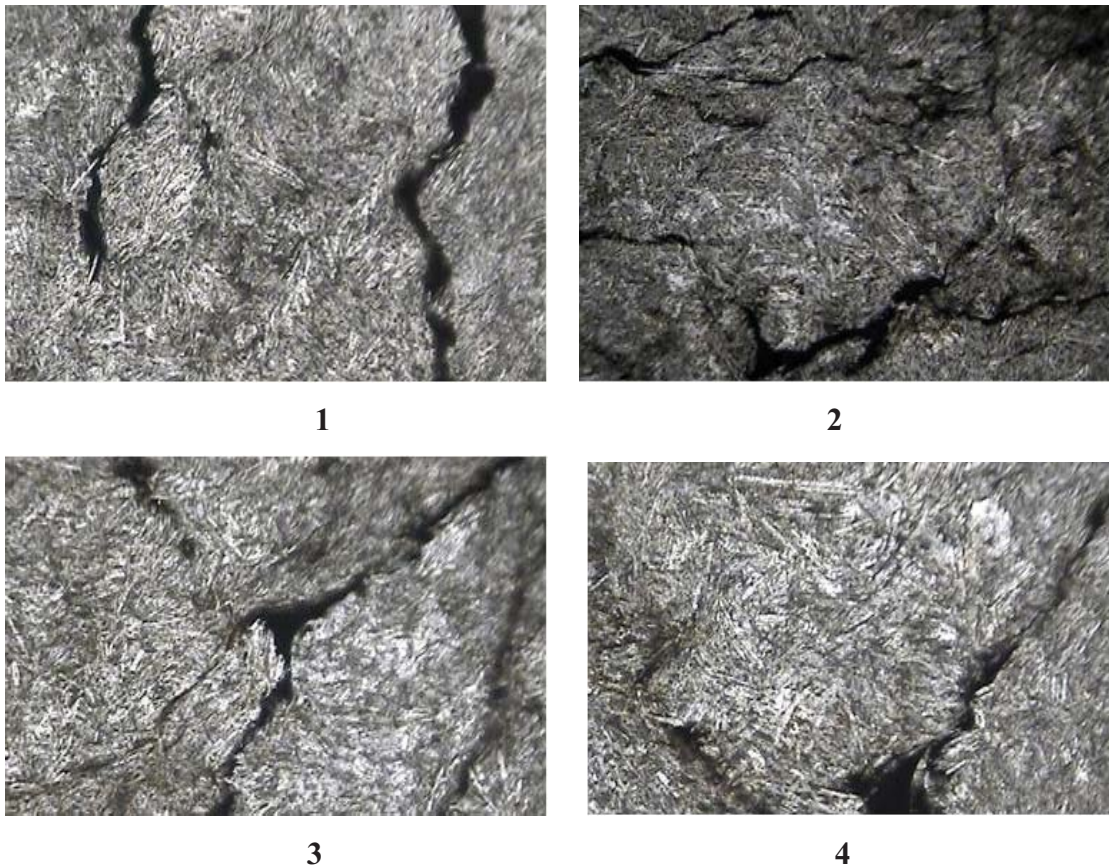


Plate -5-

Figures (1) & (2): represent grain-dominated bioclastic wackestone/packstone facies, with common to abundant Mollusc and Gastropods shells with Millioids.

It shows Well-developed composite-pore-system of micro-to-mega pores and solution-enlarged-voids, well-connected by solution-micro-channels, and oily.

In-parts of peloidal-texture, of micritized-bioclats and some of micritic-rims, may represent shoal-setting of moderate-energy-action, oily-stained. The facies of microsparitic texture, silty, and shows well-developed micro/meso-vugs oily-impregnated. It represents intensive-dissolution section with related composite-pore system of well-developed micro-to-mega/solution-enlarged-voids.

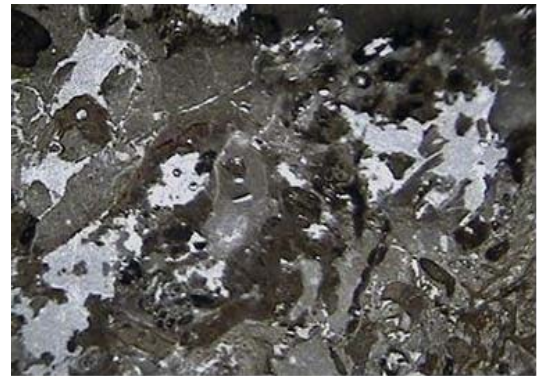
613.50-616.50m X15.

Figure (3): Lime-mudstone of anhydrite-gypsiferous facies, of white/colorless, anhedral-to-subhedral crystals, fine/medium to coarse-grained and randomly-oriented pattern, elongated-aggregates and of fibrous-texture. The crystal-fabric and pore-system pattern;

created open-pore-system improved by micro to meso-vugs of oily-stained-character, 644.55m X15.



1



2



3

Plate -6-

Figures (1) & (2): represent mud to grain-dominated bioclastic wackestone facies of floatstone texture, with less-common Mollusk-shells with micritic-rinds, Characterized by; well-developed micro-to-meso-vugs, open-character, oily.

649.70m X10. Mud-dominated bioclastic wackestone facies, sandy in-parts of fine-grained, regularly-oriented solution micro-channels, oil show.

Figure (3): represents grain-dominated bioclastic-peloidal packstone facies graded to grainstone facies of rudstone-moderately-packed-texture, with common Mollusk &

Ostracod-shells of peloidal-texture and rare forams. Partly the texture is sandy of fine-grained, and anhydritic. The facies represents shoal-buildup of high-cementation stage; by lower-phreatic-zone of diagenesis. Well-developed composite pore-system of micro-to-mega-vugs, molds/solution-enlarged-voids, of open-network, well-developed solution microchannels, oily. In-parts partially to completely cemented by fine-medium equi-mosaics, 661.55m X10.

Figure (4): Mud/grain-dominated bioclastic-peloidal packstone facies of floatstone-texture, with *Dendritina cf. rangi*, *Nodosaria sp.*, and common mollusk, and ostracod shells, less-than 2 mm in size, peloidal, and with undetermined-forams. It partly shows sandy texture, fine-grained, anhydritic and finely-recrystallized. Moderately to highly cemented, tightly-packed, 661.55m X15.



1



2



3



4

Conclusions:

The study assigns the following conclusions & recommendations concerning the stratigraphy of the studied succession:

1. The Lower Fars formation has subdivided into four sedimentary-members: the upper marl-sandy member, the middle interbedded marl – anhydrite member, the transition part, and the lower carbonate-dominated member.

2. The vertical lithofacies buildup of the Lower Fars formation is successively, which is composed of mud to grain-dominated bioclastic wackestone facies, and lime-mudstone anhydritic/anhydrite facies capped by siliciclastic sandstone facies. The Ghar litho-cycle comprises single low stand siliciclastic facies.

3. The Ghar formation has litho-strati graphically subdivided into 2-sedimentary-litho-units, the upper and the lower, mainly composed of sands, gravels and cobbles with sandstones in-layers.

4. The composite-litho-facies/pore-system characteristics; have fixed the following reservoir-units for the both formations under study:

1. Lower Fars Formation:

1.1: Lower Fars Part-A (LF-A): Non-reservoir-facies unit.

1.2: Lower Fars Part-B (LF-B):

a. Reservoir Unit: LF-B1. **b.** Reservoir Unit: LF-B21. **c.** Reservoir Unit: LF-B22.

d. Reservoir Unit: LF-B23.

1.3: Lower Fars Part-C (LF-C):

1.4: Reservoir Unit: LF-C1

1.5: Lower Fars Part-D (LF-D):

a. Reservoir Unit: LF-D1. **b.** Reservoir Unit: LF-D2.

2. For Ghar formation:

2.1: Ghar-A (GH-A). **2.2:** Ghar-B (GH-B).

5. It is highly recommended to submit the lowermost carbonate interval of the Lower Fars formation; for further investigation to verify Jeribe-like-facies.

6. For development purposes; it is highly-recommended to organize a selective-completion program to isolate the mentioned reservoir-units for both formations.

7. It is recommended to continue this study for petro-physical consideration, and for other new drilled wells to get more understandings on fields-scale aspects.

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