LITHOFACIES ASSOCIATION, DOLOMITIZATION, AND POTENTIALITY OF THE PILA SPI FORMATION, TAQ TAQ OIL FIELD, KURDISTAN REGION, NE IRAQ

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ABSTRACT

Subsurface data of four oil wells from the Taq Taq oil field of Northeast Iraq, in addition to one surface section from the near by Haibat Sultan Mountain were selected to study the lithofacies associations of the Pila Spi Formation. Detailed investigation of rock samples, cuttings, cores and wire-line logs is attempted to identify lithologic units and association, and to evaluate dolomitization effect on these rocks and its contribution to the reservoir quality.

The formation, in this area is subdivided into four distinctive lithologic units, from bottom to top are: Lower Brecciated and Silicified Unit (P1), Dolomitized Tidal Flat Limestone (P2), Lagoonal Limestone and Dolostone (P3), and Upper Brecciated Dolomitic Limestone (P4). These rocks were variably affected by diagenesis and intensively modified by dolomitization, which is drastically overprinted the original fabrics and components. Several types of dolomite were recognized including: Fenestral Fine Crystalline Dolomite (D1), Fine Crystalline Planar-e to Planar-s Dolomite (D2), Fine Crystalline Non-planar Dolomite (D3), Medium Crystalline Non-planar Dolomite (D4), and Coarse Crystalline Dolomite (D5).

Dolomitization had positively influenced the reservoir characteristics by enhancing inter-crystalline porosity, and developing intra-skeletal and moldic porosity, which evolve into the common micro-vug porosity, especially, in the middle lithologic units (P2 and P3). Reservoir flow potentiality, however, is greatly enhanced by the secondary fracture porosity.

الوحدات السحنية الصخرية، الدلمتة، والقدرة المكمنية لتكوين البيلاسبي في حقل طق طق، إقليم كوردستان، شمال شرق العراق

ديفان عثمان حسين و باسم عبد الخالق القيم

المستخلص

تشكل المعلومات تحت السطحية المستحصلة من أربعة آبار نفطية لحقل نفط طق طق في شمال شرق العراق إضافة إلى المعلومات الحقلية المأخوذة من جبل هيبة سلطان عن تكوين البيلاسبي المادة الأساسية للدراسة الحالية عن العلاقات الصخرية والسحنية لتكوين البيلاسبي.

شملت الدراسة التفصيلية فحص مختبري للنماذج الصخرية، الفتات واللباب الصخري، والمجسات البئرية وذلك لتحديد الوحدات والعلاقات السحنية الصخرية ولتقييم تأثير عمليات الدلمتة على الصخور والخصائص المكمنية.

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يمكن تقسم تكوين البيلاسبي في هذه المنطقة إلى أربعة وحدات صخرية، من الأسفل إلى الأعلى: وحدة البريشيا السليكية السفلى (P1)، وحدة الحجر الجيري الدولومايتي للمسطح المدي (P2)، وحدة الحجر الجيري والدولوميتي المستنقعي (P3) ، ووحدة حجر البريشيا العليا (P4).

تعرضت هذه الصخور إلى تغييرات مهمة وتحويرات شديدة نتيجة عمليات الدلمتة التي أثرت على المكونات والنسيج الصخري الأصلي للصخور. لقد تم تمييز عدة أنواع من الدولومايت تشمل:

الدولومايت "الفنستري" دقيق البلورات (D1)، الدولومايت دقيق البلورات المستوي إلى شبه مستوي الأوجه (D2)، الدولومايت دقيق البلورات غير مستوي الأوجه (D3)، الدولومايت متوسط البلورات غير مستوي الأوجه (D4) والدولومايت خشن البلورات (D5).

أثرت عملية الدلمتة بشكل ايجابي على تطور الخصائص المكمنية للتكوين عن طريق تحسين مسامية مابين البلورات، وتطوير المسامية الهيكلية والقالبية والتي تحولت بالنهاية إلى مسامية التجاويف الصغيرة خاصة في الجزء الأوسط من التكوين (وحدتي P1 وP2). أما قدرة الجريان المكمني فقد تحسنت نتيجة تأثير مسامية الكسور الثانوية.

INTRODUCTION

Taq Taq oil field is located 13 Km southwest of Koi Sanjaq town, about 61 Km northeast of Kirkuk, and 85 Km southeast of Erbil (Fig.1). The first well (Tq-1) was drilled in 1958 by the Iraqi Petroleum Company on the crest of the structure to about 3986 m depth. Then followed by Well Tq-2 and Tq-3, in which Tq-2 drilled to a target depth of 663 m, which is about the depth of the Eocene Pila Spi Formation, and well. Tq-3, which is drilled to the depth of 1631m and targeting the deeper Cretaceous units.

In 2005, a contract with a Turkish Company called "Genel Enerji" and "Addax Petroleum Corporation" formed a merger of new company called Taq Tqa Operation Company (TTOPCO), is signed to run the field by commencement of drilling activities. During the following years, new wells have been drilled (TT-04, TT-05, TT-06, TT-07, TT-08, and TT-09) and by targeting Cretaceous units. However, the renewed interest on the Tertiary reservoirs namely the Pila Spi Formation stimulate this and other research to investigate their different geologic aspects and their impact on the potentiality of these units.

Four wells were selected for this study (Tq-2, Tq-3, TT-04 and TT-05) with whatever available data of cuttings, core samples and different types of well logs. To support the lithologic study, a surface section was measured from Haibat Sultan Mountain, which is about 17 Km to the northeast of the field. The Pila Spi Formation is completely exposed at this ridge with accessible and road cut outcrops. Core and cutting samples of all rock types were examined by binocular microscope to record all petrological and sedimentological aspects. Selected samples were thin-sectioned and occasionally stained to investigate their petrographic components and texture using polarized microscope. Dolomite as a dominant mineral is studied in details due to its anticipated role in affecting the quality of the Pila Spi reservoir. Few samples were scanned by SEM microscope to differentiate between different fabrics of dolomites. Different types of well logs, especially: Gamma Ray, Sonic, Density, and Neutron logs were used to assist identification of lithologic boundaries as well as determination of general lithologies in an un-cored intervals of the studied wells, they also were used to evaluate porosity and permeability of the studied reservoir.

Taq Taq structure can easily be distinguished by the positive features of the topography, well exposed units with average elevation of about 600 m (a.s.l.). The general pattern and shape of the outcrops clearly reflect the underlying geological structure and lithological differences of the strata. The structure is double plunging anticline, the surface expression of the structure is 27 Km long and 11 Km width, with NW – SE oriented axis (Fig.2).

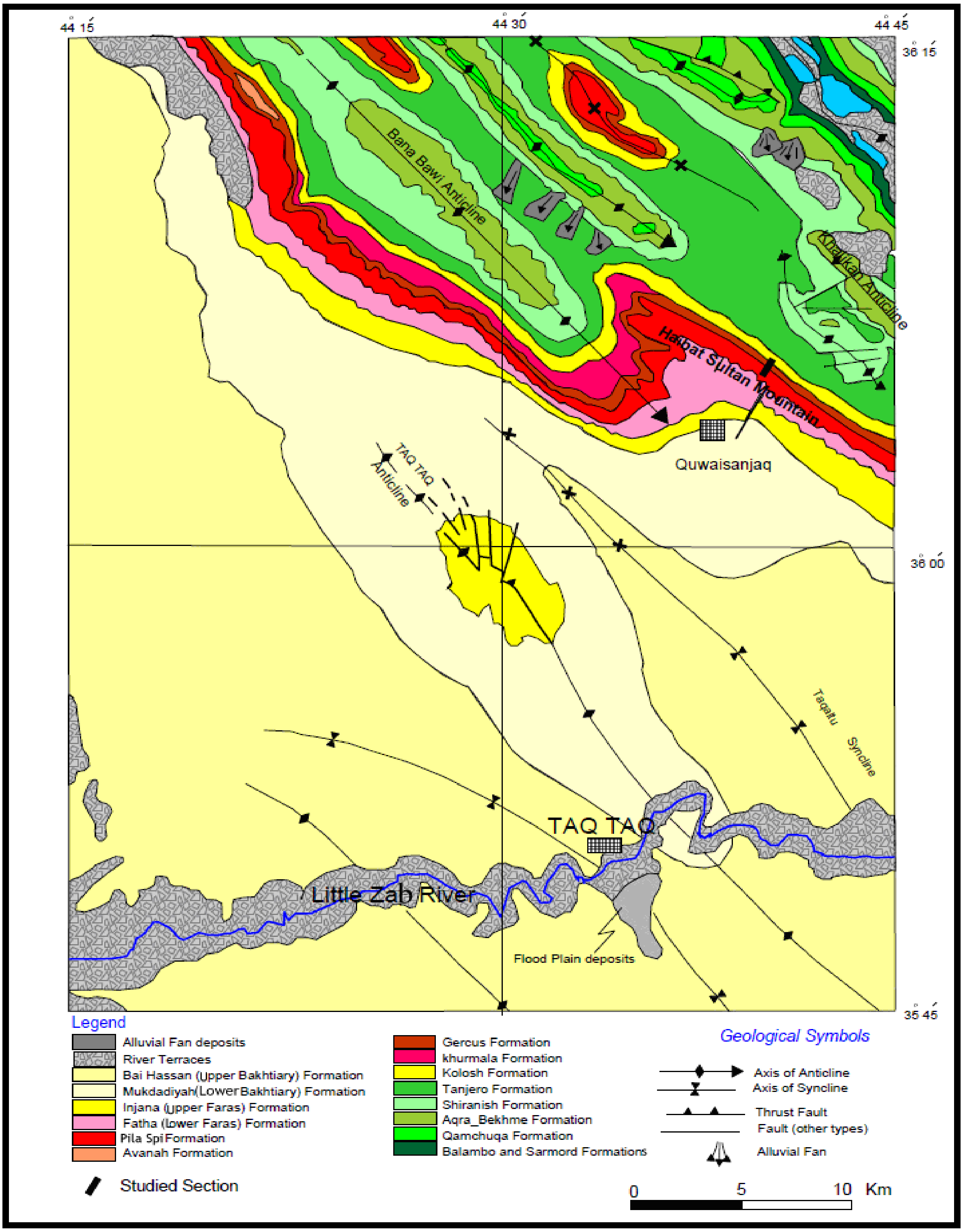

Fig.1: Geologic map of Taq Taq area showing location of Taq Taq oil field and the studied surface section (after Sissakian, 1993 and 1997).

The structure is surrounded, to the northeast and southwest by two synclines running along the same general trend and exposing younger strata of Bai Hassan (ex-Upper Bakhtiari) Formation. Synclines at northeast, and southwest reflected by topographic depressions of general elevation of 350 – 400 (a.s.l.). Further northeastwards older strata of Paleogene units were exposed forming the hard prominent ridge of the Haibat Sultan Mountain, which extends in NW – SE trend, and representing the southwestern limb of Bana Bawi anticline. This ridge is geomorphological high with 1047 m elevation (a.s.l.), where the hard limestone beds of the Pila Spi Formation form the weathering-resistant crestal part of the ridge.

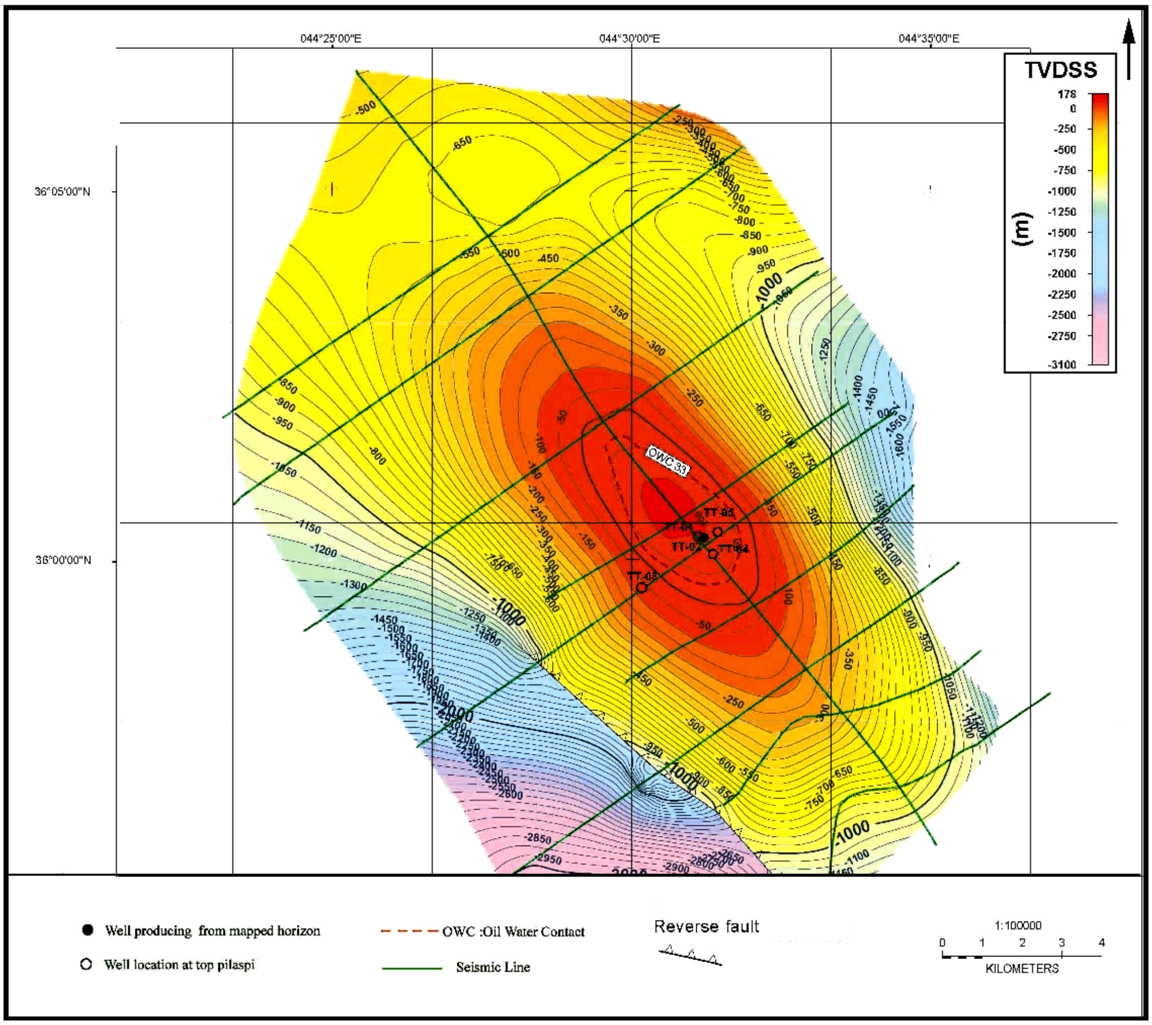

Fig.2: Structural contour map on top of the Pila Spi reservoir, reflecting nature of Taq Taq Structure (after TTOPCO field overview report, 2006)

STRATIGRAPHY

The Pila Spi Formation was first described by Lees (1930) in Bellen *et al*. (1959) from the surrounding of Pila Spi village of the High Folded Zone of northeast Iraq. It was redefined by Wetzel (1947) and amended by Bellen *et al*. (1959). The original type section was submerged under the water of the Darbandi Khan reservoir; a supplementary type section was thus described at Kashti on the Baranan Dagh Mountain, of Darbandi Khan area.

The formation, in the type section consists of two parts: The lower part shows well bedded hard, whitish, porous with vitreous, bituminous, or white, poorly fossiliferous dolostone with algal or shell sections (Bellen *et al.*, 1959). The upper part is composed of well bedded, bituminous, chalky, and crystalline dolostone, with bands of white chalky marl with chert nodules, especially towards the top. In the supplementary type section, dolomitic and chalky dolostone, with few dolomitized bands, chert intercalations, with traces of sub-ooliths and rare concentrations of gastropod debris, form the bulk of the formation (Buday, 1980). Tongues of the Nummulitic Avanah Formation occur within the basal part of the formation near and in several wells of Duhok area (Jassim and Buday, 2006 in Jassim and Goff, 2006). The thickness of the formation varies between (100 – 200) m. The variable thickness of the formation could be related to variable erosional rate or the original geometry of the sedimentary basin, especially in the High Folded Zone of northeast Iraq.

Fossils are abundant with sporadic distribution, which includes: Milolids (*Pyrgo* sp.), chilostomellids, *Peneroplis dusenbury* Henson, *Praerhapidionina huberi* Henson, *Rhapidionina urensis* Henson, *Rhapidionina williamsoni* Henson, *Rhapidionina macfadyeni* Henson, Valvulinids (Bellen, *et al*. 1959). Based on that, Bellen *et al*. (1959) claimed Middle – Late Eocene. However, Buday (1980), and Jassim and Goff (2006) believe that the formation was deposited during Late Eocene time.

In Degala, 25 Km to the north of Taq Taq area the formation consists of dolostone, which alternates with green marls with bioturbation. In Darbandi Bazian, the formation consists of three parts. The lower part consists of stromatolitic dolostone, marl, and dolomitic limestone. The middle and upper parts consist of recrystallized dolostone alternating with marls with the presence of chert nodules (Qadir, 1989). Similar lithologies were recognized in Dokan and Shaqlawa areas (Al-Sakry,1999), Dohuk area (Al-Jawadi, 1978), Darbandi Khan area (Lawa, 2004).

The lower boundary of the Pila Spi Formation appears to be conformable and gradational in the type section in NE Iraq, where it overlies the Gercus Formation. The boundary is either interfingering; as in Bekhme area (Al-Qayim and Al-Shaibani, 1997), or marked by locally distributed (0.5 – 1 m thick) conglomerate horizon; as in Shaqlawa area (Al-Qayim *et al*., 1994), and Haibat Sultan ridge (Al-Qayim *et al*., 1988). The upper boundary is frequently reported to be unconformable with the overlying Fatha (ex-Lower Fars) Formation of the Middle Miocene age. It is recognized by thick and extensive basal conglomerate horizon (Bellen *et al*., 1959; Buday, 1980; Jassim and Buday, 2006 in Jassim and Goff, 2006). In other areas, however, such as Basara gorge, south of Sulaimaniyah, a thin Oligocene unit is believed to have intervened between the Fatha and Pila Spi Formation (Khanqa *et al*., 2009). According to Bellen *et al*. (1959) and Buday (1980), the Pila Spi Formation, generally, represents lagoonal sediments, of an inshore type. The formation was deposited in a shallow extensive lagoonal setting (Jassim and Buday, 2006 in Jassim and Goff, 2006). Al-Sakry (1999) believed that the Pila Spi Formation was deposited in a shelf and shallow lagoonal environment, and some of the deposits may be developed in an intertidal environment, or over a continental shelf, probably of tropical and warmer topographic region (Al-Saeed, 1977). Numan, *et al*. (1995) suggests a general miogeosynclinal setting for the Pila Spi Formation, and Karim, *et al*. (2008), believe that it is part of the main foreland basin.

LITHOFACIES ASSOCIATIONS

The lithologic characters of the Pila Spi Formation in Taq Taq oil field show no considerable differences from the surrounding areas and are quite similar to its counter surface section of Haibat Sultan Mountain (Fig.3). The thickness of the formation at this area is about 70m.

The lower part of the Pila Spi Formation is characterized by fractured red and brecciated dolostone, with dissolution cavities. It shows alternation of thin to medium bioclastic dolostone with marly dolostone and marls. The middle part is the thickest and generally consists of cyclic alternation of dolostone and marly dolostone. Cycles are thinning upward and alternate with hard dolostone, and fissile marly dolostone. The upper part is characterized by hard gray dense dolostone with shaley interlayers, which become sandy, and reddish upwards and intermixed with rusty thin sandy crust including chert nodules. The Formation is underlain by the reddish claystones of the Gercus Formation, and overlain by the brecciated unit of the unconformity zone, which separates the Pila Spi Formation from the clastic – carbonate strata of the Fatha (ex-Lower Fars) Formation.

The subsurface lithologic characters of the Pila Spi Formation in Taq Taq oil field is well represented by the section of well Tq-2 (Fig.4). Four distinctive lithofacies units were identified using core and cutting description, petrographic examination, assisted by well log analysis, and supported by well correlation across the field and over to the surface section of Haibat Sultan Mountain. The thicknesses of these units in the studied sections are shown in Table (1), and their description is given hereinafter, from bottom to top.

Table 1: Thicknesses of the lithologic units in the studied sections

Sections and well No.	Thicknesses of the lithologic units (m)			
	P1	P2	P3	P4
Surface section	2.5	12.5	45	10
Tq-2	10	30	75	16
Tq-3	7.5	20	80	20.8
TT-04	10	20	65	15
TT-05	6	22	68	15

■ Lower Brecciated - Silicified Dolostone Unit (P1)

The lower contact of this unit with Gercus Formation is gradational (Fig.5a and b). The unit is characterized by light grey to reddish, hard, fine crystalline dolostone, with dissolution cavities, large vugs, intermixed with silicified brecciated dolostone, especially in the lower part. Inter-granular matrix is characterized by buff silty to sandy sediments, which some times occur as silty intercalations. The thickness of this unit is variable and ranges between (2.5 – 10) m. It is believed to represent a transitional zone from the underlying the red clastics of the Gercus Formation to the overlying marine carbonates of the Pila Spi Formation.

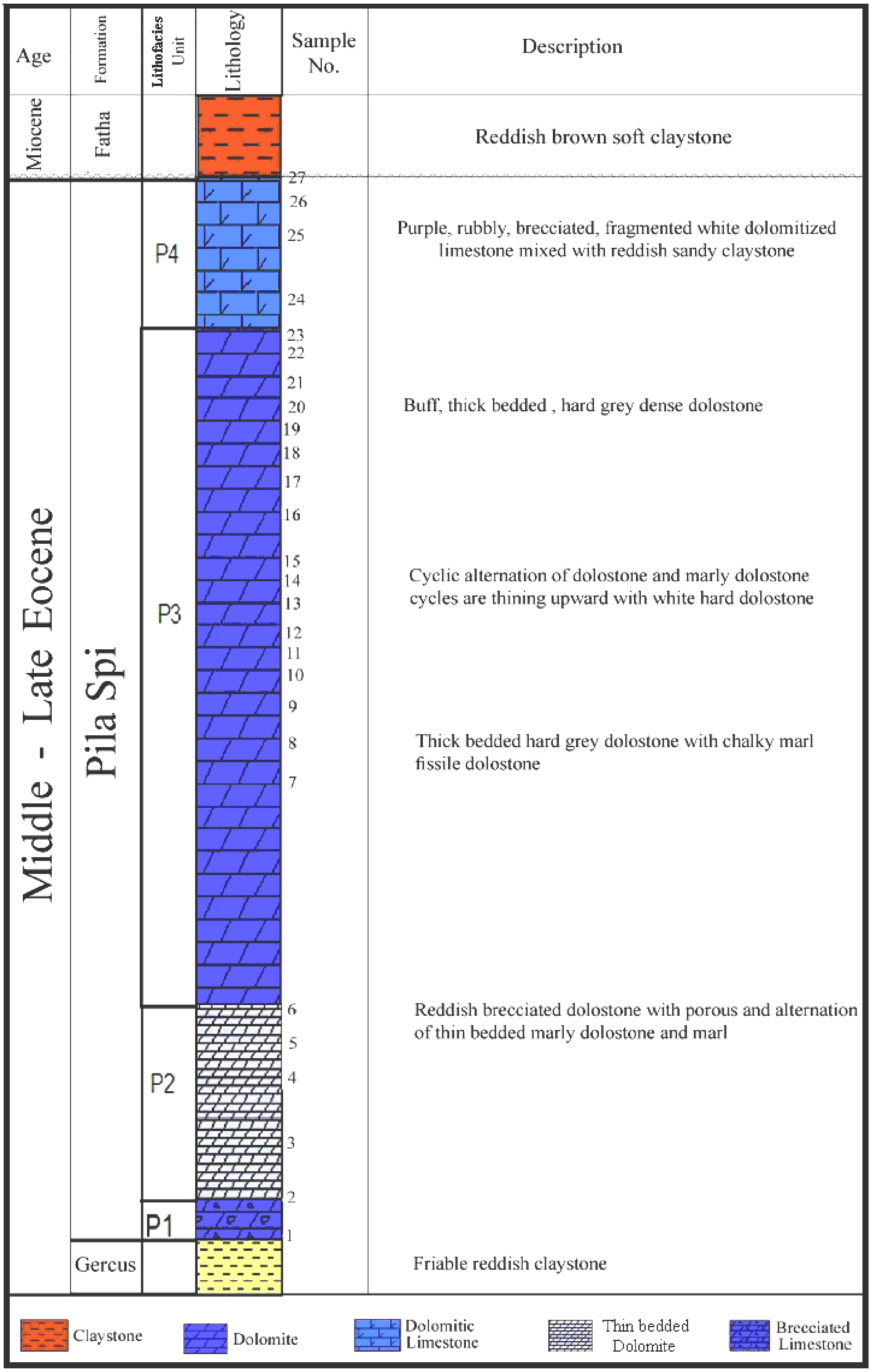

Fig.3: Stratigraphic column of the studied surface section of the Pila Spi Formation, Haibat Sultan Mountain

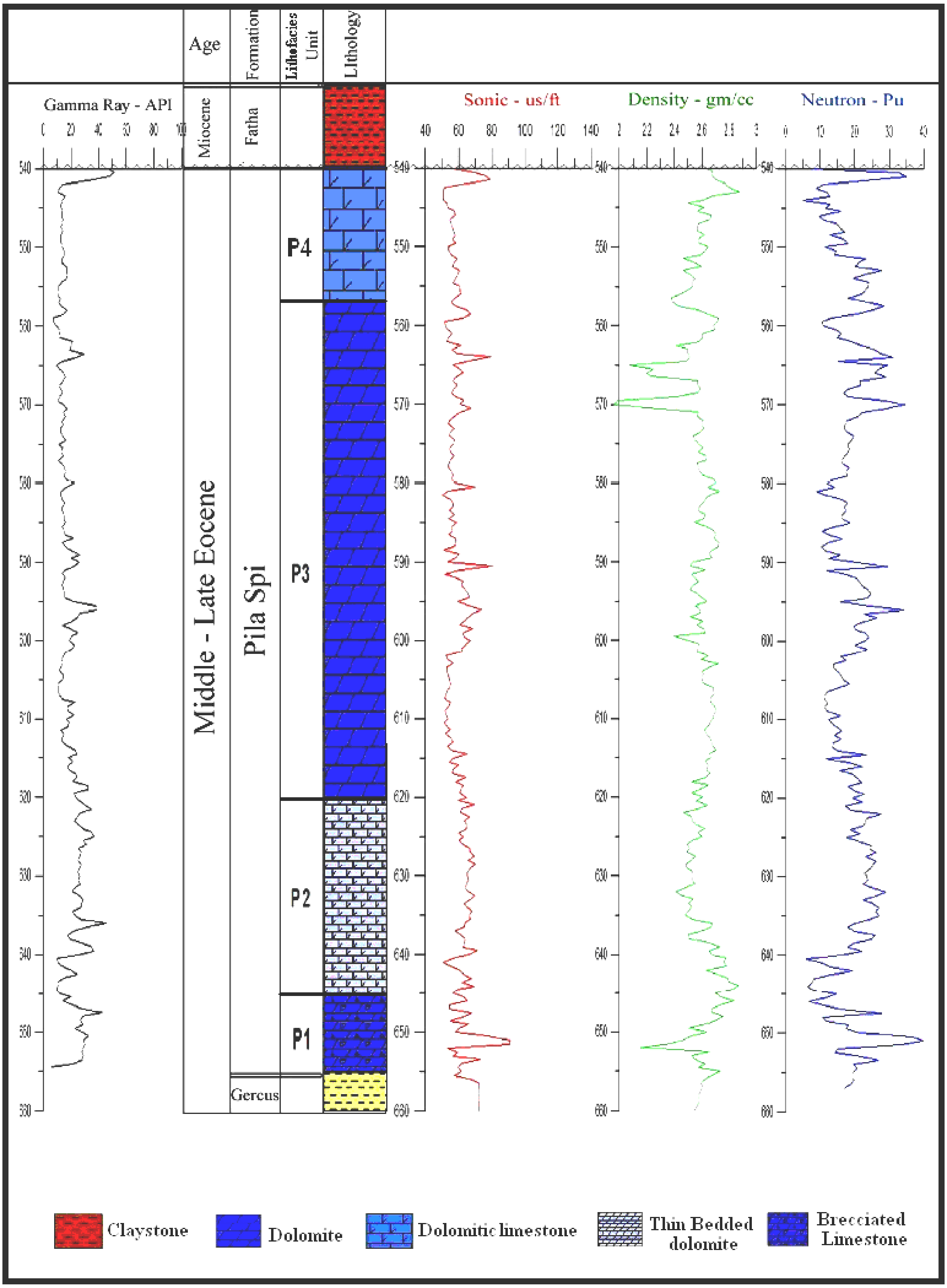

Fig.4: Stratigraphic column of the Pila Spi Formation at well Tq-2, showing log characteristics of lithologic units

■ Dolomitized Tidal Flat Limestone Unit (P2)

The thickness of this unit is variable and ranges between (12.5 – 30) m. It is characterized by light grey, fine crystalline, hard, thickly bedded to massive, dolomitized bioclastic limestone and dolostone; occasionally, alternating with thin greenish grey marl. The rocks are highly fractured and intensively microvuged (Fig.5e and d) and alternating with dark grey, fine crystalline dolomitic limestone. The pervasive dolomitization of this facies overprint most of the original depositional fabric. However, the recognition of ghosts of stromatolitic fabric and other similar petrographic signals such as fine crystalline dolomite and birds' eye porosity, imply that this unit originally represents a part of an extensive tidal flat system covered, at least, partly by the laminated, dolomitic stromatolite mats.

■ Lagoonal Dolomitic Limestone and Dolostone Unit (P3)

This unit has a thickness ranges between (45 – 80) m and represents the main part of the section. It appears in all of the studied sections. The general lithology is characterized by grey hard, dense, and medium to thickly bedded and lagoonal dolostone and dolomitic marly limestone (Fig.5h). It is highly jointed and alternating either with grey chalky limestone, or with marly dolostone (Fig.6a and b). Massive dolostone beds occur within the middle part of this unit at the surface section of Haibat Sultan Mountain. Large veins of secondary aragonite within a grey massive hard dolostone bed characterize the upper part.

In oil well Tq-2, the unit is recognized as brown to light grey bioturbated fractured dolostone with micro-moldic, skeletal, and fractured porosity, which are commonly seen saturated with oil (Fig.6c, d and e). Restored original fabric and components, which are barely escape dolomitization, indicate deposition in a sheltered lagoonal environment prevailed for a long and relatively stable period.

■ Upper Brecciated Dolomitic Claystone (P4)

The thickness of this unit ranges between (10 – 21) m in the studied sections (Table 1). It consists of dark grey, hard, macrocrystalline, and brecciated dolostone, intermixed with reddish brown sandy to clayey conglomerate or breccia. Coarse reddish brown claystone fragments of pebble size are frequently recognized (Fig.5g). The upper contact of this brecciated unit with the Fatha Formation is seemingly unconformable and marked by the occurrence of the so called "Basal Fars Conglomerate, which is clearly seen in the outcrop section of Haibat Sultan. The thickness of this conglomerates is about (2 – 3) m and is dominated by well rounded and well sorted brown chert pebbles. The nature of the upper contact with the overlying Fatha Formation at Haibat Sultan Mountain is similar to most examined localities in northeastern Iraq (Bellen, *et al*., 1959, Buday, 1980, Kareem, 2006, and Ameen, 2009). However, Khanqa *et al*. (2009) from their study at Basara gorge, southwest of Sulaimaniyah, believed that a thin Oligocene unit might occur in between. The lower contact of the unit with Unit P3 of the Pila Spi Formation is gradational.

Correlation between these units shows that they are persistent and well correlated across the field, as well as over the surface section of Haibat Sultan Mountain (Fig.7). The uniformity of the distribution of these units in this area could indicate uniformity of depositional environment. It also implies that these units, despite the extensive role of dolomitization, are associated with depositional facies rather than diagenetic ones.

The low thickness of the formation in the outcrop section as compared to the subsurface sections is noticed and could be related to:

1) Paleo-configuration of the depositional basin, **2)** Folding of the strata at surface section made it thin toward the limb, and **3)** Thickness of the formation in the studied wells is exaggerated due to the uncorrected drilled thicknesses.

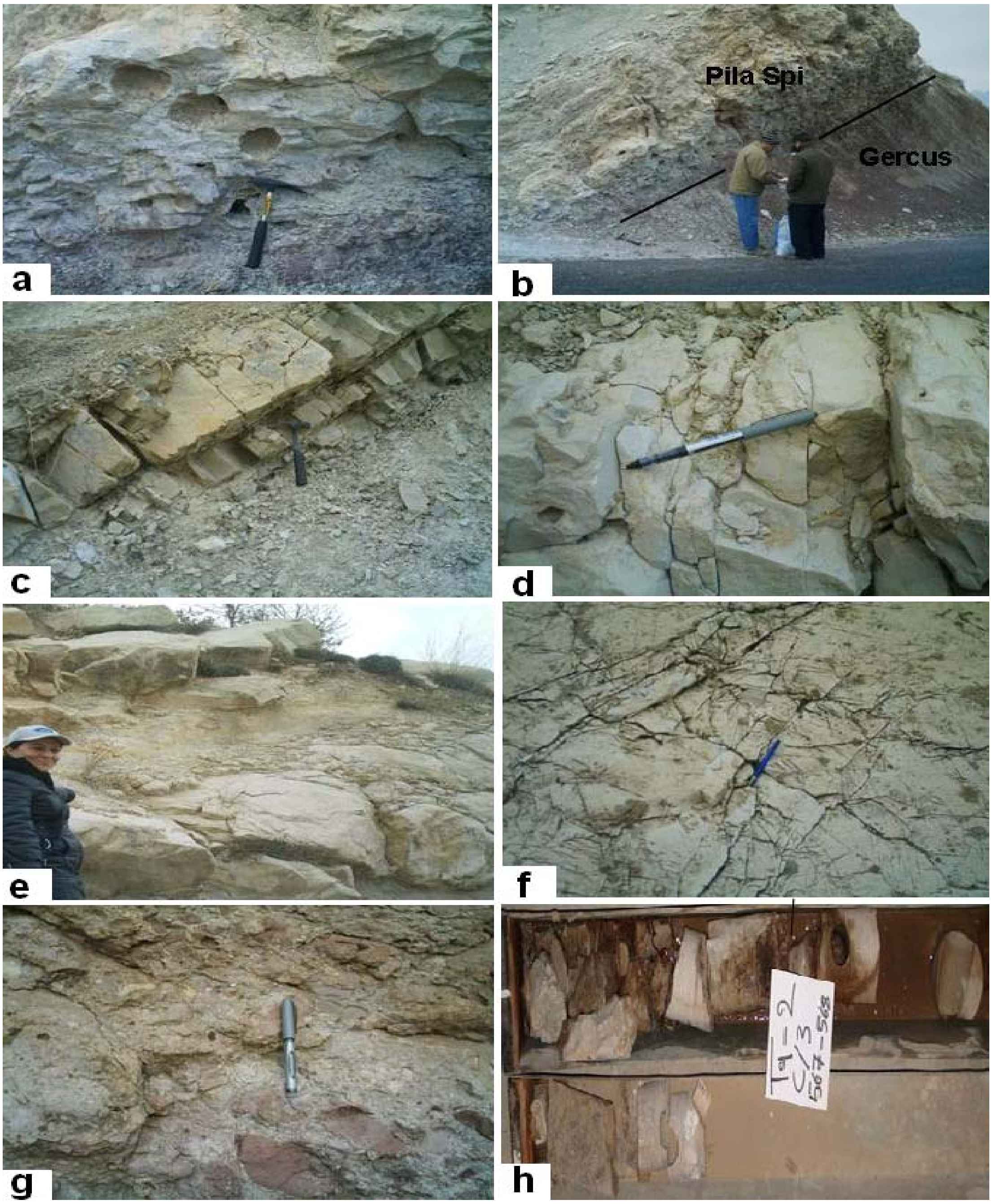

Fig.5**: (a)** Massive to thick bedded, white grey, buff, silicified, and vuggy dolostone, Unit P1, Haibat Sultan section. **(b)** A (1 – 2) m thick horizon of Unit P1 showing the boundary zone with the red clastics of the Gercus Formation, Haibat Sultan section. **(c)** Highly jointed, and medium bedded dolostone, Unit P2. Haibat Sultan section. **(d)** Highly fractured, thickly bedded, and dolomitic limestone, Unit P2, Haibat Sultan section. **(e)** Thickly bedded marly dolostone, alternating with thin bedded grey marlstone, Unit P3, Haibat Sultan section. **(f)** Highly jointed dolostone unit of the middle part, Unit P3, Haibat Sultan section. **(g)** Brecciated and fragmented dolomitic limestone with reddish brown, re-deposited coarse clasts, Unit P4, Haibat Sultan section. **(h)** Brown, oil stained dolomitic limestone core of Unit P3, oil well Tq-2.

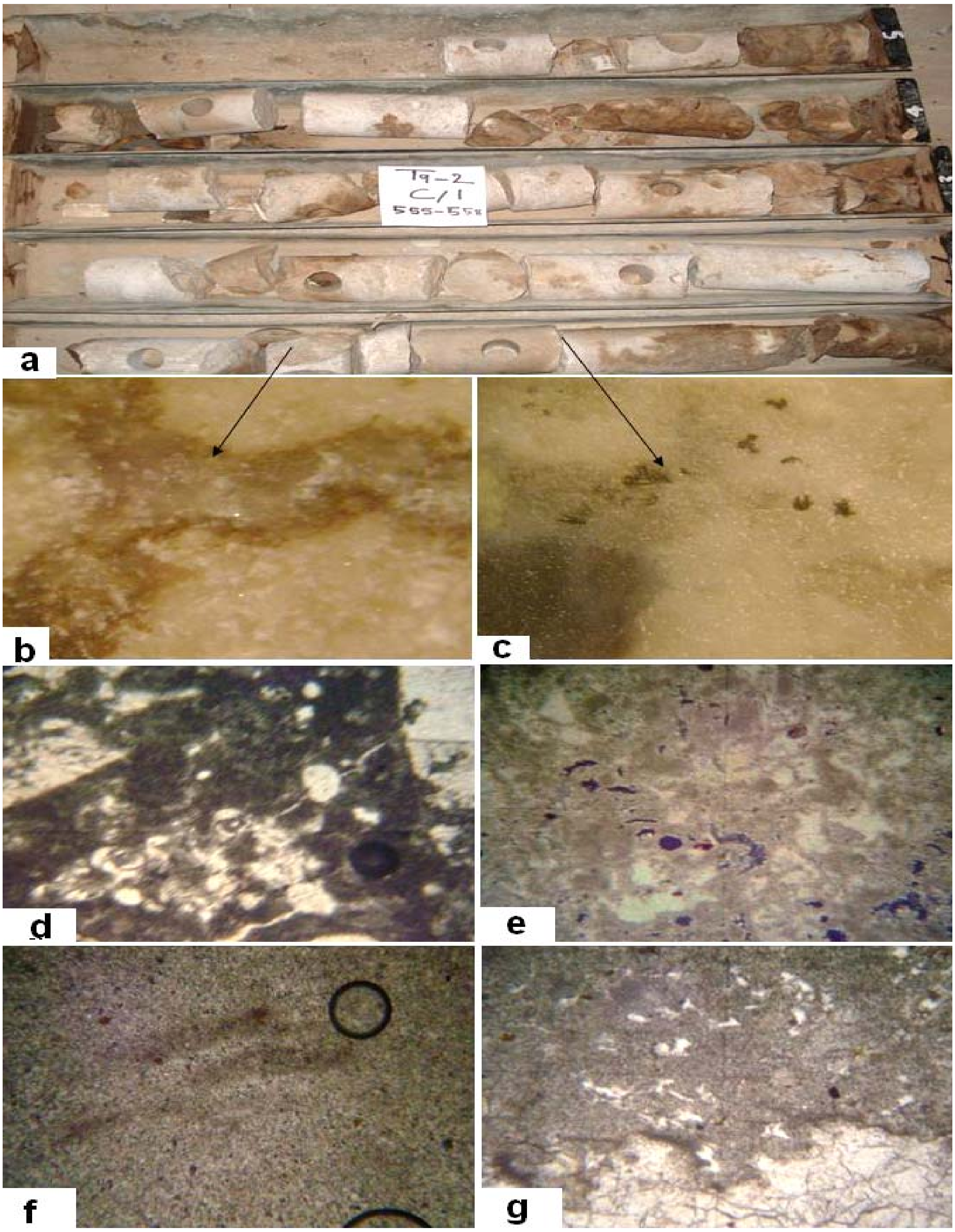

Fig.6: **(a)** Core barrel of Unit P3/P4, well Tq-2 of the Pila Spi Formation showing brown, fractured brecciated and partly oil-stained dolostone. (**b**) Enlarged spot of previous photo showing oil-stained micro-vug porosity. (**c**) Enlarged spot of Photo (a) showing buff crystalline vuggy dolostone, with oil-saturated burrows fillings, Unit P3, oil well Tq-2. **(d)** Foraminiferal dolo-wackstone microfacies rich in miliolids, Unit P3, Haibat Sultan section (100X). **(e)** Ghosts of miliolids in bioclastic dolo-packstone microfacies with common intra-skeletal pores, Unit P3, Haibat Sultan sections, (100X). **(f)** Ghosts of fenestral boundstone fabric of the originally stromatolitic limestone. Haibat Sultan section, Unit P2, (100X). **(g)** Fenestral porosity of stromatolitic dolostone, Unit P2, Haibat Sultan section, (100X).

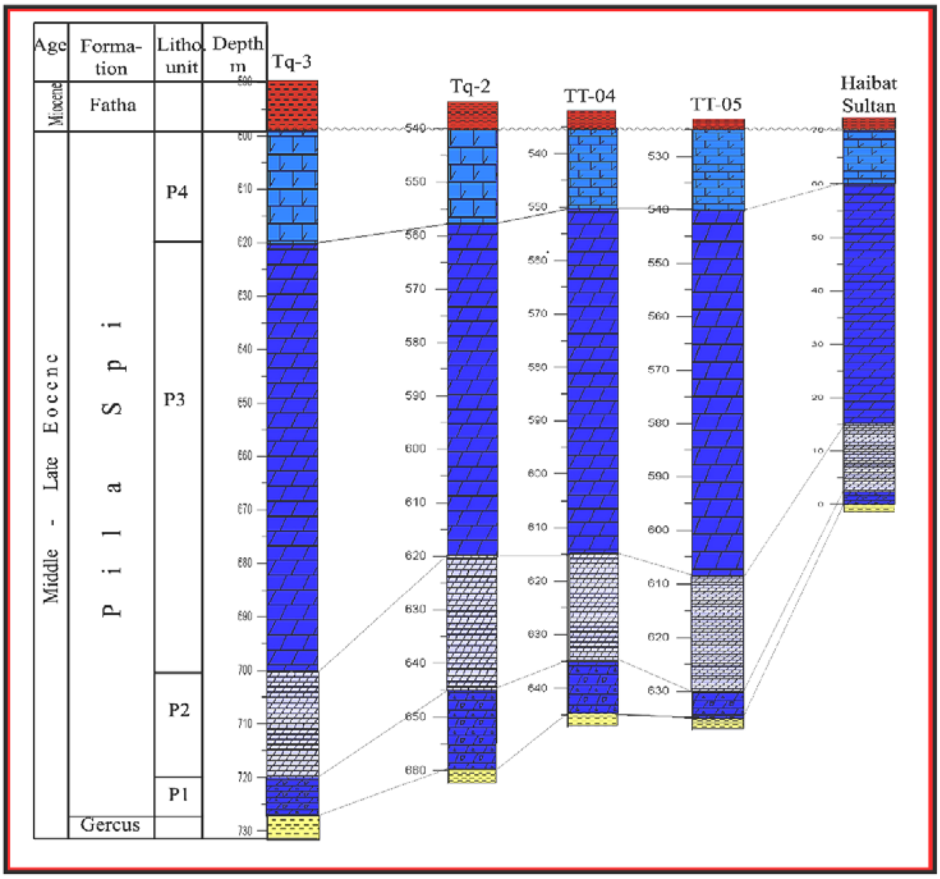

Fig.7: Correlation of lithologic units of the Pila Spi Formation
across the studied wells and the surface section
Horizontal scale is ignored (For legend see Fig.4)

MICROFACIES ANALYSIS

The ultimate goal of this analysis is to determine sedimentological control on the distribution of reservoir petrophysical parameters, and to investigate the diagenetic processes that had affected these rocks in order to evaluate its influence on reservoir potentiality. For this purpose, 106 thin-sections were studied under a polarized microscope. The studied sequence has different petrographical properties, and variable different degree of diagenetic effects, especially, dolomitization, which altered most of the original fabrics and replaced it by dolomite mosaic of different sizes and shapes.

Names of the inferred microfacies followed the classification of carbonate rocks by Dunhum (1962). However, for dolomite or dolomitic facies the work of Gregg and Sibley (1987) is followed, which combined microscopic and Scanning Electron Microscope (SEM) features to describe different dolomite fabrics.

Most of the examined samples were found to belong to either dolomitic limestone or dolostone; due to the intensive dolomitization, which affect the Pila Spi limestone and destroyed partly to completely the original fabric of the rock. Attempts were made to restore the original fabric and the primary sedimentary facies using petrographic relics and remains of the studied thin sections.

The microfacies types of the studied samples are grouped into two major groups, as discussed hereinafter.

▪ **Dolomitic Limestone Microfacies (DL)**

This group of microfacies characterizes mainly the upper part of the Pila Spi Formation. It includes three important microfacies. These are Pelloidal – Bioclastic Dolo-Wackestone to Dolo-Packstone (DL1), Miliolid – Bioclastic Dolo-Wackestone to Dolo-Packstone (DL2), and Foraminiferal Bioclastic Dolo-Wackestone (DL3). These microfacies are common to the lagoonal facies of Unit (P3). In some samples, the original microfacies is easily recognized as Wackestone microfacies, whose grains are dominated by different species of well preserved miliolids (Fig.6d). In other cases, intensive dolomitization obliterate original component of the rock leaving nothing but ghosts of miliolids or other forams (Fig.6e). In these cases, the whole rock is changed into dolostone with vague relics of original component or fabric. Some times dolomitization occurs in low degree, which affects part of the micritic matrix in the form of floating rhombs, or partially dolomitized skeletal grains.

▪ **Dolostone Microfacies (D)**

The dolomite microfacies dominate the carbonate section of the Pila Spi Formation. It occurs in different types and fabrics. These types include five different dolomite microfacies. The crystal size classes used here to classify dolomite fabric followed the general classes used in Lucia (1999) with slight modification, due to the general fine crystalline dolomite of the Pila Spi Formation. Theses classes are: Fine (< 25 micron), Medium (25 – 50 micron), and Coarse (> 50 micron). Staining technique is used to assist identification of dolomite mineral, and XRD runs were applied to few samples to assure the occurrence of the dolomite. SEM photography was used to recognize dolomite fabric interrelationship. The dolomite microfacies are discussed hereinafter.

– **Fenestral Dolomite (D1):** The occurrence ghosts of disturbed algal laminae, alternating with fine crystalline dolomite matrix, characterize this microfacies. This microfacies is characteristic of the lower part of the Pila Spi Formation (Fig.6f). In some samples, it shows that the original boundstone fabric of algal laminae had changed due to dolomitization into dolostone with the characteristic fenestral fabric (Fig.6g). The association of this microfacies with the fine crystalline dolostone indicates that this part was deposited within a shallow marine environment of tidal flat setting (Pratt, *et al*., 1992).

– **Fine Crystalline Planar-e to Planar-s Dolomite (D2):** This microfacies is characterized by fine crystalline planar-e to planar-s dolomite mosaic (Fig.8a). Planar-e dolomite has straight and planar boundaries between crystals. The crystals tend to be euhedral (Sibley and Gregg, 1987). The term planar is equivalent to term Idiotopic fabric of Randazzo and Zachose (1984) and Gregg and Sibley (1984). The other type of dolomite of this micro facies is Planar-s type of subhedral form. Most of dolomite crystals are sub-hedral to anhedral with straight compromise boundaries at many crystal face junctions (Gregg and Sibley, 1987).

This type is equivalent to hypidiotopic subhedral fabric of Randazzo and Zachose (1984). This dolomite mosaic is distributed within the studied sequence sporadically, but especially is common in the lower and upper parts of the studied sections. Porosity type associated with this microfacies includes inter-crystalline, moldic, and vuggy (Fig.8b).

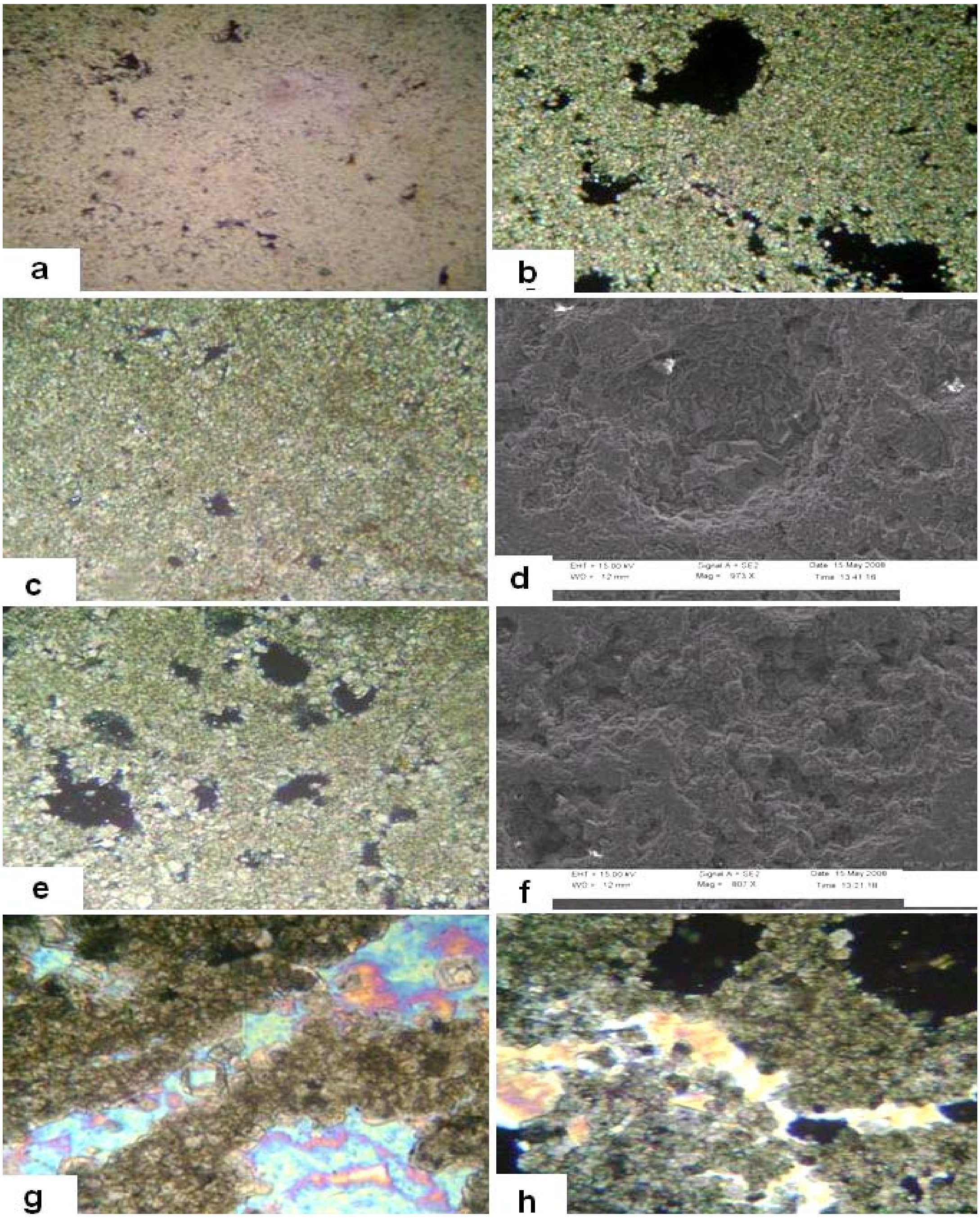

Fig.8: **(a)** Fenestral porosity in fine crystalline planar-e dolomite (D1), Unit P2, Haibat Sultan section, (100X). **(b)** Fine crystalline planar-e to planar-s dolomite mosaic (D2), Unit P3, (100X). **(c)** Fine crystalline non-planar dolomite mosaic (D3), with enlarged inter-crystalline porosity, Unit P3, well Tq-2, (100X). **(d)** SEM photo of **(c)** showing micro-vug and inter-crystalline porosity (975 X). **(e)** Medium crystalline planar-s to non-planar dolomite mosaic (D4) with micro-vug porosity, Unit P3, well Tq-2 (100X). **(f)** SEM photo of **(e)** showing nature of micro-vug porosity (800 X). **(g)** Euhedral zoned coarse crystalline dolomite partly replaced by anhydrite, Unit P3, well Tq-3 (100X). **(h)** Siliceous cement filling inter-crystalline porosity of a coarse crystalline dolomite mosaic, Unit P3, well Tq-3 (100X).

– **Fine Crystalline Non-Planar-a Dolomite (D3):** This type of microfacies is characterized by fine crystalline non-planar-a dolomite mosaic (Fig.8c and d). Non-planar texture is represented by closely packed anhedral crystals, with mostly curved, lobate, serrate, or otherwise irregular inter-crystalline boundaries (Gregg and Sibley, 1984). The term non-planar is equivalent to the term Xenotopic of Randazzo and Zachose (1984); Gregg and Sibley (1984). It is distributed within the most of the studied intervals of the Pila Spi Formation. Ghosts of original skeletal fragments indicate that the original depositional microfacies type of this dolostone is seemingly associated with Foraminiferal – Bioclastic Wackestone. Good amount of porosity seems to be related to this microfacies especially micro-vugs (Fig.8c).

– **Medium Crystalline Non-Planar-a Dolomite (D4):** This microfacies is composed of medium crystalline non-planar dolomite mosaic with common in moldic and micro-vug porosity (Fig.8e and f). This microfacies is the most common dolomite type in all of the studied sections, and is distributed in the middle part of the studied intervals, especially in the Unit P3. Owing to the large amount of moldic and micro-vug porosities, this microfacies might be developed by intensive dolomitization of a limestone with originally bioclastic packstone type (Randazzo and Zachose, 1984).

– **Coarse Crystalline Dolomite (D5):** This type of microfacies is not common and it is characterized by coarse crystalline dolomite mosaic. Crystals are of planar-e to planar-s forms (Fig.8g and h). This microfacies is not common and has restricted distribution especially within the upper part of the Pila Spi Formation. It is also seen in outcrop section within the Upper Brecciated Unit (P4) and below. It is also associated with secondary anhydrite inclusions or secondary siliceous cement filling pores and spaces between the coarse crystalline dolomite mosaic (Fig.8h).

RESERVOIR POTENTIALITY

The results of the microfacies analysis were used to support lithofacies determination, and to recognize a possible relationship between of basic types of porosity and the identified microfacies, in order to evaluate the ultimate link between lithofacies and reservoir petrophysical properties. The qualitative estimation of porosity, from thin-section, in the studied samples is also attempted. To do that, the vertical distribution of the recognized lithofacies and microfacies, are plotted against type and value of estimated and measured porosity in each sample for each section (Figs.9 and 10). Well Tq-2 is displayed here as a representative to the subsurface sections of the Taq Taq oil field.

As we see in Fig. (10), the qualitative porosity variation as compared to the calculated porosity curve (calculated from plugs in the laboratories by the operating company) can indicate that the porous part of the studied section of the Pila Spi reservoir is associated with Unit P3. It is obvious that these potential parts are associated with the dolostone units, which acquired its high secondary porosity due to dolomitization. The most porous parts are characterized by fine crystalline dolomite mosaic, which generated the extensive inter-crystalline porosity network. Moreover, leached skeletal grains of the original limestone became associated with either intra-skeletal porosity or moldic porosity after intensive dolomitization. In addition, successive dolomitization completely obliterate the original fabric and contribute to the development of extensive network of micro-vugs pores, which add to the secondary porosity (Lonoy, 2006).

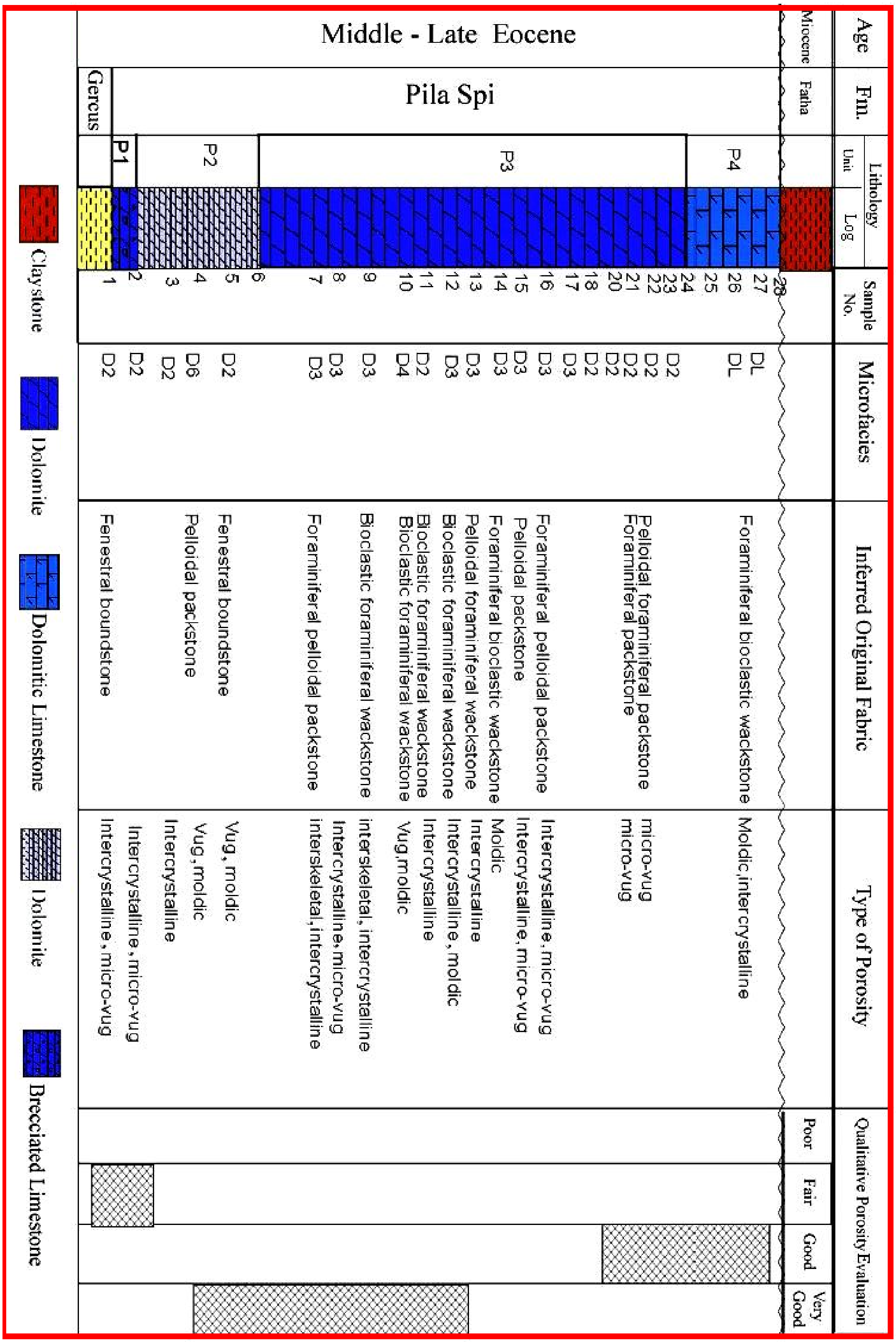

Fig.9: Lithofacies, microfacies types and qualitative porosity estimation of the Pila Spi Formation, Haibat Sultan section

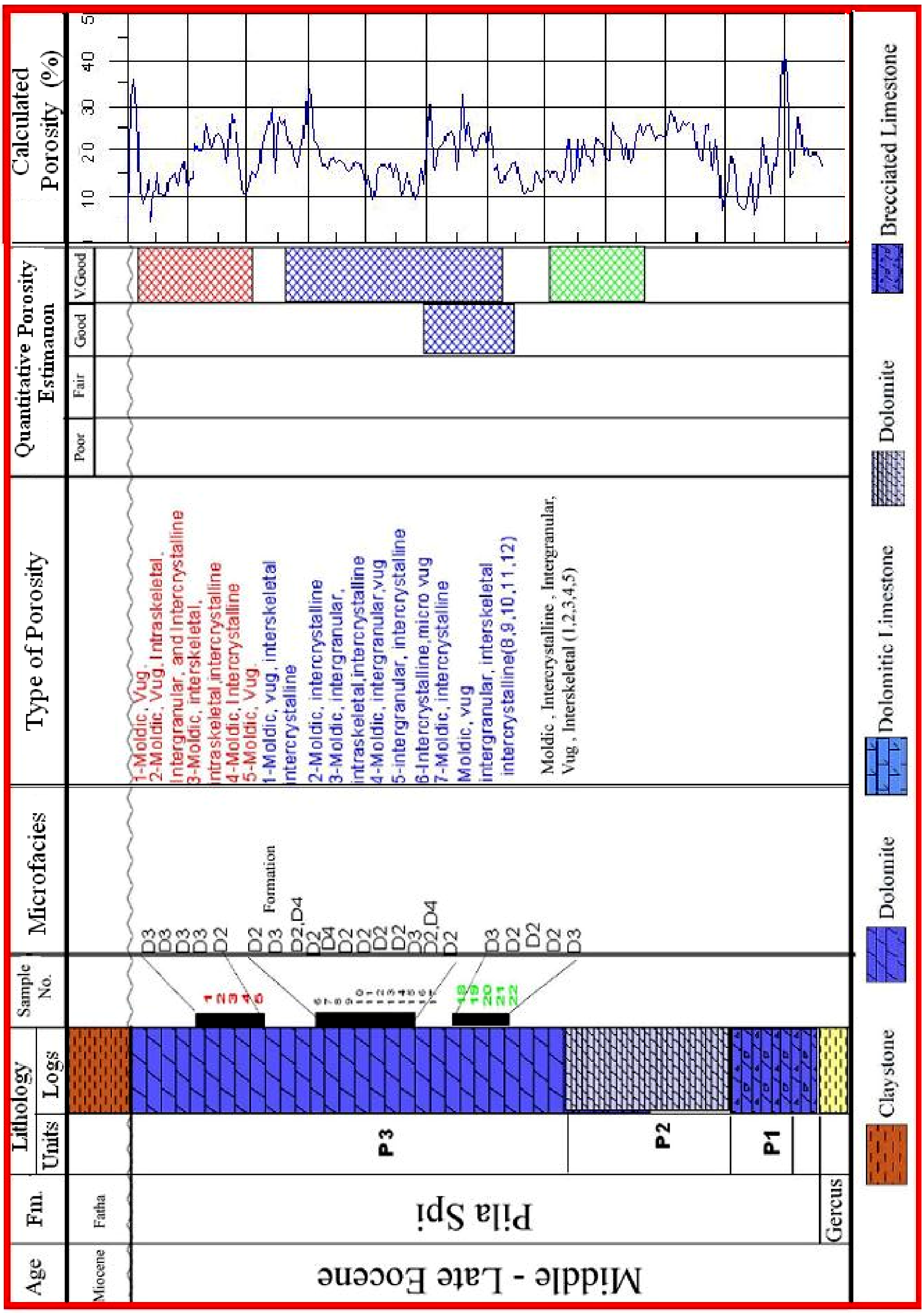

Fig. 10: Lithofacies, porosity type and vertical distribution of the Pila Spi Limestone reservoir, well Tq-2, Taq Taq oil field

The plotting of porosity against permeability values, which have been calculated from analysis of well logs (Sonic and Bulk Density), following Rider (1996), for Unit P3 in oil well Tq-2 is shown in Fig. (11). This diagram is constructed according to the method suggested by Lucia (1999) to reveal that the reservoir property of this unit in this well is of moderate porosity (7 – 33 %) and relatively of low permeability (Less than 0.1 md), with nano to micro throat size. It shows the type of flow in this unit is mainly of matrix flow, which means in this case the domination of inter-crystalline pore system. It also shows that some parts are characterized by fracture flow superimposed on matrix flow. This type of flow usually enhances collective porosity and develops permeability. Fracturing and jointing are common in the Pila Spi rocks, especially to the middle part where successive tectonic deformation during the Zagros folding phases were better inflected on the competent units of the Tertiary sequence of northeastern Iraq (Numan, *et al*., 1997).

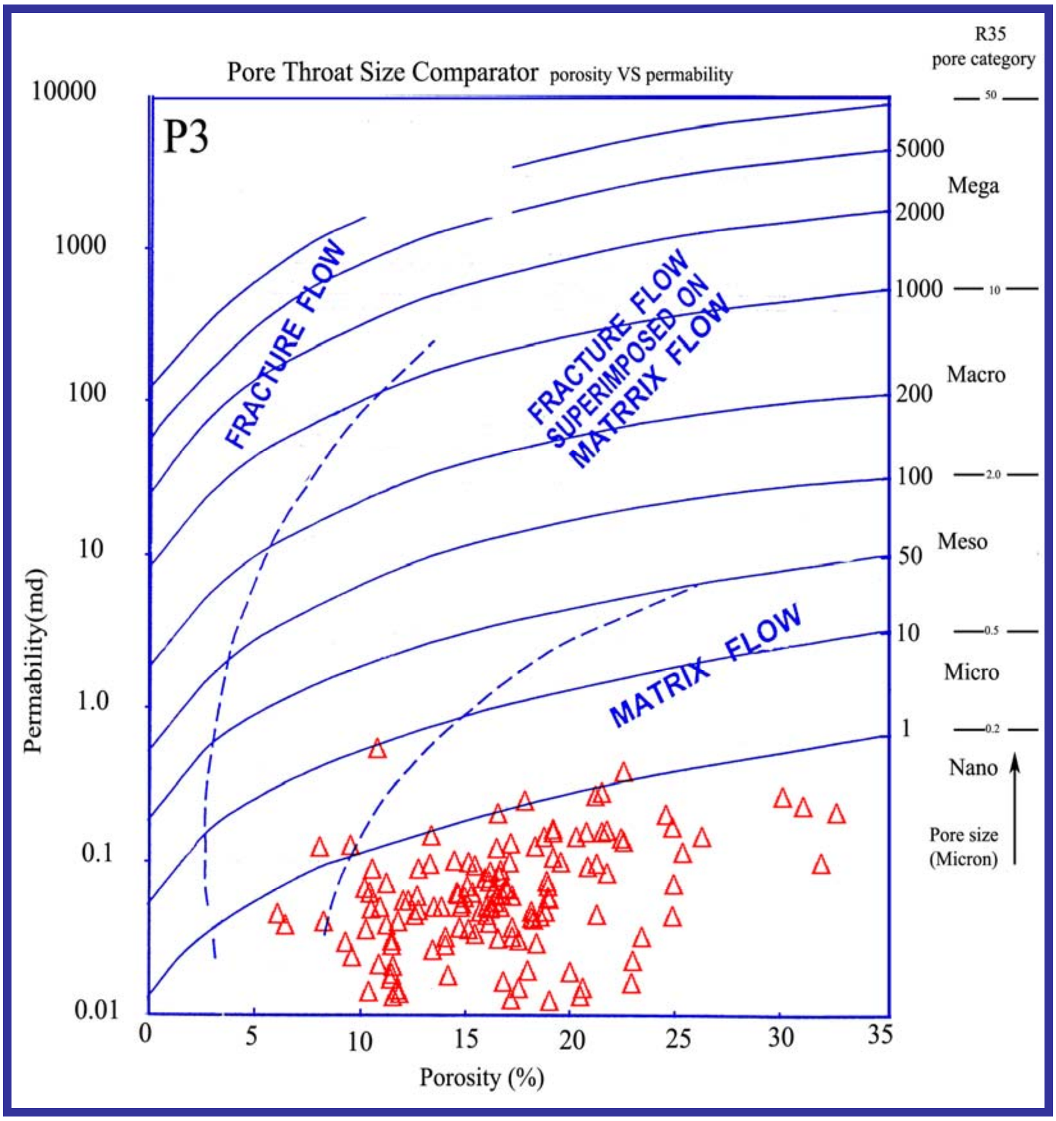

Fig.11: Porosity – permeability (log measurements) cross-plot showing petrophysical properties and nature of flow for Unit P3 (oil well Tq-2)

CONCLUSIONS

- The Pila Spi Formation of the Taq Taq oil field and its correlatable surface section of Haibat Sultan Mountain is divided into four distinctive lithologic units. The differences between these units are controlled by occurrences of marl and shale interlayers, type of original depositional fabric and variability in the degree of dolomitization.
- Dolomite occurs through out different intervals of the formation and in different types ranging from fine to coarse crystalline mosaic. The dominated type of dolomite, however, is characterized by fine crystalline (< 25 µm) planar-e to planar-s mosaic, which acquired the Pila Spi reservoir it's best inter-crystalline. Moldic and micro-vug porosity were inherited from dolomitization and contributed to the reservoir porosity.
- Fracturing of certain parts of the rocks of the Pila Spi Formation, due to successive tectonic events; contributed in initiating of the secondary porosity, enhancement of the permeability, and development of the reservoir perspective potentiality.

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