# Reservoir Characterizations of the Cretaceous Upper Qamchuqa Formation in Taq Taq Oil Field, Kurdistan Region, Northeast Iraq

**A THESIS**

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**IN GEOLOGY**

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# ABSTRACT

Four wells: Tq-1, TT-06, TT-07 and TT-09 from Taq Taq oil field in Kurdistan Region of Northern Iraq, were selected for examination of petrographic properties and well logs signatures to evaluation of reservoir characters of the Upper Qamchuqa Formation.

Core and Cutting samples examination include macro and microscopic studies with the help of log interpretations show that Upper Qamchuqa Formation here can be divided into two basic lithological units from top to bottom are: Dolomite unit (D) and Limestone unit (L) with intercalation of Dolomitic Limestone (DL).

Petrographically three groups of microfacies were identified which comprise three limestone microfacies; Milliolid-Textularid Wackstone ($L_1$), Orbitulina Bioclastic Wackstone-Packstone ($L_2$) and Rudist Bioclastic Wackstone-Packstone ($L_3$). Five Dolomitic Limestone Micro facies; Milliolid-Textularid DoloWackstone($DL_1$),Porphyrotopic Foraminiferal Clayey DoloWackstone ($DL_2$), Pelliodal-Bioclastic DoloWackstone-DoloPackstone ($DL_3$), Orbitulina DoloWackstone-DoloPackstone ($DL_4$) and Bioclastic Foraminiferal DoloBound stone ($DL_5$) . Dolomite microfacies which include five subgroups; Coarse crystalline ($D_1$), Medium crystalline ($D_2$) and Fine crystalline ($D_3$) with subdivision of them, Fine-Medium ($D_4$) and Polymodal($D_5$).

Upper Qamchuqa Reservoir in Taq Taq Oil Field is intensively affected by diagenesis processes especially dolomization and dissolution. Other diagenetic processes according to their abundances, cementation, and compaction. Dolomitization has important role in developing secondary porosity as intercrystalline and vugs and dissolution in development of moldic pores as well as fracturing has great effect on Upper Qamchuqa reservoir.

Interpretation and analysis of the available Wierline logs (Gamma ray ,Spontaneous potential, sonic, density, neutron, resistivity and image log ) were used to predict and support prediction of lithological characters and petrophysical parameters such as bulk porosity, effective porosity, permeability,

bulk volume of water and oil as well as movable and residual oil and movable water and irreducible water.

Based on plug analysis and well logs four porosity units were identified with average porosity value range from 3% to about 16.6% and with average effective porosity ranging 11%- >20%. These units from top to bottom are U1, U2, U3 and U4. In each porosity unit average porosity, average pay porosity, pay thickness and pay /gross ratio are estimated which show that (U1) porosity unit in all wells represent best potential unit in the Taq Taq Oil Field.

Interpretation of other petrophysical parameters of R35, porosity- water saturation plot and porosity- permeability cross plots shows that types of flow in Upper Qamchuqa reservoir is fracture and fracture superimposed on matrix flow.

Based on fracture index, flow types and image log interpretation the Upper Qamchuqa Reservoir is intensively fractured reservoir which is mainly responsible for the potential of the reservoir in Taq Taq oil field.

Depending on porosity cut off and water saturation cut off with calculation of other petrophysical parameters (hydrocarbon saturation, water saturation, bulk volume of oil and water with average porosity) in generally Upper Qamchuqa reservoir is dividing into Upper ($RU_1$) potential reservoir unit, is saturated with water by 18% and 82% by oil .Middle ($RU_2$) reservoir unit,70% of this unit is oil saturation and 30% is water saturation and Lower ($RU_3$) reservoir unit, 20% of this unit is saturated by water and 80% is saturated by oil.

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# Chapter One

# Introduction

## 1.1: Preface

Several studies have been done to Cretaceous reservoirs especially Upper Qamchuqa Reservoir in north of Iraq oil fields, like Al-peryadi (2002) and Qadir (2008). But those fields which are discovered before and now but they are under development stage; no detailed reservoir study had been made to include reservoir evaluation of Upper Qamchuqa Formation in Taq Taq Oil Field.

In Taq Taq Oil Field, Oil present in commercial value from the productive carbonate reservoirs of the Tertiary Pila Spi Formation (Heavy Oil) and from the Shiranish, Kometan and Upper Qamchuqa Formations. Cretaceous light oil with estimated recoverable reserves 700-750 million barrels and in the future plans and when the field is completely developed, it will produce up to 200.000 to 250.000 barrels per day (TTOPCO, 2007).Therefore, interest become increasingly important in the Qamchuqa reservoir in general and Upper Qamchuqa reservoir in specific to enhance exploration plans.

## 1.2: Taq Taq Oil Field

### 1.2.1: Historical Review

Drilling in Taq Taq Field spudded in February 1960, stopped in April 1960, started again in May 1978, and finished drilling in Tq-1 in September 1978 by North Oil Company (NOC). Numbers of wells drilled until this line reached nine wells, Tq-1, Tq-2 and Tq-3 was drilled by North Oil Company, while TT-04, TT-05, TT-06, TT-07, TT-08 and TT-09 drilled by Taq Taq Operation Company (TTOPCO), which is in charge of developing the field.

### 1.2.2: Geological Setting of Taq Taq Oil Field

The Taq Taq Oil Field geographically locate in the Kurdistan Region of Iraq within Zagros Oil Province, some 60 kilometers northeast of Kirkuk city,
80 kilometers southeast of Hawler city and 120 kilometers northwest of Sulaimani city. Tectonically it is located within Foot Hill Zone (Butmah-Chemchemal Subzone), northeast unit of the foothill zone according to Jassim and Goff(2006), it has NW-SE trend parallel to Kirkuk ,Bai Hassan ,Khabaz ,Chamchamal and other Zagros province Fields.

Taq Taq Field represent by well defined double plunging structure of asymmetrical anticline .The surface expression of the structure is 27 km length and 11 km in width, with general NW-SE trend.

Taq Taq structure can easily be distinguished by the positive feature of the topography, well exposed strata; with average elevation about 600 meters (amsl) which is clearly reflect the underlying geological structure and lithologic differences of the outcropping rocks.

Towards Northeast a narrow syncline separates Haibat Sultan structure from Taq Taq structure and the exposure strata of the Miocene, Eocene, Palaeocene and Upper Cretaceous are cropping out forming geomorphological high with approximately 1000 meters elevation around Koya town.

Synclines at Northeast and Southwest form geomorphological lows with elevations of average 400 and 350 meters. Sediments of the Bakhtiari and Upper Fars Formations cropping out at the surface around Taq Taq anticline, (TTOPCO, 2007 in Hussein, 2008) (Fig.1-1).

The drilling in well Tq-1 penetrated Tertiary, Cretaceous and Jurassic Successions (Final well report, NOC, 1978) whereas the new well TT-09 the drilling depths penetrated to Upper Sarmord Formation (Albian), TT-06 and TT-07 the drilling depth approached to Upper Qamchuqa Formation (Albian) (Final well reports, TTOPCO, 2007) (Fig. 1-2, A).

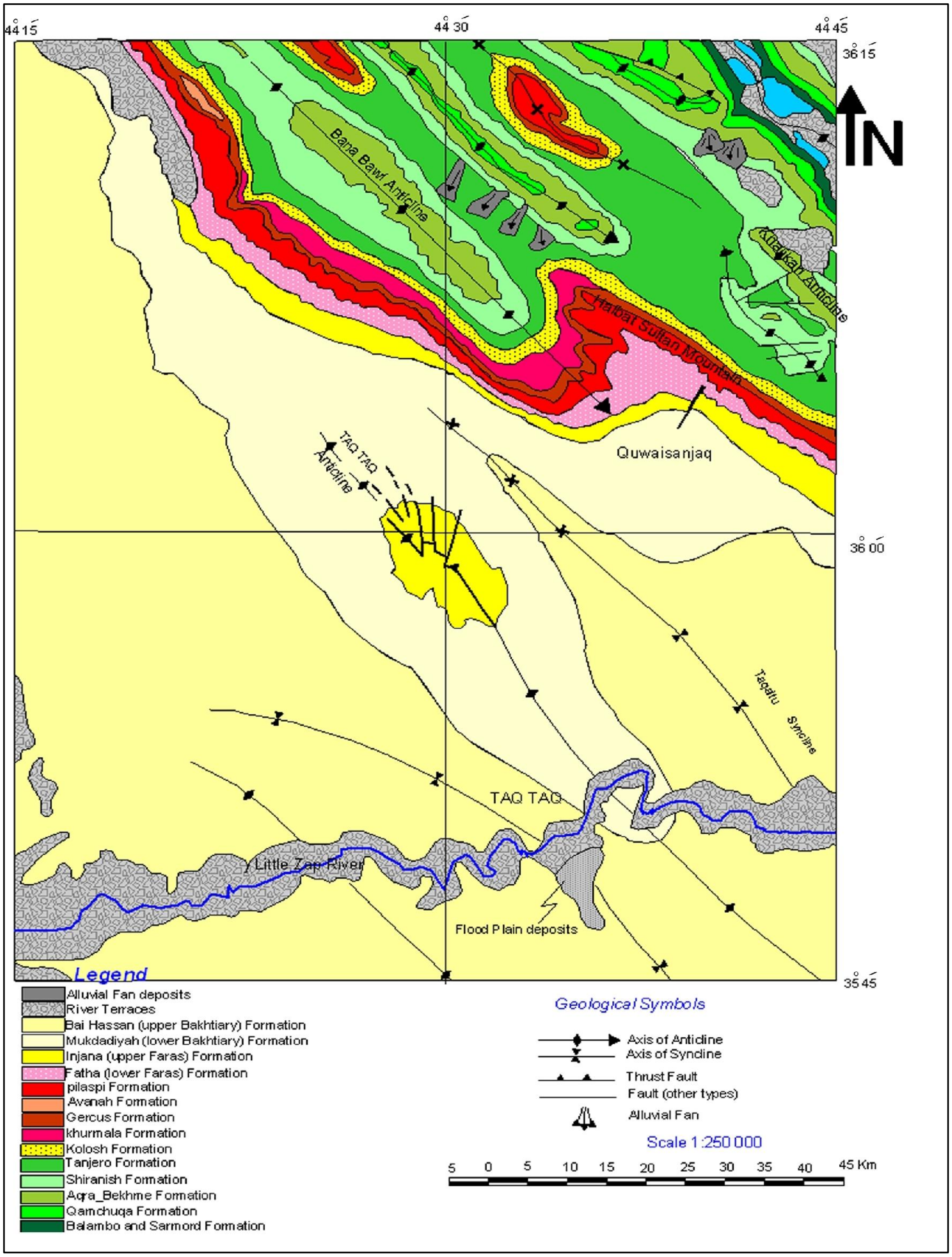



Fig .1-1: Geological Map of Taq Taq Structure and surrounding area, Enlarged from Sissakian, et al (1993, 1997).

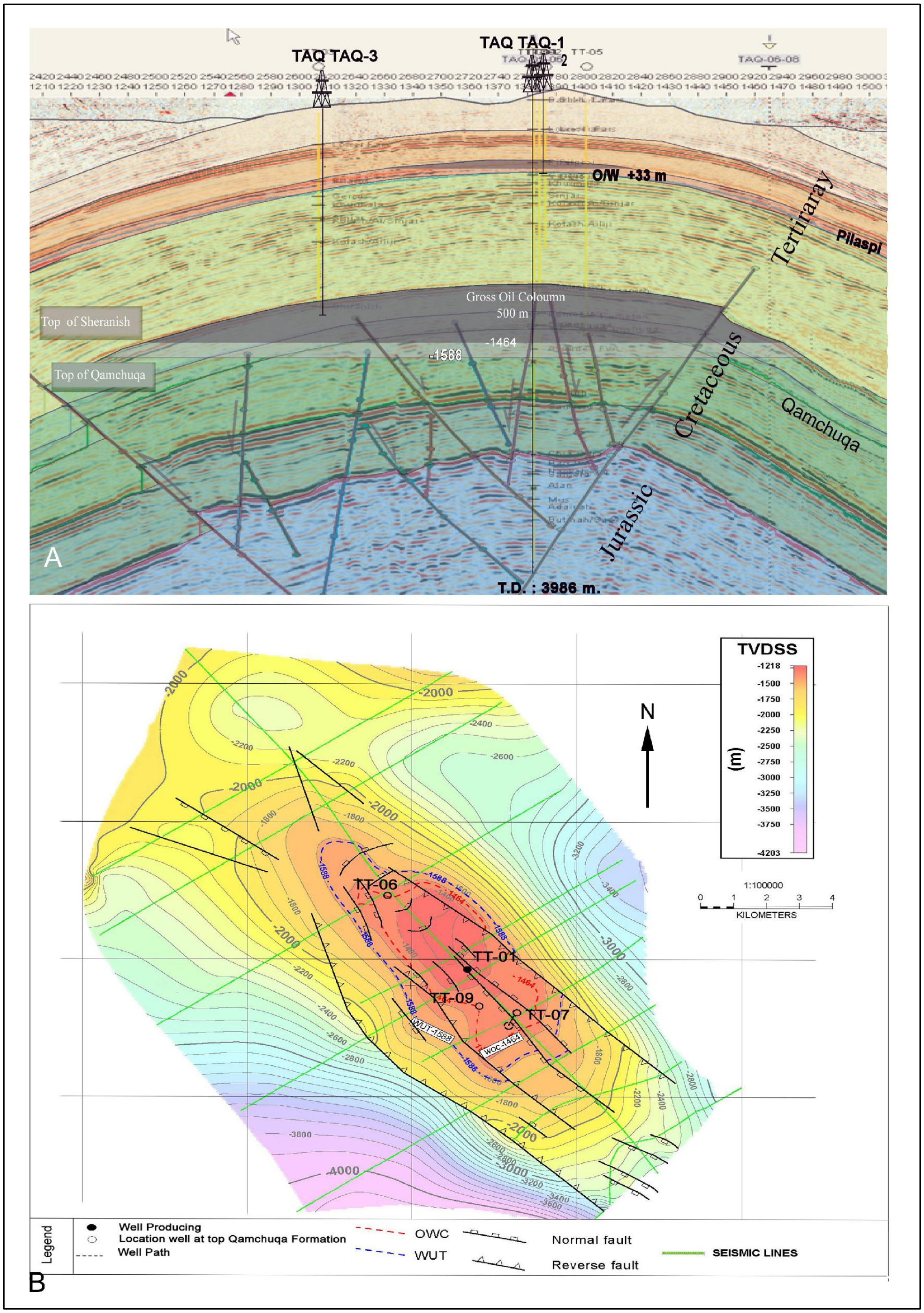



Fig .1-2:

A: Structural-Seismic Cross Section of Taq Taq structures with general stratigraphic Succession (not to scale). (TTOPCO, 2006)

B: Depth contour map of top of Qamchuqa reservoir in Taq Taq Oil Field, (TTOPCO, 2007).

### 1.2.3: Studied Wells

Studied wells include four wells which give the best section of Upper Qamchuqa Formation and these well are Tq-1, TT-06, TT-07 and TT-09.

**Tq-l well**: it is exploration well and located nearly at the crest of the structure. This well penetrated the Jurassic and crossed four reservoirs or payment zones. Elevation 630.5 RTKB.

**TT-06 Well**: it is appraisal well, is a step-out located approximately 4.0 km Northwest of Tq -1 well the length-wise axis of the TaqTaq Field,

It is the first attempt to define the areal extent of the Taq Taq structure.

**TT-07 Well**: it is appraisal well, is a step-out well, it is the second well which is attempting to define the length-wise areal extent of the TaqTaq structure. Located approximately 2.5 km Southeast of Tq-1 well and 7 kilometers in the opposite direction of the crest of the field from TT-06.

**TT-09 Well**: it is appraisal well, is a step-out well, and located approximately 1.5 kilometers southwest of the Tq-1well. This well is the first of two wells designed to appraise the flanks of Taq Taq structure. Wells location at top of Qamchuqa and in Taq Taq field shown in Fig.1-2, B.

## 1.3: Previous Works

The most common studies of Qamchuqa Formation are:

Al-Naqib (1960) divided the Qamchuqa carbonates, based on faunal content, into an upper and lower parts .The Lower Qamchuqa consists of neritic shoal limestone and dolomites with occasional tongue of the Middle Sarmord Formation. The Upper Qamchuqa is similar in lithology to the lower part, but it normally contains the Upper Sarmord tongue.

Chatton and Hartt (1960) divided the Qamchuqa Formation into Upper and Lower units based on fauna contents, they considered Maudud Formation as equivalent to Upper Qamchuqa in subsurface sections.

Gaddo (1965) made detail study of Cretaceous reservoir in Bai Hassan Oil Field. He divides reservoirs into porous and fractured, also divided Qamchuqa Formation into Upper and Lower Reservoir and considered Qamchuqa as porous type of reservoir due to presence of oil in pore and vug between grains or interparticle.

Gaddo (1966) considered Qamchuqa as an important reservoir in Kirkuk and Jambour Oil Fields, due to dolomitization causes high porosity of Upper Qamchuqa Formation which makes it better reservoir than Lower Qamchuqa. He also suggested that Qamchuqa Formation in Jambur Oil Field is better than both Kirkuk and Bai Hassan Oil Field due to favorable position of this structure as well as direct contact of Qamchuqa reservoir with source rock of Balambo Formation.

Hart and Hay (1974) in Ain Zalah Structure applied term Qamchuqa group, and stated that "Qamchuqa, originally defined as Formation, now is recognized as group, including Maudud, Gir Bir, and Wajnah Formations.

Al-Shakiry (1977) Studied Sedimentlogical and Digenesis processes of Upper Qamchuqa in Jambur Oil Field. He concluded that, depositionally, the studied rocks lie within two basic facies; a high-energy shelf margin facies (as Upper Qamchuqa shoal banks and Lower Qamchuqa reefs) and a relatively low to moderate energy shelf facies (as Upper Qamchuqa and Lower Qamchuqa formations).

Al-Sadooni (1978) did study the sedimentology of Upper Qamchuqa in outcrop in Safen Mountain and Kirkuk, jambur and Bai Hassan Oil Fields. He compared the stratigraphy with the outcrops at Safeen-Dagh and Geli Ali Beg, and inferred that the deposition of the Qamchuqa Group is a rudist- algal-hydrozoans bank.

Buday (1980) discussed the Upper Qamchuqa Formation and its lateral extension, distribution in north and middle of Iraq.

Al-Rawi et al., (1980) studied petrological (sedimentology and Diagenesis) and Geochemistry of the Upper Qamchuqa, Batiwah and Lower Qamchuqa Formation in Jambur Oil Field.

Sissakian and Youkhana (1984) studied upper most part of Qamchuqa Formation in Shaqlawa vicinity, northern Iraq with focus on aspects strartigraphical study of Upper Qamchuqa Formation and its contact with Bekhme Formation.

Ahmed et al., (1986) performed Petrographical and geochemical studies of cretaceous carbonate rocks in Ain Zalah Oil Field which cover the Upper Qamchuqa Formation.

Sahar (1987) studied the dolomitization processes of Upper Qamchuqa Formation in northern Iraq including Kirkuk, Chamchamal, Butma, and Tel Hajer Fields.

Al-Shididi et al., (1995) did a comprehensive study of sedimentology, Diagenesis and Oil occurrence of Qamchuqa group in Jambour Oil Field.

Werdi (2001) applied sequence stratigraphy and sedimentology study to the lower Cretaceous Formations which include Upper Qamchuqa Formation in Bai Hassan, Khabaz and Jambur Oil Field.

Al-Peryadi (2002) gave Sedimentlogical and reservoir study of Upper Qamchuqa and Jawan Formation in Bai Hassan Oil Field. He divided upper Qamchuqa into four reservoir units.

(Al-Sadooni and Al-Sharhan, 2003) Carried out a regional strartigraphical, microfacies description and petroleum potentiality of Mauddud Formation which is considered the equivalent of Qamchuqa Formation in Northern Iraq.

(Jassim and Buday, 2006 in Jassim and Goff, 2006) gave general and detail stratigraphy and tectonic study of Upper Qamchuqa "Mauddud" Formation in Iraq

Al-Juboury et al., (2006) studied the facies analysis of Upper Qamchuqa Formation in Kirkuk area based on distribution of subsurface lithology, petrographic constituents and well log analysis of five wells in Kirkuk area.

Ameen (2008) studied sedimentlogy and lithostratigraphy of Qamchuqa formation in Kurdistan region, and divided Qamchuqa Formation to eight units based on lithology and fossils content.

Qadir (2008) who did study concerning with the reservoir characters of Upper Qamchuqa in Khabaz Oil Field, and he divided Qamchuqa reservoir into three lithologic unit and six reservoir unit**.**

Sharbazheri (2008) studied the sequence Stratigraphy of Qamchuqa Formation from selected sections in Kurdistan region; she indicated that in Safin section Qamchuqa Formation consist of two lithologic limestone and dolomite units.

Bawa (2008) studied diagenesis and geochemistry of Qamchuqa Formation from selected section in Kurdistan region; he showed that Qamchuqa Formation has been affected by both early and late diagensis processes.

## 1.4: Aim of the Study

The aims of this research are to study the character of reservoir of Upper Qamchuqa Formation in Taq Taq oil field, including:

a- Facies identification of Upper Qamchuqa Formation, with there lateral and vertical distribution.

b- Evaluation of microfacies and diagenesis effects on the reservoir development.

c- Estimation of total porosity, permeability, flow types and determination of effective porosity and dividing the reservoir into porosity units with determination of net pay in each unit.

d- Examination the relationship between porosity and permeability with reservoir fluids.

e- Evaluation of movable oil, residual oil, movable water and irreducible water in Upper Qamchuqa reservoir.

f- Investigation of fracture impact on the development of the reservoir rock.

g- Attempting the subdivision of reservoir rocks based on different Petrographical parameters into potential reservoir unit.

## 1.5: Research Method and Material

The study of reservoir character of Upper Qamchuqa Formation based on two trends:

**A**: Study and description of macrofacies which include:

a-Macro description of core samples in Tq-1, TT-06, TT-07 and TT-09, thickness of core in Upper Qamchuqa Formation interval in these four wells about 64.4 meters as shown in table (1-1).

The description of physical properties of rock samples, like colour, hardness, oil saturation, sedimentary structure, macro porosity, joints, fractures…etc.

b- Micro description: study of thin section with petrographical description, microfacies definition and classification using 370 slides of core and cutting samples.

Using Alizarin red by (Friedman, 1965) method to differentiate the dolomite from Calcite in 60 slides following (Dickson, 1965).

c- Application of Scanning Electron Microscope (SEM) to 10 samples of dolomite of Upper Qamchuqa interval to show crystal shape and size and relations of dolomite and pore types and geometry.

**B**: The second part of the study is based on description and identification of reservoir characters using different type of well logs analysis and there interpretation, these logs include;

Litholog ,SP , Gamma Ray , Resistivity ,Sonic , Density ,Neutron log or composite log , Image log ( EMI or ,XRMI ) (Table 2-1).

**Table 1-1: Explain information about studied wells in Taq Taq Oil**

| Well | Type | Total Depth m | Upper Qamchuqa Formation | | | Cores Details | | | No of samples | No of thin section |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Thickness m | Top m | Bottom m | No | Intervals m | | | |
| Tq-1 | Exploration well | 3986 | 213 | 1957 | 2170 | 12<br>13<br>14<br>15 | 1978 - 1985<br>1986 - 1988<br>2049 - 2061<br>2137 – 2142 | 6.72<br>2<br>12<br>4.1 | 227 | 306 |
| TT-06 | Appraisal Well | 2265 | 194 | 2071 | 2265 | 3<br>4 | 2070.4 - 2076.6<br>2076.6 - 2087 | 4.95<br>9.8 | 28 | 29 |
| TT-07 | Appraisal Well | 2186.5 | 161.5 | 2025.5 | 2187 | 2<br>3<br>4<br>5 | 2028.0 - 2032.4<br>2032.4 - 2039<br>2041.7–2039<br>2041.7 - 2047 | 4.02<br>6.3<br>2.22<br>5.14 | 23 | 25 |
| TT-09 | Appraisal Well | 2444 | 219 | 2006 | 2225 | 2<br>3 | 2015.20 – 2021<br>2058 – 2060.5 | 5<br>2.1 | 9 | 10 |

These logs were digitized by Get Data software to:

a-identification of reservoir properties and measurement of primary porosity, secondary porosity, permeability, oil saturation, water saturation, flow unit type and classification of reservoirs into unit based on reservoir characters after digitization and corrections of log data.

b- Lithological and mineralogical identification of reservoir rock, by using Schlumberger charts (Neutron – Density, Neutron – Sonic and M-N cross plot).

c- Application of (EMI-Model) image log to identify and describe the reservoir character and fractures and Lithological description, in which new technique is used in TT-06, TT-07 and TT-09 wells.

d: Core and Plug Analysis

Including laboratory analysis and measurement of plugs from cores of the Upper Qamchuqa Formation. Tq-1and TT-07 to measure porosity, permeability and compare them with log measurement (Table 1-1).

**Table 1-2: Log types which are used in studied wells.**

| Well No | Log types | | | |
|---|---|---|---|---|
| | Image | Resistivity | Porosity | Others |
| Tq-1 | | Laterolog Deep (LLD)<br>Laterolog Shallow (LLS)<br>Micro spherical<br>Focused Log (MSFL) | Sonic<br>Neutron<br>Density | Gamma Ray (GR)<br>Spontaneous Potential (SP)<br>Caliper<br>Litho log |
| TT-06 | X-tend Range Micro Imager-XRMI<br>"Electrical Micro Imaging"-EMI | Laterolog Deep (LLD)<br>Laterolog Shallow (LLS)<br>Micro spherical<br>Focused Log (MSFL) | Sonic<br>Neutron<br>Density | Gamma Ray (GR)<br>Spontaneous Potential (SP)<br>Caliper<br>Litho log |
| TT-07 | X-tend Range Micro Imager-XRMI<br>"Electrical Micro Imaging"-EMI | Laterolog Deep (LLD)<br>Laterolog Shallow (LLS)<br>Micro spherical<br>Focused Log (MSFL) | Sonic<br>Neutron<br>Density | Gamma Ray (GR)<br>Spontaneous Potential (SP)<br>Caliper<br>Litho log |
| TT-09 | X-tend Range Micro Imager-XRMI<br>"Electrical Micro Imaging"-EMI | Laterolog Deep (LLD)<br>Laterolog Shallow (LLS)<br>Micro spherical<br>Focused Log (MSFL) | Sonic<br>Neutron<br>Density | Gamma Ray (GR)<br>Spontaneous Potential (SP)<br>Caliper<br>Litho log |

# Chapter Two
# Stratigraphy and Microfacies

## 2.1: Preface

Zagros basin constitutes a rich petroleum province. The lower Cretaceous Qamchuqa group comprises one of its major reservoirs (AlShidid et al, 1995).

Qamchuqa Formation was divided into Upper and Lower unit based on fauna contents by Chatton and Hartt (1960). They considered the equivalent of these two units, i.e. Upper and Lower Qamchuqa Formations, and the Sarmord tongue between them as Maudud, Shuaiba and Upper Sarmord Formations respectively in the subsurface sections.

Dolomitization and other digenesis processes affect the Upper Qamchuqa, in particular at upper part which makes good porosity system and development of reservoir characters. In this chapter the strartigraphic unit, lithofacies distribution, and microfacies types and their relation to the good reservoir character of Upper Qamchuqa Formation in Taq Taq Oil Field have been described and discussed.

## 2.2: **Upper Qamchuqa Formation:**

### 2.2.1: Paleogeography and Sedimentary Basin

Thickness and facies distribution for the Albian-Cenomanian units follow approximately the pattern which is found in the preceding Aptian age in the southwest , following an early uplift and peneplanation, an extensive marine sandstone blanket was deposited (correlative with the producing sands of the Burgan field).Basinal sedimentation continued in the east and neritic limestone spread over the high northwestern area, in center of the region, west of Kirkuk and south of Qalian, the Albian is represented by a thick sequence of marls, chemical limestone, and anhydrites. The neritic limestone provides excellent potential reservoir carrier formations, so oil is found in porous, neritic albian limestone reservoirs in Kirkuk and Ain zalah (Fig. 2-1) (Dunninghton, 1958).

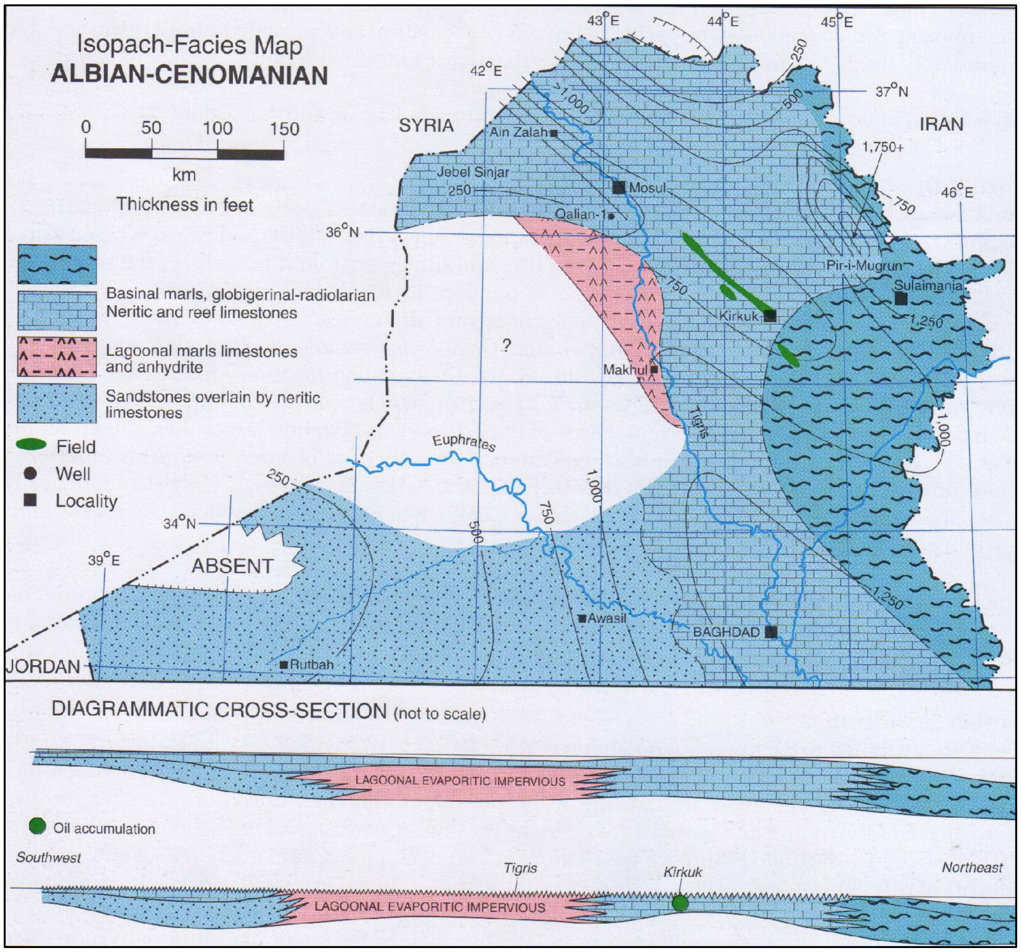


Fig.2-1: Isopach facies map of Albian-Cenomanian rocks in Iraq (Dunnighton, 1958)

The Albian-Aptian paleogeographic organization of Iraq was distinguished by the permanent basin with basinal facies occupies most of the eastern border of Iraq and is mainly represented by basinal biomudstone with *Globogerina*. The middle shelf, west of the permanent basin is characterized by neritic deposits dominated by the presence of fragments of Rudists. The inner shelf, presents two types of deposits. On the eastern part of the, lagoonal pelletal limestone is present, whereas on the extreme westward side of the basin super tidal conditions are common, with interdigition between both facies. The emerged areas are arranged into the Mousl block and the Gara-Khleisa height is characterized by a lacuna, and Siliciclastic sediments in the southwestern of the basin (Al Shididi et al, 1995).

The Mauddud formation is equivalent to the Upper Qamchuqa and is the most widespread lower Cretaceous Formation in Iraq. Its thickness varies due to lateral facies changes and erosional truncation (Fig. 2-2), Upper Qamchuqa Formation passes into the Balambo Formation on the NE part of the High Folded Zone. On the Mousl High the formation passes into the Upper Sarmord or Jawan Formations (Jassim and Buday, 2006 in Jassim and Goff, 2006)

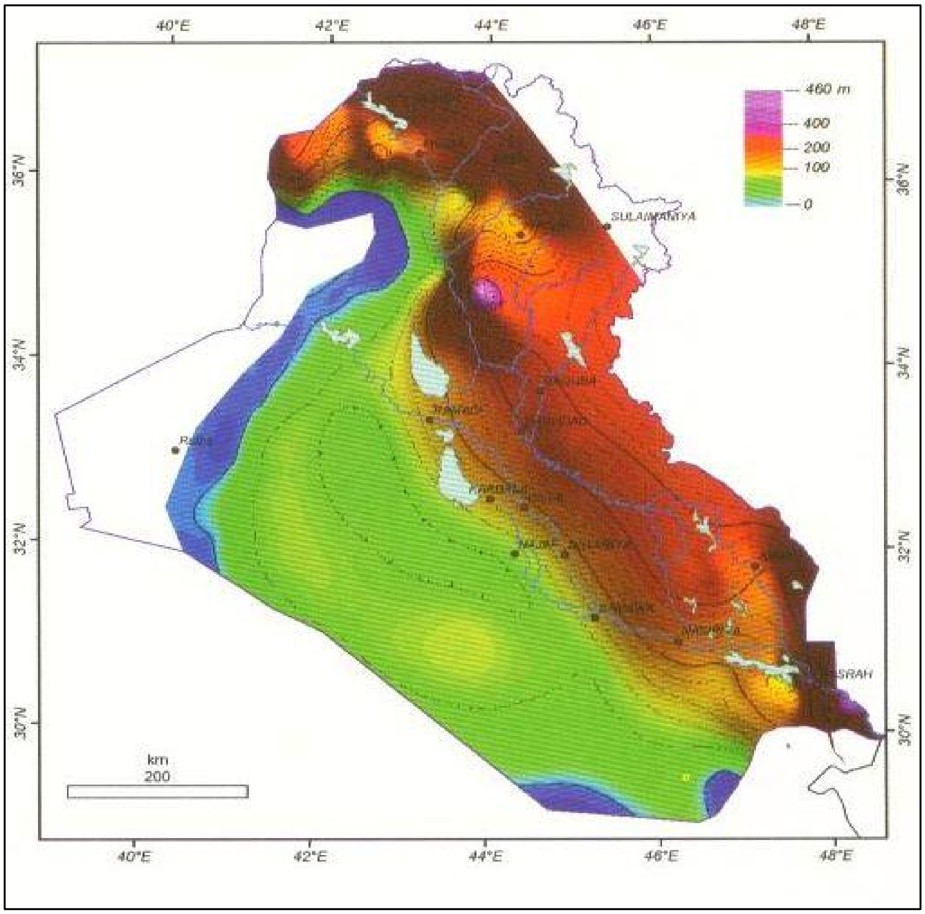



Fig.2-2: Thickness of Albian carbonate unit including (Upper Qamchuqa, Mauddud and Jawan Formations) (Jassim and Goff,2006).

The lower part of Maudud Formation represents an *Orbitulina*-bearing limestone. The vertical and horizontal extension of this facies all over the Arabian basin indicates long term stability of the basin. In areas of relatively higher energy, localized Rudist banks were established on the basin margin that gradually graded to the deep water carbonates of the Sarmord Formation or the pelagic facies of the Balambo Formation to the east. A gradual change from the *Orbitulina*-bearing limestone to pelletal and anhydritic limestone was noticed in the K-116, K-117, which are situated on the western part of Kirkuk field in northern Iraq (Sadooni and Alsharhan, 2003).

The formation is present on the stable shelf (apart from the northern part of the Rutba –Jazira Zone), and in the Foothill and High Folded Zones. The thickness of the formation decreases in the SE across the Anah-Qalat Dizeh Fault where the formation passes into basinal limestone of Balambo Formation. The southern depocentre trends in a NW-SE direction along the NE boundary of the Mesopotamian Zone on the Tikrit-Amara paleoridge of the Tigris Sub zone. At outcrop in NE Iraq the Qamchuqa Formation comprises organodetrital and derital and locally argillaceous limestone with variable degrees of dolomitization and in south Iraq the Mauddud formation comprises frequently dolomitize organodetrital limestone (Jassim and Buday, 2006 in Jassim and Goff, 2006)

### 2.2.2: Stratigraphy and Boundaries

Bellen et al, (1959) described Upper Qamchuqa Limestone Formation in type section from Kurdistan region. It is consists prevalently of dolomites, replacing neritic-detrital limestones and of non dolomitized detrital limestones, locally argillaceous. They divided Qamchuqa Formation in its type locality into six lithologic units: upper dolomite, upper limestone, middle dolomite, middle limestone, lower dolomite and lower limestone units.

Al-Naqib (1960) divided sediment of Albian Upper Qamchuqa Formation in Kirkuk liwa into dolomite, limestone and dolomitic limestone which laterally and toward west intertounged with anhydrite facies of Jawan Formation.

Chatton and Hartt (1960) divided the Qamchuqa Formation into Upper and Lower unit based on fauna contents, they considered Mauddud Formation is equivalent of Upper Qamchuqa and Shuaiba is equivalent of Lower Qamchuqa Formation in subsurface.

In northern Iraq a different strartigraphic nomenclature has been adopted for the Mauddud equivalent strata. This is because the strartigraphic nomenclature there was based on the field work in the mountain region of northern Iraq which preceded the exploration drilling in that area. In Kirkuk field (K-116 and K-117) the Qamchuqa formation was divided into Upper and Lower Qamchuqa formation separated by shale unit of Upper Sarmord Formation. This subdivision scheme was then adapted for northern Iraq by petroleum geologists of Northern Oil Company as well as Al Shididi (1995) (Sadooni and Alsharhan, 2003).

Upper Qamchuqa Formation comprises of alternation beds of dolomite and limestone with thickness of 237m in well Kirkuk-130 and become 250m in well Chamchemal-2 or toward deep basin (Sahar, 1987) changed to 213m of dolomite, dolomitic limestone and limestone rock in Tq-1 in Taq Taq Oil Field (Fig.2-3).

The Upper Contact is an erositional unconformity but with out discordance with Kometan Formation in type section (Bellen etal, 1959).This boundary is marked by a break or unconformable surface in North central, north and northeast part of Iraq (Jassim and Buday, 2006 in Jassim and Goff, 2006).Ameen (2008) indicated there is no unconformable contact or erosional gap in upper contact, he considered is conformable with Kometan and/or Dokan Formations.

Lower contact of Upper Qamchuqa Formation is conformable and gradational with Sarmord Formation in type locality (Buday,1980), or Batiuwa Formation in Bai Hassan field (AL-Peryadi- 2002) or with Nahrummer in Ain Zalah Field (Sadooni and Alsharhan, 2003) and Balambo or lower Sarmord (Jassim and Goff,2006).

The upper contact of Upper Qamchuqa Formation in Taq Taq oil field represent by unconformable contact with Dokan Formation, recorded by isolated peak of

Gamma ray in all studied wells as recorded previously by Unconformable, erosional surface with Dokan Formation in Bi Hassan Field (Alperyadi, 2002),as well as in Khabaz oil field (Qadir,2008).

The lower contact of Upper Qamchuqa Formation in Taq Taq oil field recorded by conformable contact with Upper Sarmord Formation which drilled in Tq-1 and TT-09, show by gradational increasing of Gamma ray log , this phenomena recorded and mentioned before in Bai Hassan oil field(AL-Peryadi, 2002), and Khabaz oil field (Qadir,2008).

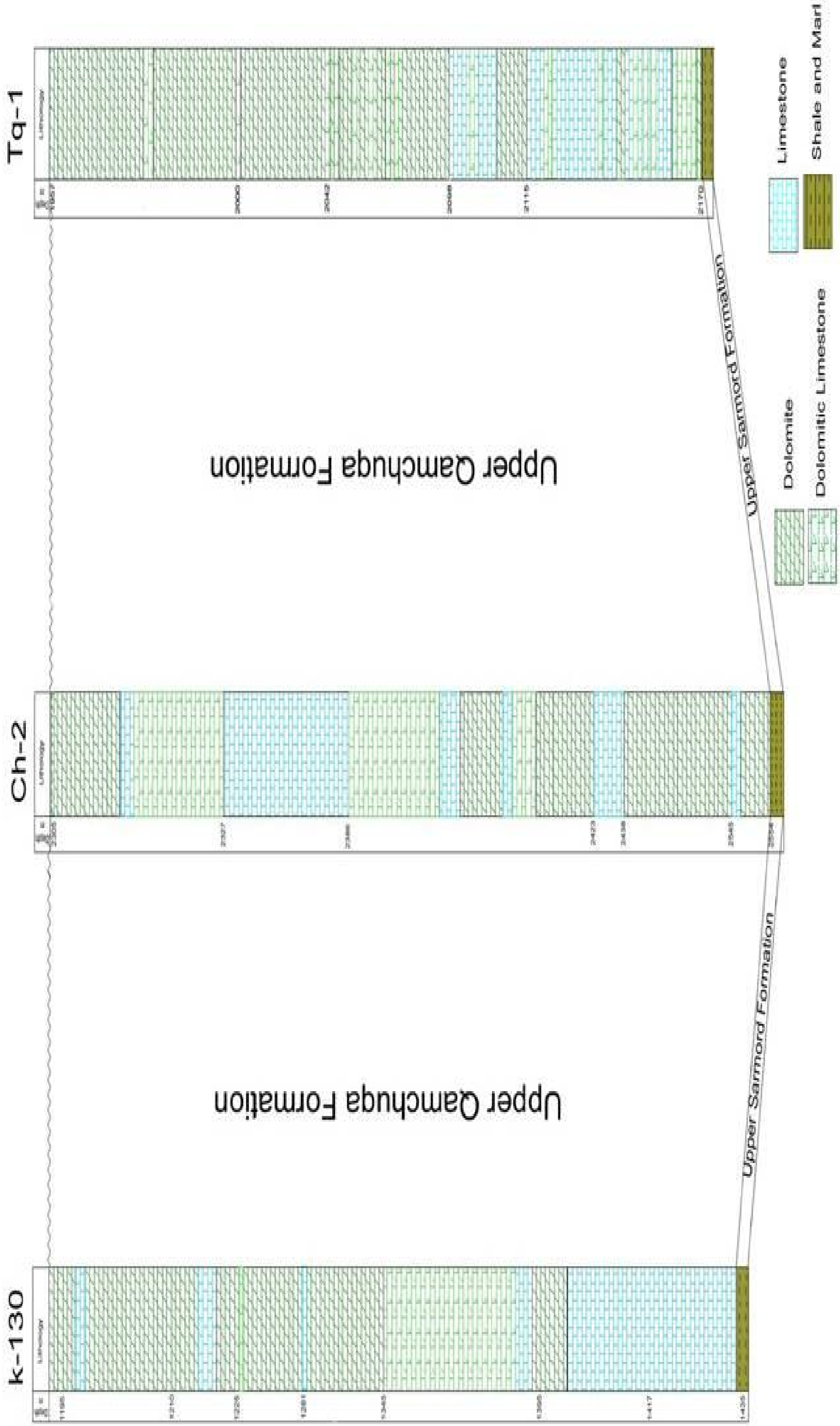


Fig.2-3: Stratigraphic correlation of Upper Qamchuqa Formation in K-130, Ch-2 (Sahar, 1987) and Tq-1, without horizontal scale.

## 2.3: Upper Qamchuqa Formation in Taq Taq Oil Field

The thickness of Upper Qamchuqa Formation in Taq Taq Oil Field ranges between 213m and 219m with maximum thickness in TT-09.the general lithologic character of the formation in Taq Taq Oil Field is light grey to yellowish brown crystalline dolomite and grey to light grey of limestone, overlained by Dokan Formation and underlies by Upper Sarmord Formation.

### 2.3.1: Core Description:

**Well: Tq-1**

Core no 12

Interval: 1978 – 1979.83m

Light brown, crystalline, hard, dolomite, dolomite unit, with vug and micro fractures pores, generally have pale yellowish color indicator to oil stain(Fig. 2-4, A.

Interval: 1979.83 – 1982.43m

Light grey ,light brown crystalline dolomite and dolomitic limestone, hard, massive, Stylolitic, vug and macro vug, micro fracture visible pores, ,oil stain begin in the lower part which take light brown color to it, while upper part with out it (Fig.2-4,B).

1982.43 – 1984.72

Light brown, crystalline, hard, and massive, dolomite, in dolomite unit, visible fractured, macro vug pores, completely stained by oil (Fig.2-5, A).

Core on 13:

Interval: 1986-1988

Light to dark grey, crystalline, dolomite, hard, vug pores; dolomite filled same pores, highly fractured, and stained with oil, dolomite unit (Fig.2-5, B).

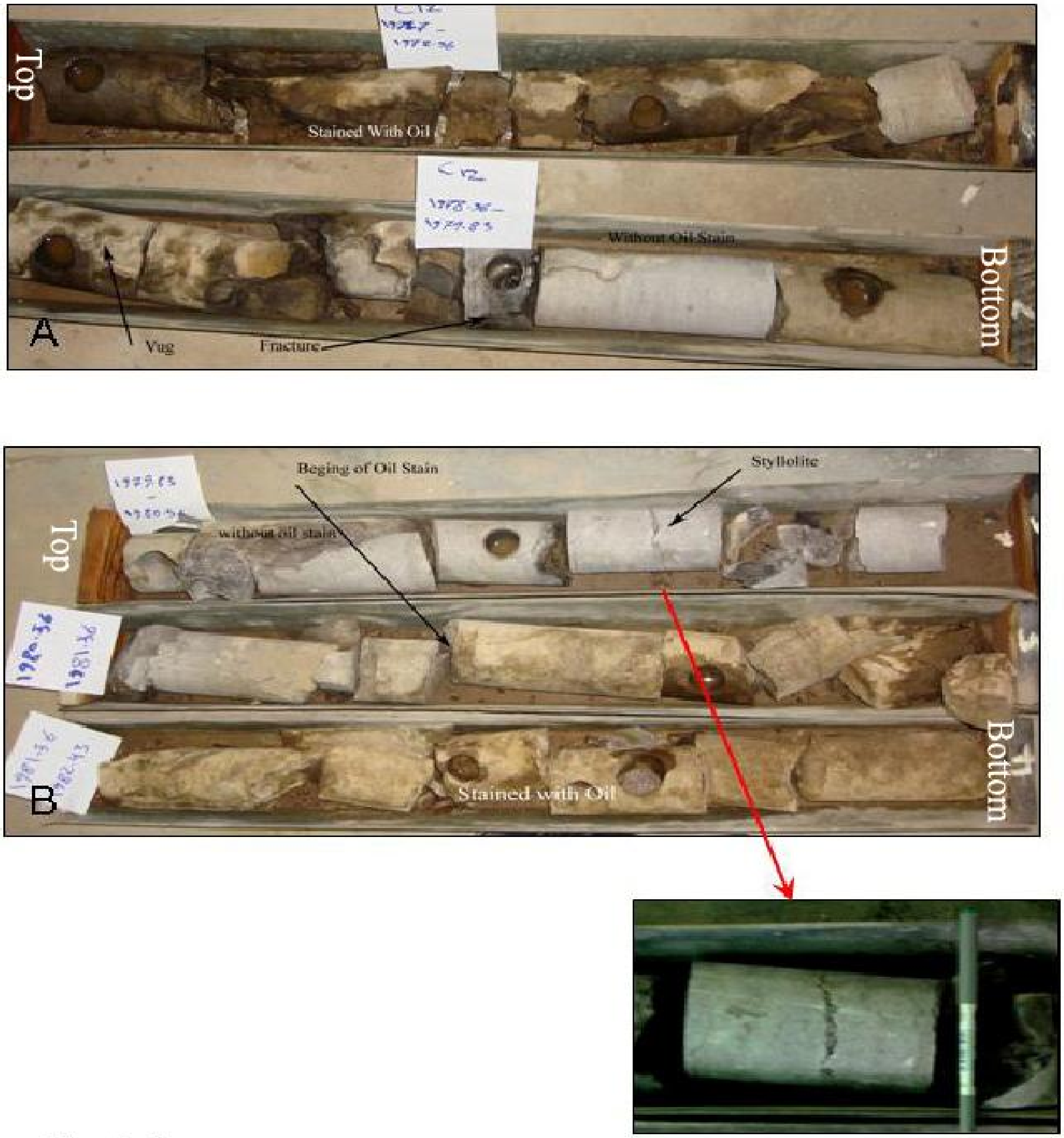



Fig. 2-4:

A: Light brown to grey , hard, crystalline dolomite in dolomite unit, have vug pores with microfractures, show oil staining in most parts Core interval(1978.6-1979.83)m of Tq-1.

B: Light grey , crystalline dolomite and dolomitic limestone, hard, styllolitic, vug and microfracture, oil stain in the lower part which take light brown color to it, while upper part with out it , core interval (1979.83-1982.43)m of Tq-1.

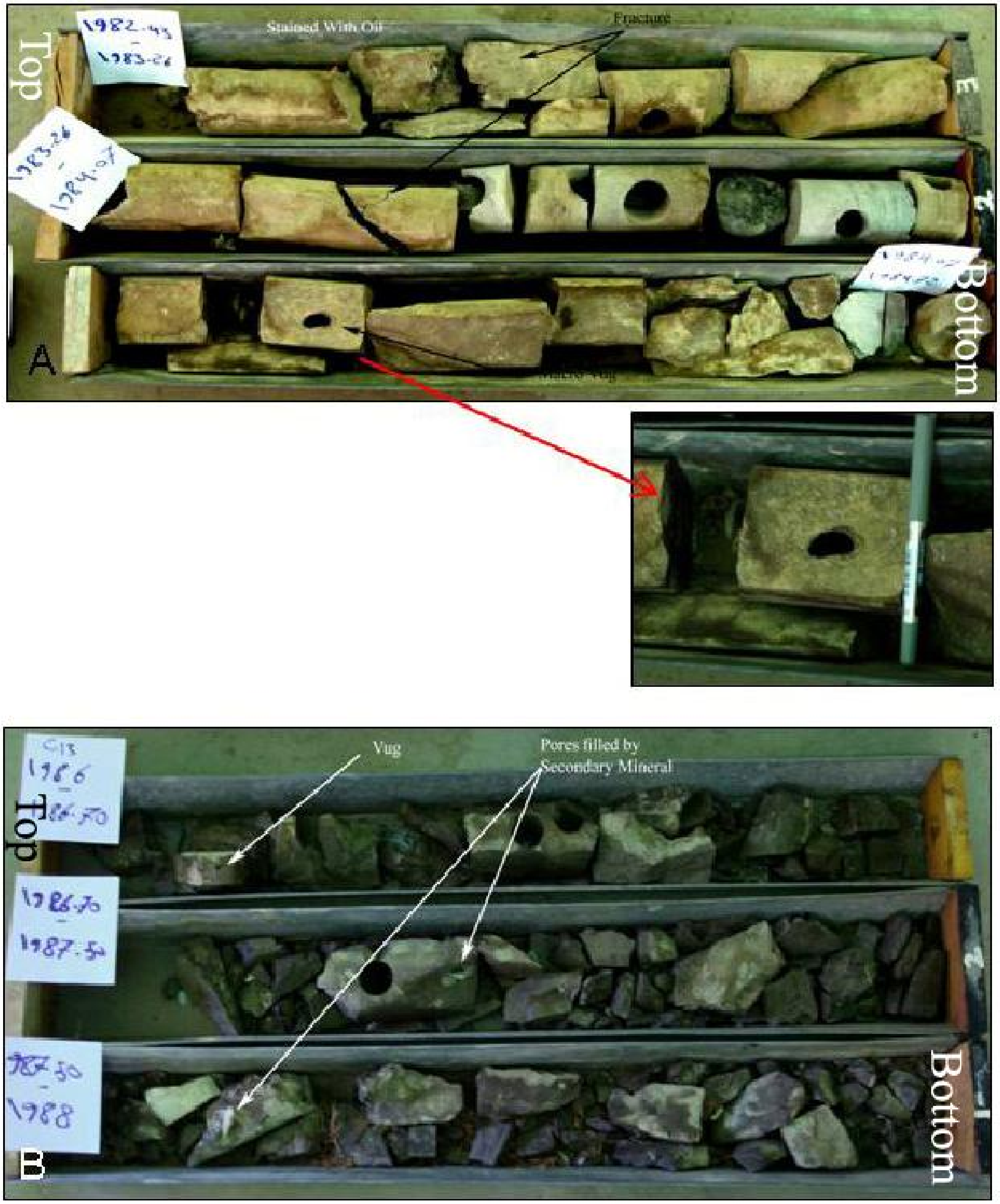



Fig.2-5:

A: Light brown, crystalline, hard, massive, dolomite, visible fractured, macro vug pores,dolomite unit,stained by oil, core interval(1982.43-1984.72)m of Tq-1.

B: Light to dark grey, crystalline, hard, dolomite,highly fractured, vug pores, dolomite filled same pores, stained with oil,dolomite unit, core interval(1986-1988)m of Tq-1.

Core no 14:

Interval: 2049-2051.31m

Light grey, fine to medium crystalline dolomite, mosaic, porous, same micro fracture fill with calcite, anhydrite fill some pores. Highly vugged pores in lower part, no indication to oil stain (Fig.2-6, A).

Interval: 2051.31-2053.77m

Light brown, coarse to medium crystalline, hard, dolomite and dolomitic limestone, vug, vertical and horizontal fractures, some pore filled by calcite, oil stain which give saturated cooler to rock samples (Fig.2-6,B).

Interval: 2053.77-2058.50m

Light same time dark brown, medium to coarse crystalline, hard, dolomite and dolomitic limestone, highly vuged pores, some time macrovug, fractured, yellowish saturation cooler show good oil stain (Fig.2-7,A and B).

Interval: 2058.50-2060.4m

Light brown, coarse crystalline, dolomite with dolomitic limestone, Stylolitic, vuggy pores, no saturation color and any indication to oil stain (Fig .2-8, A).

Core no 15:

Interval: 2137-2141.1m

Light grey, fine crystal, compacted, limestone, same time stylolitic, fractured, microfrcature fill with calcite, some part dolomitize, and no oil staining. Limestone unit (Fig .2-8, B).

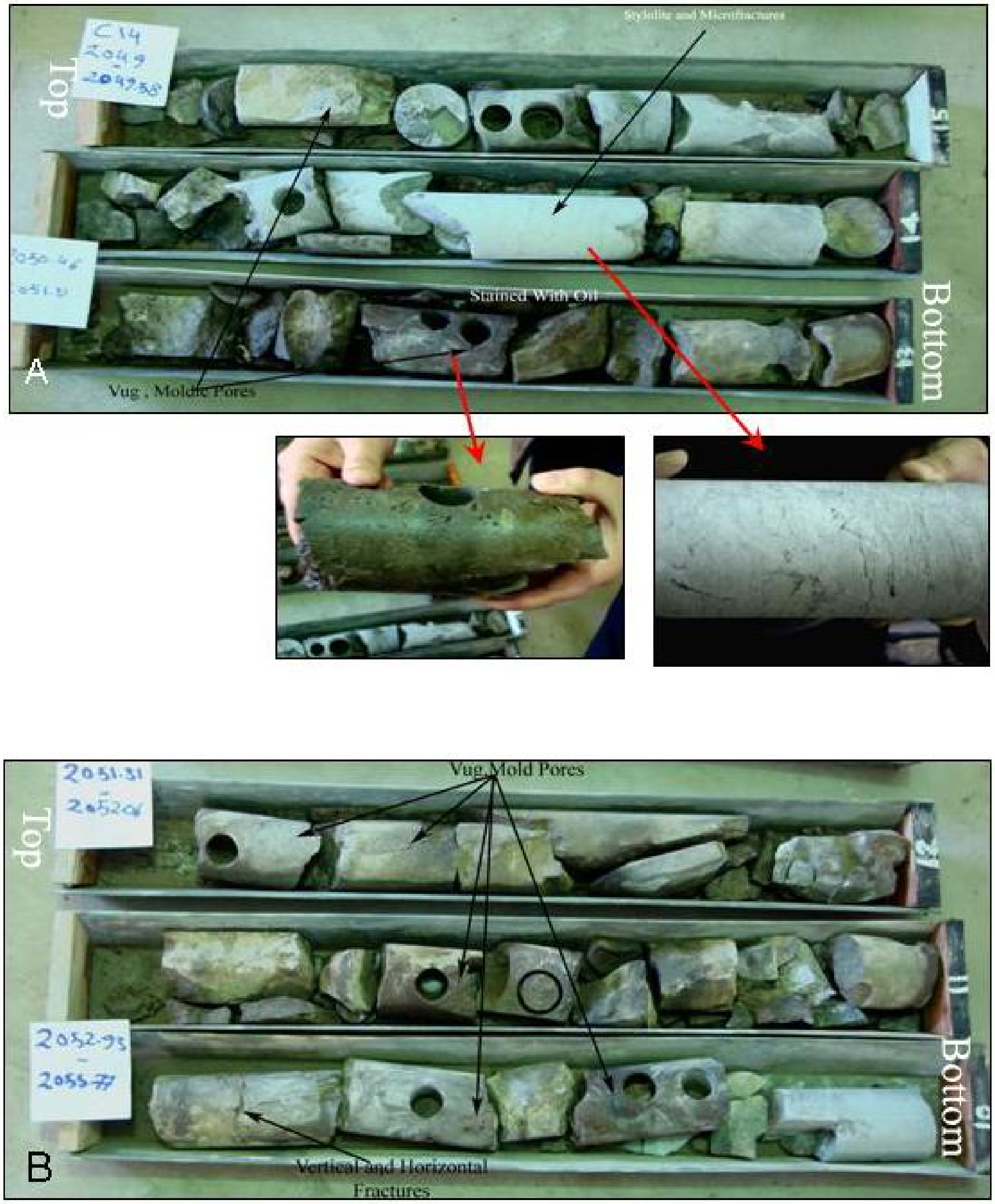



Fig.2-6:

A: Light to dark grey, crystalline dolomite, fractured, porous, no oil staining while lower part highly vugy pores stained with oil, dolomite unit, core interval(2049-2051.31)m of Tq-1.

B: Light brown, crystalline, dolomite and dolomitic limestone, vug, vertical and horizontal fractures, stained with oil, dolomite unit, core interval (2051.31-2053.77)m of Tq-1.

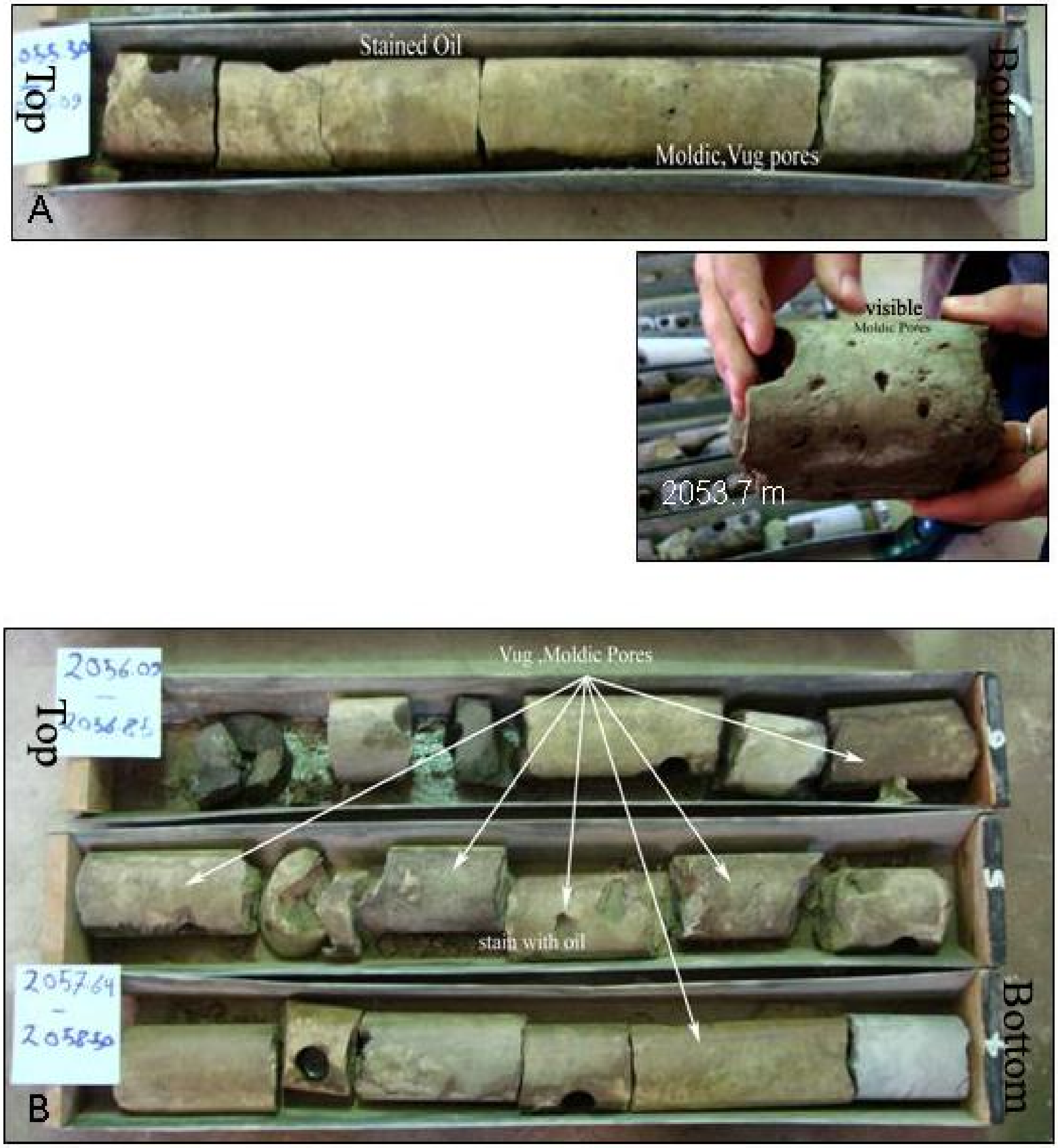



Fig.2-7:

A: Light yellowish brown, hard, crystalline dolomite, highly moldic and vug pores, stained with oil , dolomite unit, core interval(2055.30-2056.09)m of Tq-1.

B: Light to dark brown, crystalline, hard, dolomite and dolomitic limestone vuged pores, occasionally macrovug, fractured, show oil staining, dolomite unit, core interval(2056.09-2058.50)m of Tq-1.


Fig.2-8:

A: Light grey, crystalline, dolomite with dolomitic limestone , stylolitic, vugy pores, without oil staining, dolomite unit, core interval(2058.50-2060.40)m of Tq-1.

B: Light grey, crystalline, compacted, limestone, occasionally stylolitic, fractured, micro fracture fill with calcite, same part dolomitized, no oil staining, limestone unit, core interval(2138.65-2140.26)m of Tq-1.

## Well: TT-06

Core no. 3:

Interval: 2073.4m to 2075.35

Moderate grayish brown, massive, homogeneous, medium crystalline dolomite, occasional hair like fracturing, occasionally slightly vuggy, moldic pores, occasional spotty asphaltic staining on fracture faces, and stained with it (Fig .2-9, A,B).

Core no.4:

Interval: 2076.6m to 2088.6 m

Pale brownish grey to moderate grayish brown, commonly massive, homogeneous, mostly medium , fine crystalline dolomite, locally strongly stylolitic with high vuggy porosity, moldic pores, occasional oil filled vugs, and oil staining (Fig.2-9, C,D,E and F).

## Well: TT07

Core no.2

Interval: 2028.0m to 2032.4m

Dark yellowish brown, very hard to extremely hard, blocky to angular, medium crystalline dolomite, sucrose, no visible porosity grading to very good visible porosity towards base of core, commonly large fractures at 2028m, 2031m with oil flowing from fracture and 2032m.high degree of oil staining ( Fig 2-10, A).

Core no: 3

Interval: 2032.4m-2038.7m

Dark yellowish brown to dusky yellowish brown, very hard to extremely hard, blocky to angular, fine to medium crystalline dolomite, rarely no visible porosity grading to very good honeycomb visible porosity, common large vugs, and commonly fractured filled by oil staining, (Fig.2-10,B).


Fig.2-9:

A,B: Greyish brown, massive, crystalline, dolomite, fractured, slightly vugy, moldic pores, stained with oil, dolomite unit, core intervals (2072.4 and 2074.2)m of TT-06.

C,D: Pale brownish grey to greyish brown, massive crystalline, dolomite, stylolitic with vuggy and moldic pores, staining with oil, dolomite unit, core intervals (2080.6 and 2082.6)m of TT-06.

E,F: Yellowish grey, crystalline, hard, massive, dolomite, highly moldic and vug pores, stained with oil, dolomite unit, base of core no.4(2088.60)m of TT-06.

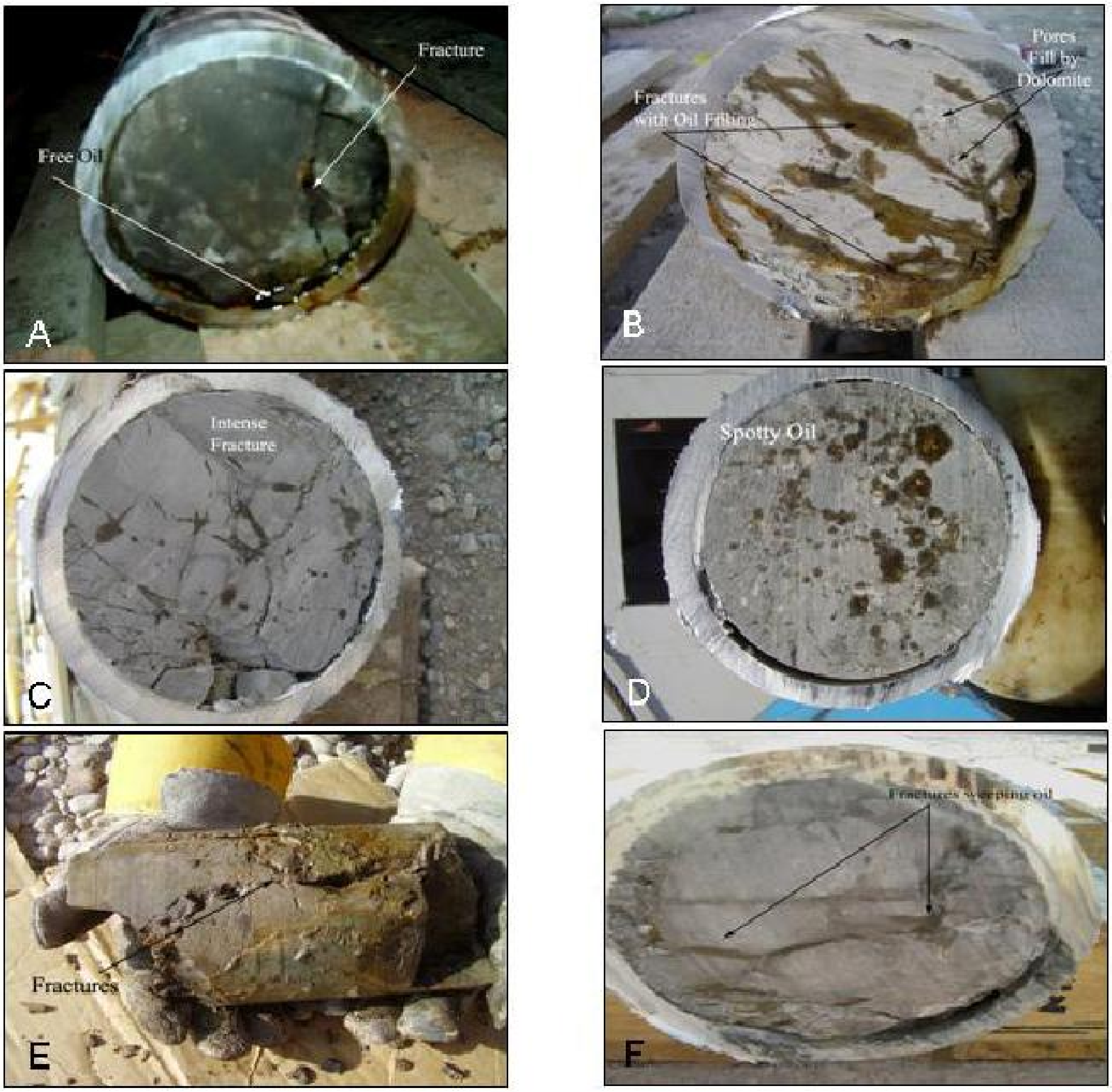



Fig.2-10:

A: Dark grey, hard, crystalline, dolomite, highly fractured, stained with free oil, dolomite unit, core depth 2031m, TT-07.

B: Light grey, crystalline, hard, dolomite , fracture filled with oil, dolomite unit, core depth 2033m, TT-07.

C: Light grey, hard, crystalline, dolomite, intense fractures, most fractures filled with oil staining, dolomite unit,core depth 2039m, TT-07.

D: Dark grey, hard, crystalline, dolomite cement filled same pores, spotted oil staining, core depth 2044m, TT-07.

E: Brownish grey, hard, crystaline dolomite, vug , moldic pores , intense fractures, stained with oil, dolomite unit, depth 2046.84m,TT-07.

F: Yellowish brown, crystalline, hard ,dolomite, fractures weeping oil, dolomite unit, core depth 2019m, TT-09.

Core no: 4

Interval: 2039 – 2041.7m

Dark yellowish brown, extremely hard, blocky, angular, medium crystalline, dolomite, poor visible porosity, rare large vugs, large fracture becoming grey to brownish black, and stained with oil (Fig .2-10,C).

Core no: 5

Interval: 2041.7m – 2047

Brownish grey to grayish black becoming light brownish grey, extremely hard, blocky, fine to medium crystalline, dolomite, rare vugs, no visible porosity, common hairline fractures, local large to very large fractures commonly in filled. stained with oil, and appear as spotted staining (Fig .2-10, D) and (Fig.2-10, E).

**Well: TT-09**

Core no: 2

Interval: 2015.2-2020.2m

Dark yellowish brown, black brown, crystalline dolomite, extremely hard, tight, no visible porosity, blocky. Common large fractures, large voids showing oil staining. Common hair like fractures weeping oil, and patchy oil stain (Fig .2-10, F).

Core no: 3

Interval: 2058-2060m

Dark grey to brownish grey, very hard, coarse crystalline blocky dolomite, no visible porosity, common hairline fractures, extensive large fracture.

### 2.3.2: Lithology Units of Upper Qamchuqa Formation in Taq Taq Oil Field:

Based on macroscopic description and Petrographical study "Thin Section" of core, plug and cutting samples with assistance of available Litholog the Upper Qamchuqa Formation in Taq Taq Oil Field can be divided into two distinct lithological units: Dolomite and Limestone unit .these two units were found to be equivalent to the Upper Dolomite unit and Upper Limestone units of the outcrop area of Kurdistan section of Bellen et al., (1959).

**A- Dolomite Unit**

It represent the Upper and thickest unit of the Upper Qamchuqa Formation.192m thick in type locality , ranges in thickness from 141-190m in Taq Taq field (Table 2-1).it is characterized generally by brownish grey, fractured, massive, coarse to fine crystalline sucrosic dolomite with characteristic vugs and small molds of ghosts identified in the studied wells. It occasionally alternate with thin dolomitic limestone. This unit overlained by Dokan Formation in Tq-1, TT-06, TT-07 and TT-09 and overlies Limestone unit of Upper Qamchuqa Formation which drilled in Tq-1 and TT-09 wells.

**B-Limestone Unit**

This unit is the lower part of the Formation with less thickness, 28 m thick in type locality, range in thickness from 55-72 m in Taq Taq field and represented the undolomitized part of the original carbonate facies of the formation. It occasionally alternate with thin dolomitic limestone and dolostone horizons. Overlies Upper Sarmord Formation in Tq-1 and TT-09. The Limestone Unit separated from Lower Qamchuqa Formation by First appearance of Green shale of Upper Sarmord Formation Which recorded inTq-1 and TT-09.

The nature and properties of the major lithologic types of these units is discussed below:

#### 2.3.2.1: Dolomite (D)

Most abundant and lithologic type in the upper Qamchuqa formation in Taq Taq Oil field. It consist of dark yellowish brown, pale brownish grey to moderate grey brown, brownish grey hard to very hard occasionally extremely hard, massive, blocky , and locally sucrosic, dolomite.

Table 2-1: show thickness and general description of each unit in studied wells.

| Well no. | Lithologic unit | Thickness m | General Character |
|---|---|---|---|
| Tq-1 | Dolomite | 141 | Light grey, brown to yellowish brown, hard, massive crystalline dolomite, vugy and moldic pores, stylolitic, fractured, stained with oil especially upper part, and occasionally dolomitic limestone. |
| | Limestone | 72 | Light grey, compacted, crystalline limestone, no visible pores, filled fractures, and no oil staining. |
| TT-09 | Dolomite | 164 | Brown to yellowish brown, hard, blocky, crystalline dolomite, fractured, poor in oil staining, occasionally dolomitic limestone. |
| | Limestone | 55 | Light grey, yellowish brown, crystalline limestone, no visible porosity, and no staining. |
| TT-06 | Dolomite | 190 | Grayish brown, pale brown, massive, crystalline, moldic and vugy visible pores, fractured, and stained with oil in upper part. |
| TT-07 | Dolomite | 162 | Light grey, yellowish brown, hard, massive, crystalline, moldic and visible vug pores, fractured and stained with oil in upper part. |

Coars, medium and fine crystalline dolomite mosaic are representing main and abundant microfacies of this unit with high degree of dolomitization and effect of other diagensis processes like dissolution, cementation and compaction.

Good amount of porosity developed in this unit and build best reservoir unit in upper part of this unit, intercrystalline, moldic, vug are common types of porosity of dolomite unit as well as stylolite which filled by oil " dead oil staining" and fractures which occasionally stained by oil stain or fill by cement.

Skeletal grains and other component effect by diagensis have low chance to preservations, but some ghost of skeletal grain remain especially in lower part of dolomite unit such as *Orbitulina* and *Textularina*.

Macro fractures are common in this unit especially in Tq-1, TT-06 and TT-07 which located at or near the crest of anticline and developed good reservoir porosity and permeability, most of them stained by oil.

### 2.3.2.2: Limestone (L)

This unit consists of gray, grayish brown, dark brown color, hard, blocky, microcrystalline Limestone, represented by lime Wackstone to Packstone which are rich in grains of completely or partially preserved like, *Orbitulina, Milliolid*, *Textularina*, pelloid and algae as well as shell fragment of bioclast of Rudist. These shells are commonly replaced or filled by cement which preserved them in fine micritic matrix or ground mass.

Occasionally stylolitic, have rare moldic, vug pores are filled by cement and have neglible or very low degree of porosity, this unit is less affected by diagenetic processes than dolomite unit. This unit characterize by poor reservoir characters.

### 2.3.2.3: Dolomitic Limestone (DL)

Dolomitic Limestone (DoloWackstone, DoloPackstone and DoloBounstone) microfacies which represent the original fabric partially dolomitized and the lime ground mass (matrix) usually remain. Grains of *Milliolid, Textularina*, *Orbitulina*, Algae and Pelloid were preserved in micritic matrix or ghost of them preserved with floating rhomb of dolomite (Porphyrotopic dolomite).

Most of the facies of dolomitic limestone are stylolitic and are filled by oil.Dolomitic limestone present as tongue in limestone and dolomite units IN Upper Qamchuqa Formation especially in Tq-1 and TT-09.

The vertical and lateral distribution of lithological units of Upper Qamchuqa Formation in the studied wells showed in figures 2-11, 2-12, 2-13, 2-14and 2-15.

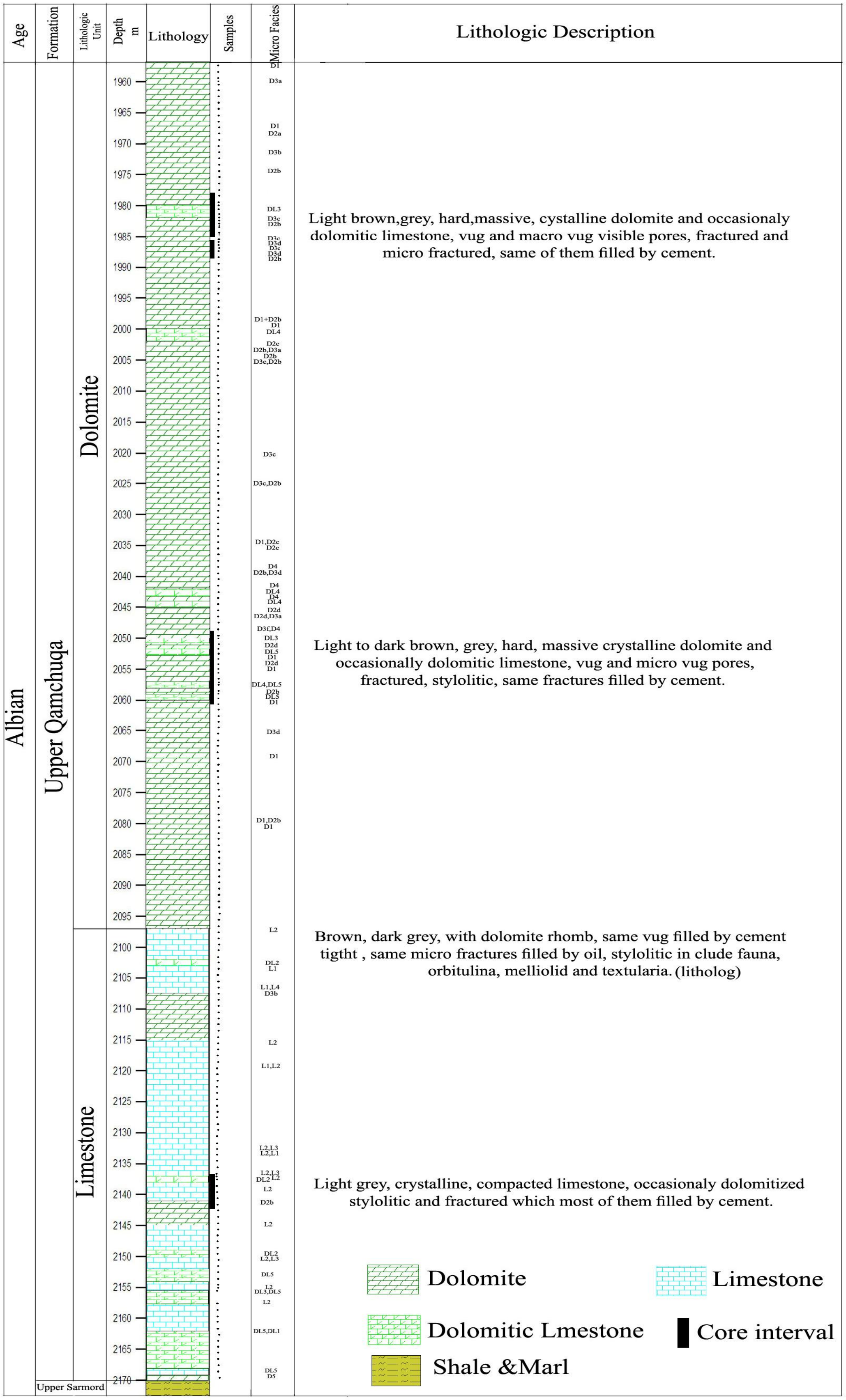



Fig .2-11: Strartigraphic Column of Tq-1, showing lithologic unit and microfacies of Upper Qamchuqa Formation .

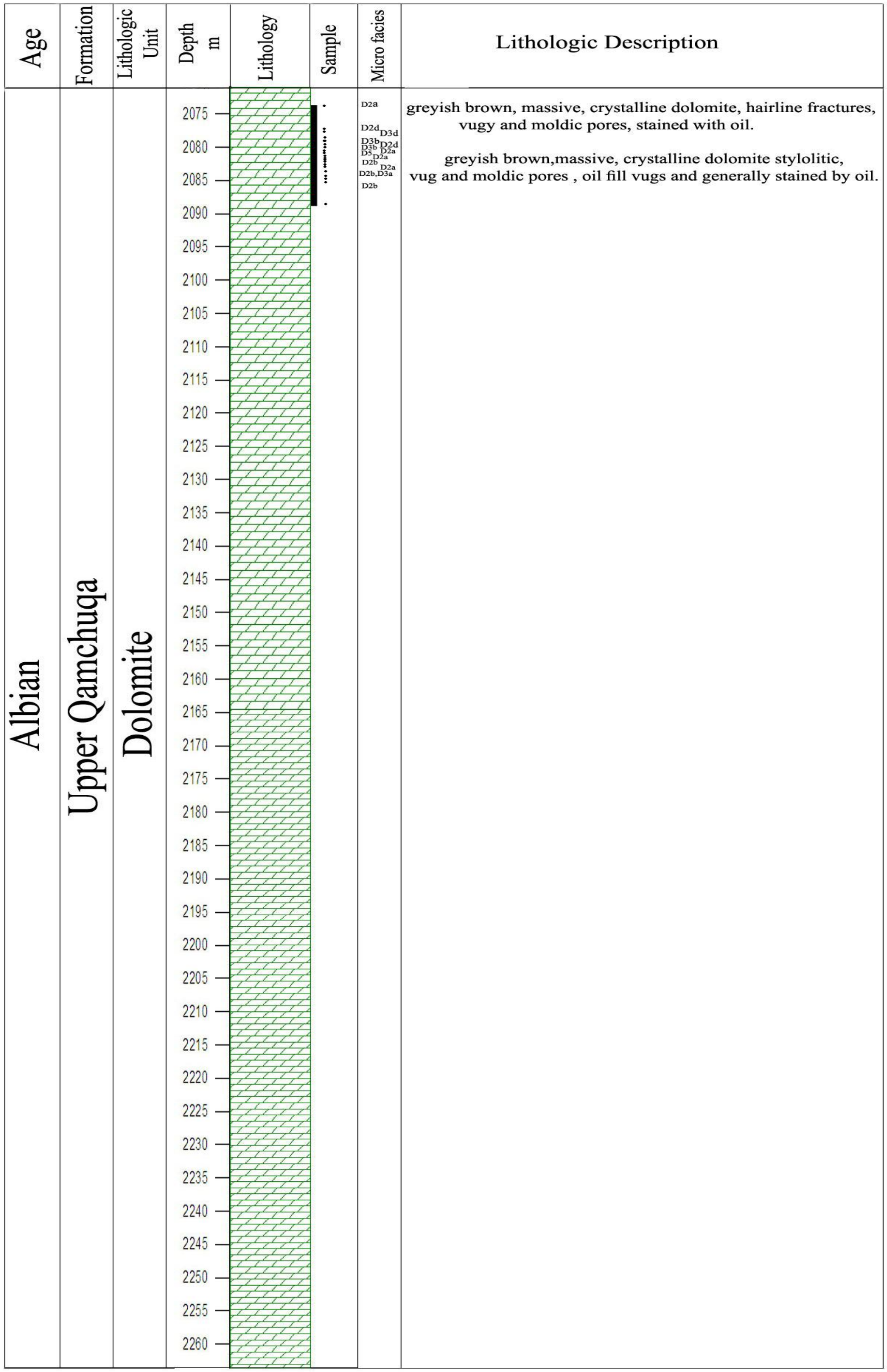



Fig.2-12: Strartigraphic Column of TT-06, showing lithologic unit and microfacies of Upper Qamchuqa Formation, from thin sections and Litholog (Legend the same of Fig.2-11).

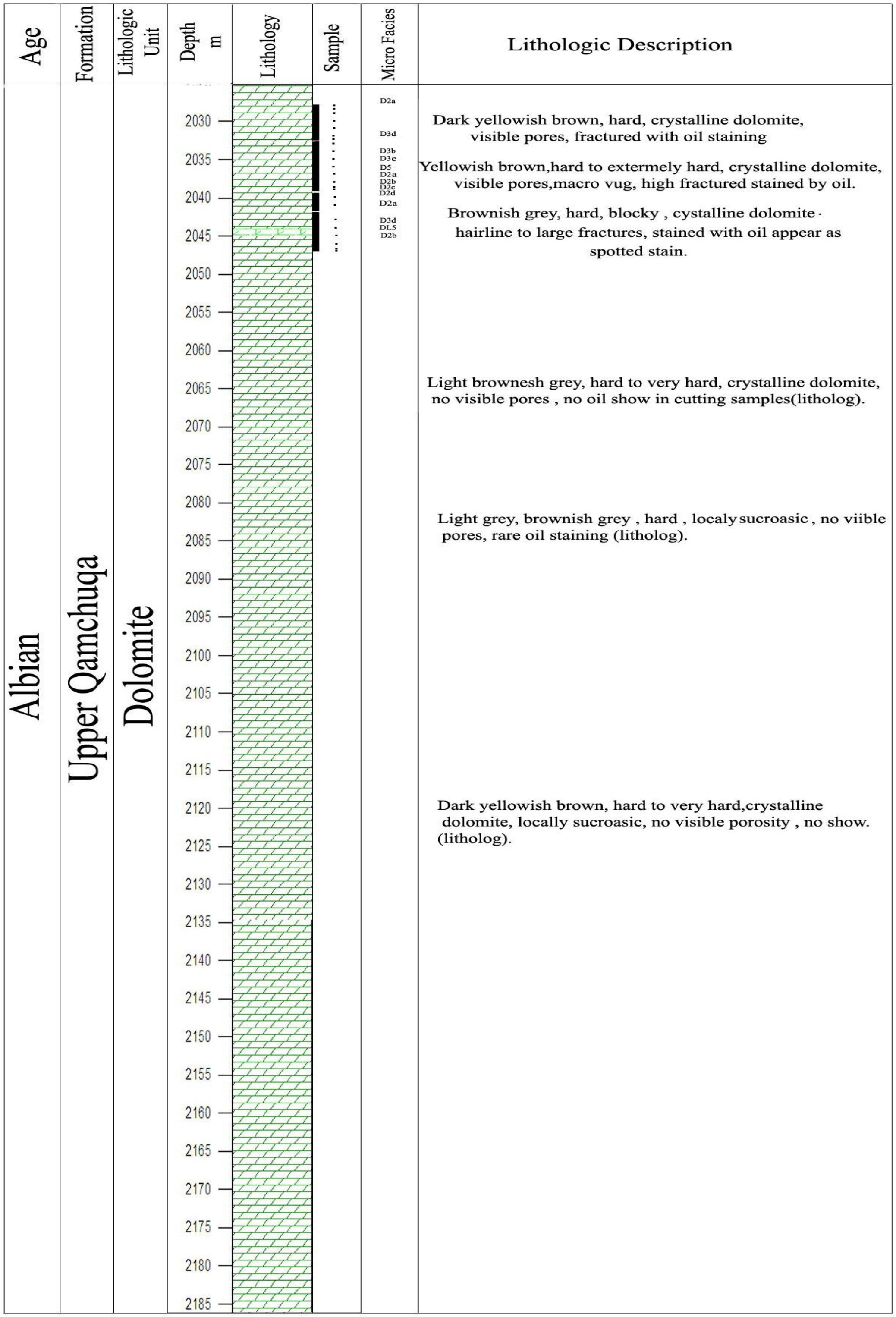



Fig.2-13: Strartigraphic Column of TT-07, showing lithologic unit and microfacies of Upper Qamchuqa Formation, from thin sections and Litholog (Legend the same of Fig.2-11).

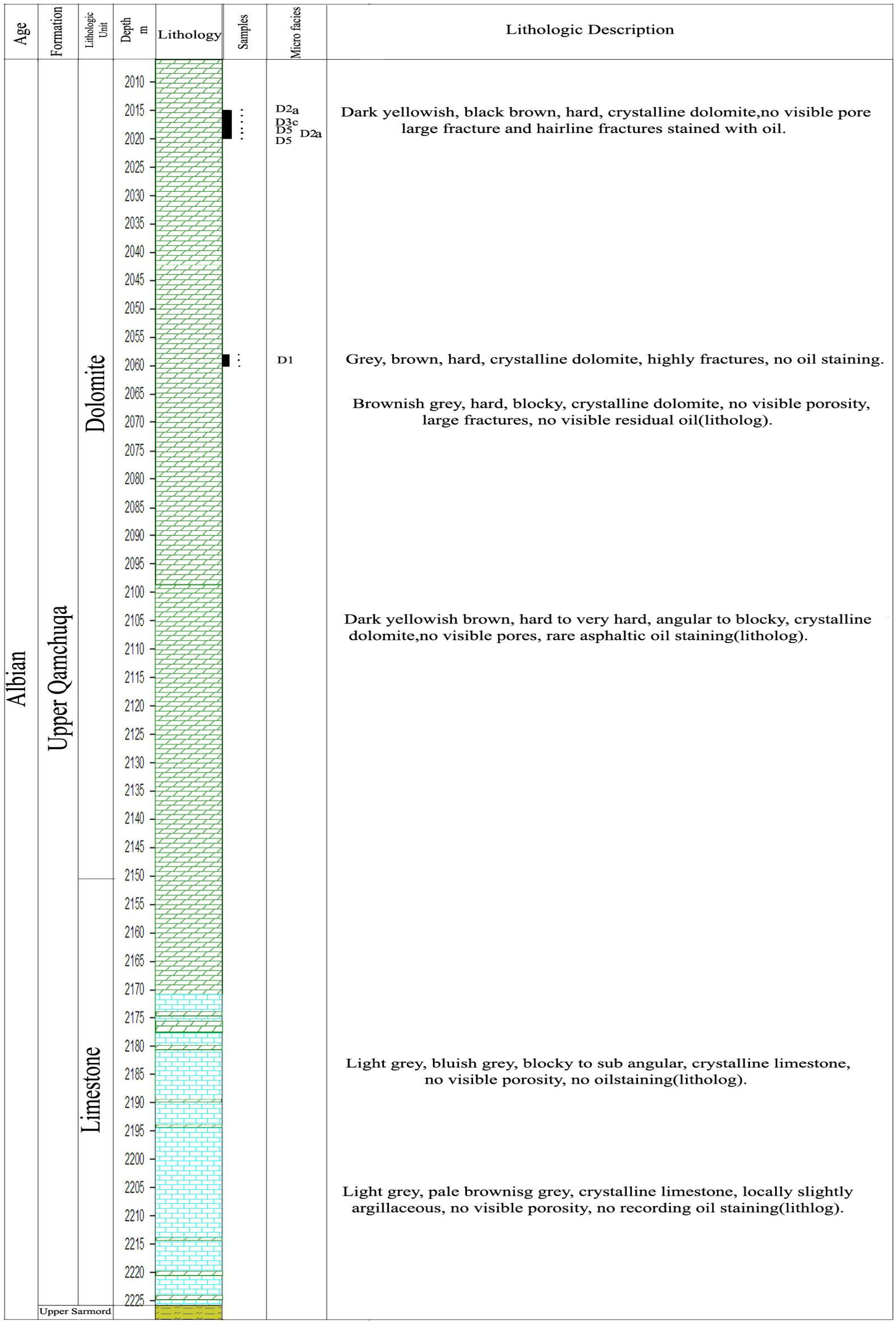



Fig .2-14: Strartigraphic Column of TT-09, showing lithologic unit and microfacies of Upper Qamchuqa Formation, from thin sections and Litholog (legend the same of Fig.2-11)

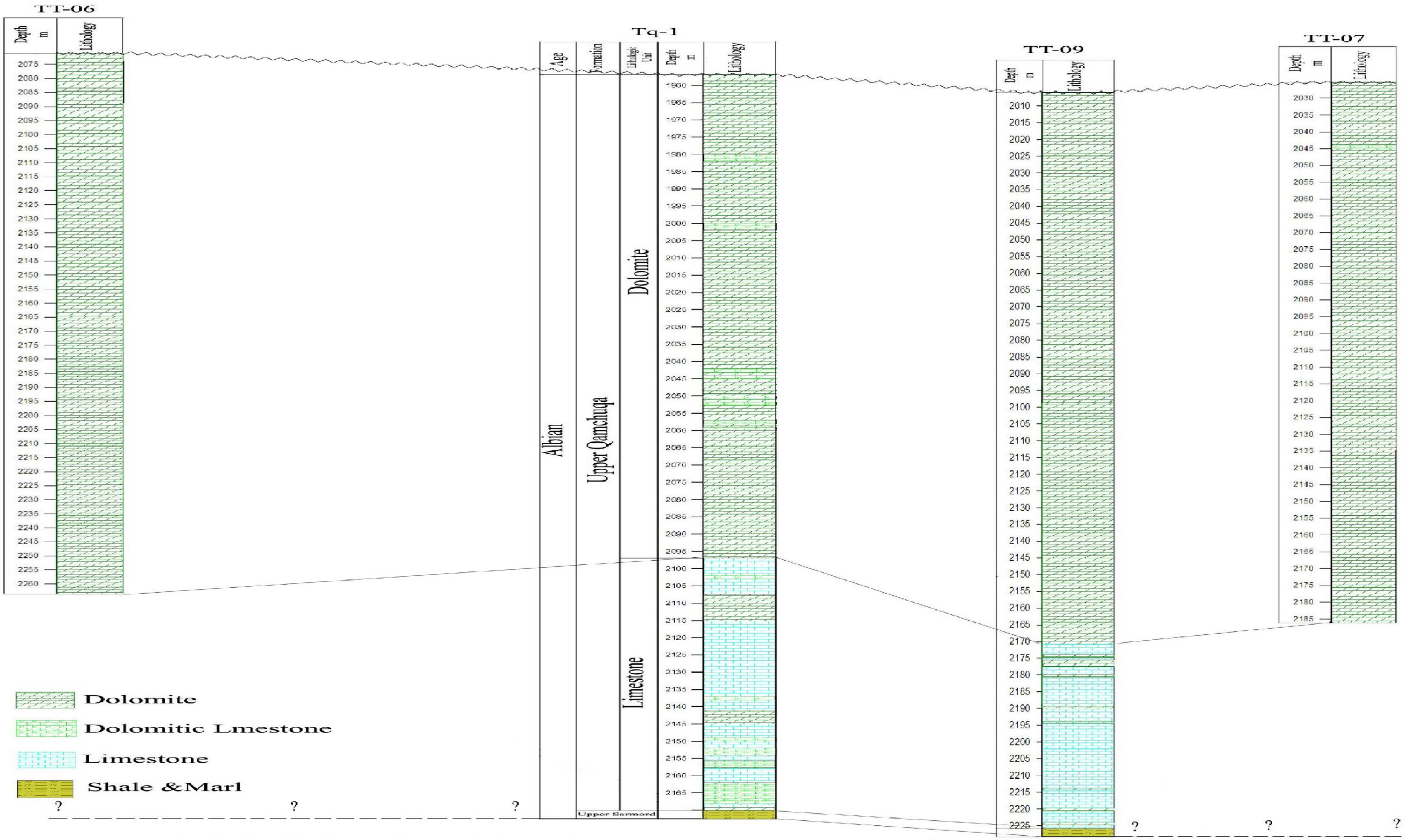



Fig. 2-15 : Stratigraphic correlation between studied wells in Taq Taq oil field.Without horizontal scale.

## 2.4: Diagenesis and Microfacies

Microscopic study of reservoir rocks is the most important technique to identify these rocks, origin and modification by diagenetic processes. It helps in recognizing pore types and interpretations as well as possible origin and forming processes of detailed study of limestone and dolomites may be difficult because of their susceptibility to diagenetic alteration (Wilson, 1975).Sedimentary petrography is the analysis of both depositional and diagenetic fabric from thin section (Tucker, 1985).In this chapter we used thin sections to describe of microfacies and its relation with reservoir properties as well as diagenesis effect on these microfacies and reservoir character, because most of the studied reservoir rock are intensively affected by diagenesis, the microfacies analysis would mainly include diagenetic microfacies. This requires review of diagenetic processes and effect before discussion original rocks microfacies.

### 2.4.1: Diagenesis

Diagenetic processes include physical, chemical and biological changes affecting sediments during deposition and lithification under normal pressure and temperature before onset of metamorphism and weathering (Larsen and Chalinger, 1979).

The diagenesis of carbonates and carbonate rocks include all of the processes involving solution, cementation lithification and alteration of the sediments during the interval between deposition and metamorphism (Flugel, 1982).

Diagenesis processes can be related to digenetic environment to provide models for interpreting the geometry of cemented and porous units (Longman, 1980).

The effects of diagenesis on porosity are usually to reduce the available pore space through various forms of cementation and mineral growth within the pores, however it increase porosity by leaching of the grain matrix (dissolution) to form secondary pore space, dolomitization processes can also result in an increase or create or reduce or redistribute and preserve porosity (House, 2007, Alsharhan, 1995).

The main types of digenesis processes which affect the Upper Qamchuqa Formation are dolomitization, compaction, cementation and dissolution.

**2.4.1.1: Dolomitization**

Dolomitization is the replacement of calcite mineral by dolomite mineral (Tucker, 1991).Replacement of calcium carbonate by calcium magnesium carbonate in a limestone, replacing the calcite by dolomite should increase the porosity of a sediment, dolomite mineral commonly occurs as euhedral rhomb(Reijers and Hus, 1986).The replacement of calcium carbonate by dolomite involves a loss of volume about 12.3%, and a consequent increase in porosity by that amount , if the replacement is molecule for molecule (North, 1985).

Dolomitization produces a wide variety of fabrics that may enhance or reduce reservoir quality; such fabrics depend on their formation on original sediment characteristics, pore-water enrichment in Mg and mobility of such fluids (Alsharhan and Whittle, 1995).

Dolomitization processes are faster in high-Mg calcite than Low-Mg calcite, because high Mg-calcite has higher standard free energy than low-Mg calcite (Sibley and Gregg, 1987).

Fridman (1965) used the term Xenotopic, Hypidotopic and Idiotopic to describe both equigranular and inequigranular fabrics, and the terms Porphyrotopic and Poikilotopic describe inequigranular fabric.

Randazzo and Zachose (1984) classified Dolomite texture into three types based on grain shape.

1- Idiotopic texture: the crystal texture of this type is Euhedral shape.

2- Hypidotopic texture: the crystal texture is Subhedral shape.

3- Xenotopic texture: the type of this texture is Anhedral shape.

Idiotopic (euhedral) dolomite commonly has porosity and makes a good reservoir rock for oil and gas. Hypidotopic dolomite may or not be porous, and Xenotopic dolomite normally has little or no porosity (Friedman, 1965).

Sibley and Gregg, (1987) classified dolomite crystal as:

Nonplaner closely packed anhedral crystal mostly curved, lobate, serrated or otherwise irregular intercrystalline boundaries preserved crystal face.

Planer-e (Euhedral) most of dolomite crystal are Euhedral rhomb, crystal supported with in intercrystalline area filled by another mineral or porous.

Planer-s (Subhedral) most dolomite crystal is Subhedral to anhedral with straight comprises boundaries and many crystal face junctions.

Dolomitization processes is the most common type of diagenesis which affect the Upper Qamchuqa formation and controlled porosity development of reservoir in formation especially in dolomite unit. Dolomite crystals have different size, greater than 100 μm is coarse crystal, medium have 20-100 μm crystal size and fine is smaller than 20 μm and they have planer-e to planer-s and with Porphyrotopic shape, those types of dolomite crystals present as free one or with others. Coarse and medium crystals of dolomite indicate secondary dolomitization while small crystal size shows primary dolomitization (Selley, 1988).The common type of porosity in the Upper Qamchuqa reservoir is intercrystalline pores which some time filled by oil staining especially in potential parts of the reservoir (Fig2-16,A,B C and D) Microvugs are another type of pores associated with dolomite rock type of the reservoir these are of different shape, size and concentration (Fig., 2-16, C, 2-17, A). Some times these vugs seam to have been developed from original moldic porosity (Fig. 2-16, D).occasionally cloudy-centered clear-rimmed dolomite crystal present in coarse crystal dolomite Fig (2-17, D), cloudy-centered clear-rimmed (CCCR) dolomite crystal are common in rocks of all types and facies and result from the concentration of inclusions towards the center of dolomite crystals (Sibley, 1982) present in coarse crystalline dolomite mosaic.

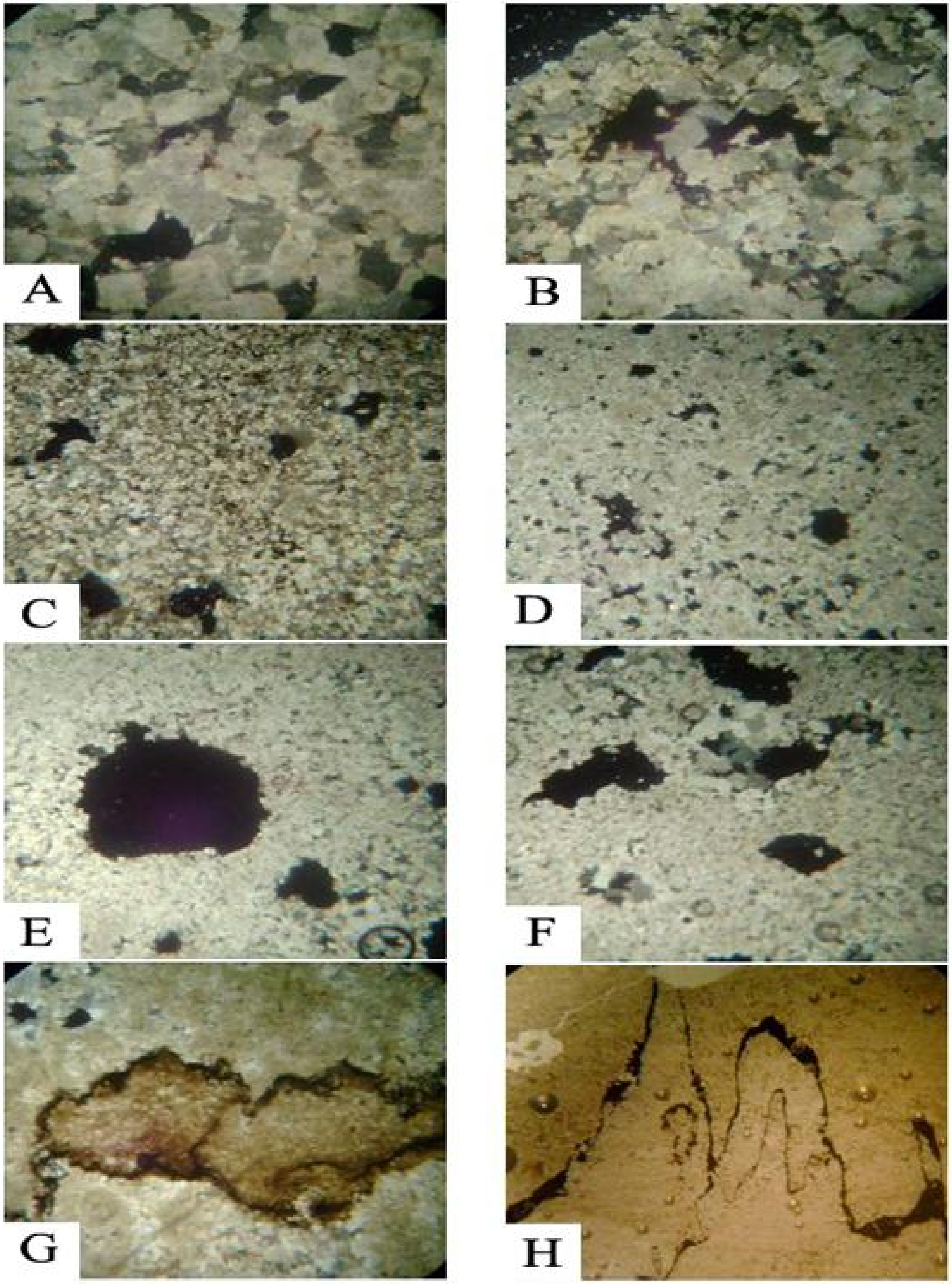



Fig.2-16

A- Coarse crystalline dolomite ,depth: 2055.69m,Tq-1,100X,PP.
B- Medium crystalline dolomite , interval : 2040- 41m,Tq-1,100X,PP.
C- Fine crystalline dolomite,depth: 2030m, TT-07,100X,PP.
D-Fine crystalline dolomite, depth: 2043m, TT-06,100X,PP.
F- Moldic and Vug pores, depth: 2040m,TT-07,100X,PP.
G- Vug pores, depth: 2039m, TT-07,100X,PP.
F- Stylolite filled by oil stain, depth: 1982.4m, Tq-1, 40X,pp.
H- Stylolite filled by oil, depth: 2082.72m, TT-06,20X,PP.

Origin of the dolomite in the Upper Qamchuqa Formation in Taq Taq field is different origins, commonly late diagenetic type because dolomite crystals has different size and mosaic shape, heterogeneous distribution, and completely dolomitized of original fabric and removed of skeletal grain indicate late stage of dolomitization especially in dolomite unit, this phenomena discussed by Sahar (1987), he believed that origin of the dolomite of the Upper Qamchuqa reservoir, commonly late diagenetic.

**2.4.1.2: Dissolution**

It is diagenetic processes which causes the development of porosity. Secondary porosities are the main observed features in Upper Qamchuqa Formation. This have been formed by partial or complete leaching of carbonate components by unsaturated solution with calcium carbonate and the presence of chemically unstable mostly aragonite mineral. Pores generated by solution may be small or large depend on the ratio of water flow and duration of solution phase (Longman, 1980).

The effect of dissolution processes is clearly well observed with the skeletal grains and also the micritic groundmass of the Qamchuqa Formation in all units especially in dolomite unit and rare in limestone unit. The dissolution digenesis affect all micro facies which recorded, some time completely or partially remove grains and make moldic or vug pores, the productive secondary pores (moldic and vug) with difference size depending on degree of dissolution, macro vug and macro moldic pores (Fig.2-16, E, and F) some time intercrystalline pores are enlarged by dissolution effect to develop micro or even Macrovug (Fig.2-16, D).

**2.4.1.3**: **Compaction**

The decreasing in the bulk of the rocks by any process is called compaction (Flugel, 1982). The compaction is divided into two categories, the first is the Mechanical compaction, and the second is the intergranular compaction (pressure solution) (Tucker, 1991).

During the early stages of compaction, tight packing and the transfer of point grain contacts to long contacts occurred, resulting in reduced primary depositional porosity (Mahboubi etal, 2002).

Compaction of sediments occurs to some degree throughout all diagenetic environments, with increasing compaction directly proportional to overburden pressure which leads to the development of stylolite (Alsharhan and Whittle, 1995).Porosity in limestone decrease exponentially with depth, this porosity reduction is caused by the combined effects of mechanical compaction, intergranular pressure solution .Mechanical compaction refers to porosity reduction by grain rearrangement due to overburden pressure, intergranular pressure solution consist of pressure induced dissolution along grain contacts, resulting in reduction of pore volume (Heydari, 2000).

The importance of stylolites to reservoir geology is their association with a significant reduction in porosity and permeability and their effects on hydrocarbon fluid flow and migration (petroleum residues coat the first-generation, post-compaction cements, suggesting that oil migration occurred after initiation of pressure dissolution) the limestone dissolved as the stylolite formed is reprecipitated as cement nearby, causing partial or total filling of the intergranular pore space, this phenomena affects the reservoir capacity and such reduction depend on degree of stylolitization.(Alsharhan and Sadd,2000).

Because the upper Qamchuqa formation have a depth greater than 2000m, so this formation is greatly affected by compaction and causes reduction of porosity with increasing depth especially the limestone unit which is not affected by dolomitization and developed stylolite which some of them filled by oil residue which indicate oil migration after stylolite formation (Fig.2-16, G, and H) .

### 2.4.1.4: Cementation

Cementation is a chemical deposition of calcium carbonate mineral between or inside the grains or in the pores and cracks by solution that leads to growth of spary calcite in these cavities (Chilinger et al., 1979).

Cementation occurs when primary and/or secondary pore space is partially or entirely filled by authigenic minerals. In carbonate this is mostly calcite, but dolomite, anhydrite, and even halite are also known as cements (Reijers and Hus, 1986).

The basic problem in carbonate porosity concerns not the creation of porosity but rather its preservation which is depend upon the absence of pore-filling cement ,(Purser, 1978 in Alsharhan,1995).

Dolomite cement is most abundant type of cement which fills some moldic and vug pores and fractures in all units and microfacies in upper Qamchuqa reservoir. Crystals have coarse to very coarse size or occur as spary dolomite cement which fills those pores resulted from dissolution or filled fractures(Fig.2-17,A,B,G and H) anhydrite, calcite and silica cements are another types of cements which have negative effect on reservoir property causes destroyed and reducing porosity effect(Fig.2-17,C,E and F).

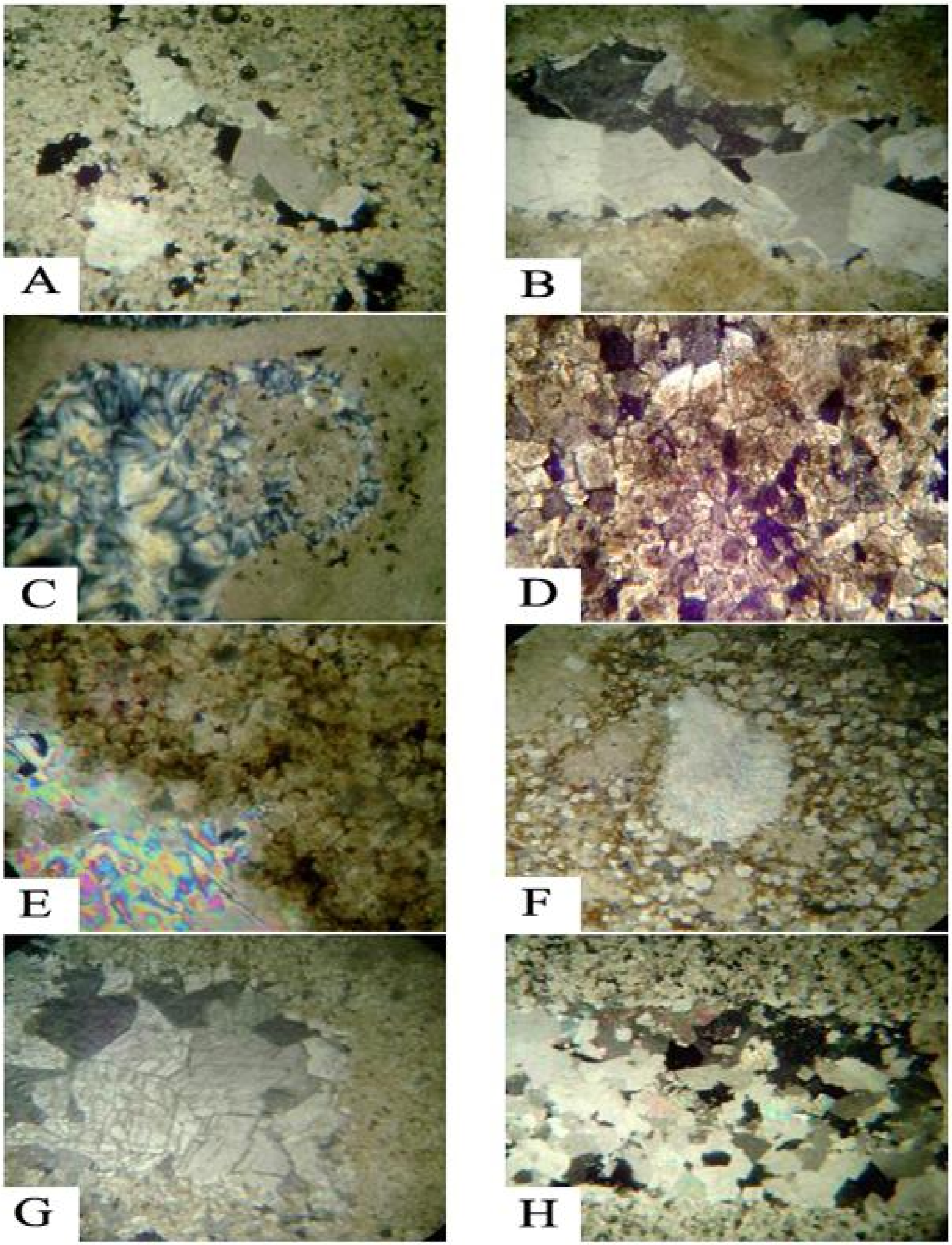



Fig.2-17

A - Coarse crystal dolomite cement filled moldic pores,depth:2036m,TT-07, 40X,PP.

B - Spary dolomite cement filled filled pores, depth: 1983m, Tq-1,40X,PP.

C - Siliceous cement filled moldic pores, interval: 2005-2010m, Tq-1,100X,PP.

D - Cloudy-centered, clear rimmed dolomite crystal,coarse dolomite, interval:2091-92m,Tq-1,40X,PP.

E - Anhydrite cement with in coarse dolomite,interval: 2079-80m, Tq-1, 100X,PP.

F - Calcite cement filled shell of foram, interval: 2079-80m, Tq-1, 100X, PP.

G - Coarse dolomite fill pores in medium crystalline dolomite, depth: 2081.63m, TT-07, 40X,PP.

## 2.4.2: Microfacies

The Microfacies is the representation of all properties of thin section petrography that appear under polarized microscope (Flugel, 1982).

The description of microfacies criteria of limestone unit depend on Dunham Classification (1962) (Fig.2-18, A), microfacies description for dolomite microfacies including dolomite textural classification based on Sibley and Gregg (1987) (Fig-2-18, B).

Crystal size of dolomite; greater than 100 micron are coarse crystal, 20 to 100 microns are medium crystals and smaller than 20 microns are fine crystals dolomite, used to classification of crystals of dolomite (Qadir, 2008 and Hussein, 2008).

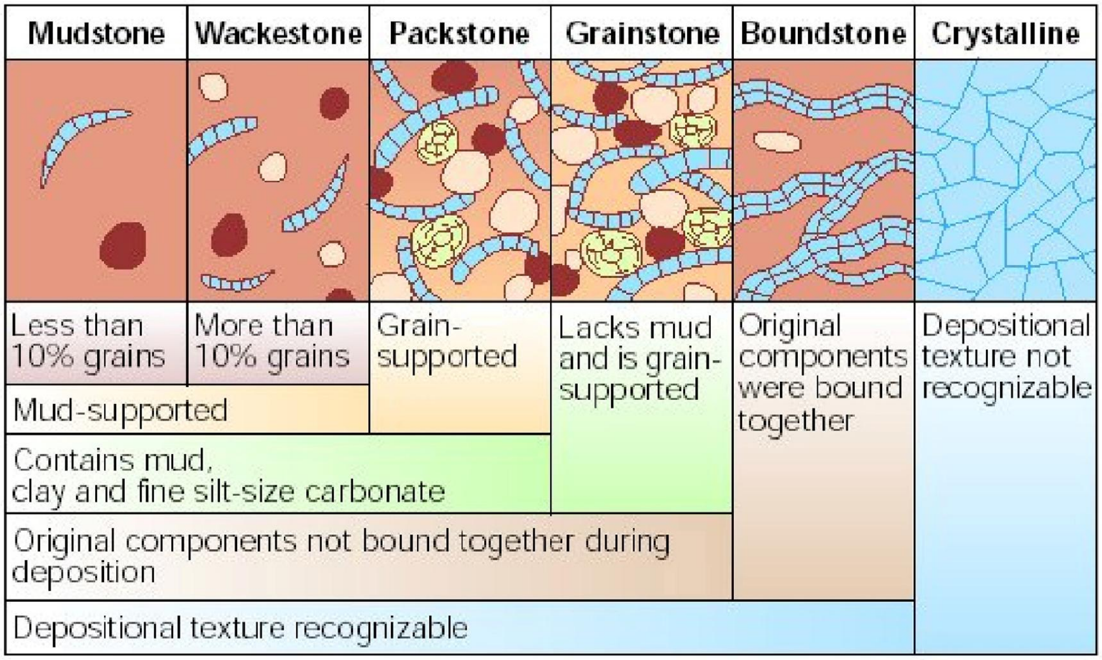
Type of porosity which present in all different facies described based on classification of carbonate pore type followed (Choqutte and Pray, 1970)

(Fig.2-19). Pore size (pore type) classified based on pore size classification (Table2-2) of carbonates by Luo and Machel (1995). Amount of pores estimated from each microfacies in thin section based on semi quantitative evaluation of porosity of (Table 2-3) (North, 1985). Types of diagenesis which affect on each facies and its relation with reservoir character development, especially porosity development relation with different types affect of diagenesis explained in each microfacies.

Dolomite microfacies present in dolomite unit and limestone microfacies in limestone unit while dolomitic limestone microfacies present in both dolomite and limestone units.

Dolomite microfacies represent good reservoir quality in upper part of formation due to effect of dolomitization and dissolution which developed porosity system in this microfacies with intense and wide range effect of fractures which discussed in reservoir chapter.

A




B

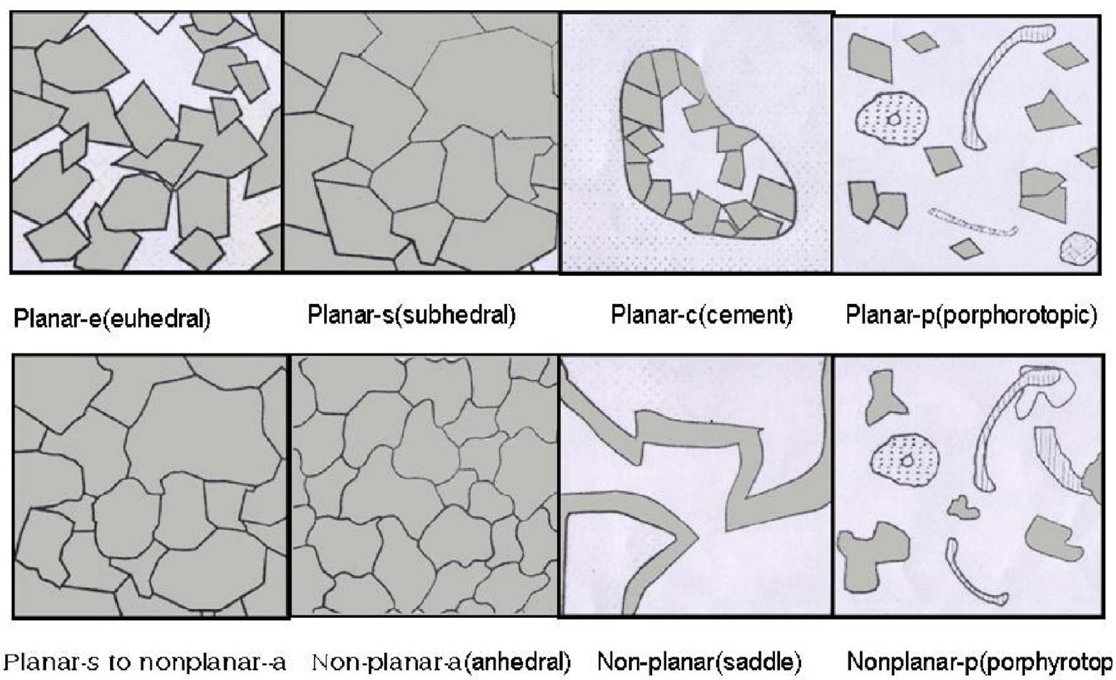



Fig.2-18
A- Classification of carbonate rock (Dunham, 1962)
B- Dolomite textural classification combined from Gregg and Sibley (1984), and Sibley and Gregg(1987).

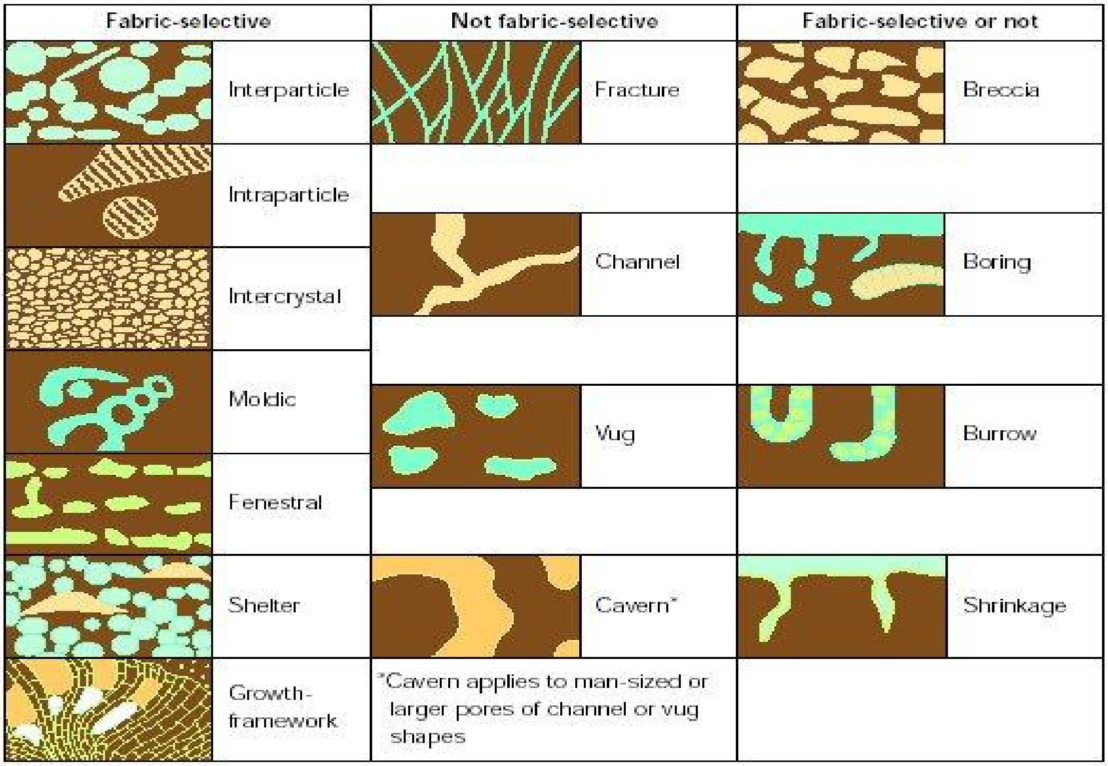



Fig.2-19: Classification of carbonate porosity (Choqutte and Pray, 1970 ).

Table 2-2: pore size classification of carbonates, (Leuo and Machel, 1995).

| Pore type | Scale |
|---|---|
| Mega porosity | > 256 mm |
| Macro porosity | 1-256 mm |
| Meso porosity | 1-1000 μm |
| Micro porosity | < 1μm |

Table 2-3: Range of porosity values (North, 1985).

| Porosity % | Qualitative evaluation |
|---|---|
| 0-5 | Neglible |
| 5-10 | Poor |
| 10-15 | Fair |
| 15-20 | Good |
| 20-25 | Very good |

Three main groups of microfacies observed in studied wells .these are Limestone, Dolomitic Limestone and Dolomite microfacies.

The main and common microfacies of Upper Qamchuqa reservoir include:

**2.4.2.1: Limestone Micro Facies**

This group includes the following microfacies which are common within the limestone unit of the reservoir.

**a-Milliolid-Textularid Wackstone ($L_1$)**

It is characterized by floating small size Millolids , Textularids and silt size bioclasts in micritic matrix forming mudstone to wackstone with pyrite mineral in micrite.Calcite cement filled or replaces shell fragments, dissolution have rare effect to dissolve the grains and development of pores. Some parts have moldic pores, very rare or neglible.This microfacies present in the upper part of the limestone unit especially in Tq-1 and upper part of it(Fig.2-20,A,B,C and D).

**b-Orbitulina Bioclastic Wackstone - Packstone ($L_2$)**

Its characterized by large Benthonic Foraminifera (*Orbitulina*) found as argillaceous mudstone with sand size Bioclasts of *Orbitulina* origin, occasionally contain pyrite mineral. Orbitulina some time mixed with large shell fragment, which extensively micritized.

Some time spary calcite replaces parts of Orbitulina or dissolution removed it and moldic pores remain. Dolomitization in some portion of this microfacies effective and form mosaic of dolomite rhombs with intercrystalline pores. Mostly stylolitic which filled by oil. Intercrystalline, Moldic and Vug with mesopore size are poor amount. This submicrofacies appears first in the Limestone unit especially in Tq-1and is most common in limestone unit (Fig.2-20, E and F).

**c-Rudist Bioclastic Wackstone-Packstone ($L_3$ )**

Rudist Fragment mixed with Shell fragment and other bioclasts in micritic matrix which mostly micritized or filled by spary calcite cement, pyrite mineral also exist. Dissolution affects the same fragment and makes moldic and Vug porosity. Most time this microfacies appear with Orbitulina. Moldic and vug pores, mesopore and neglible amount. This microfacies is common in the upper part of Limestone unit in Tq-1 and some other parts of this unit also contain this microfacies (Fig.2-20, G and H).

## 2.4.2.2: Dolomitic Limestone Micro Facies

This group of microfacies is affected by dolomitization either partially affected grains or sometime completely or preserved as ghost. Based on dolomitization effect and Dunham classification of carbonate rock with describing of type, size and amount of porosity and effect of others diagenesis processes, dolomitic limestone microfacies have the following types:

### a- Milliolid-Textularid Dolo Wackstone ($DL_1$)

This microfacies is represent by floating small size Milliolid and Textularid and silt size bioclasts in micritic matrix mudstone-wackstone, with silt size euhedral floating rhomb of dolomite forming DoloWackstone with pyrite mineral as accessory mineral present as assemblage.

Dolomitization affects some shell and bioclast, and dissolution removed same of them and leaving moldic and vug pores. Dolomite cement fills some of these pores. The dominant types of pores are intercrystalline, moldic and vug with good amount and mesoporosity size, this microfacies is common in lower part of limestone unit in Tq-1(Fig.2-21, A).

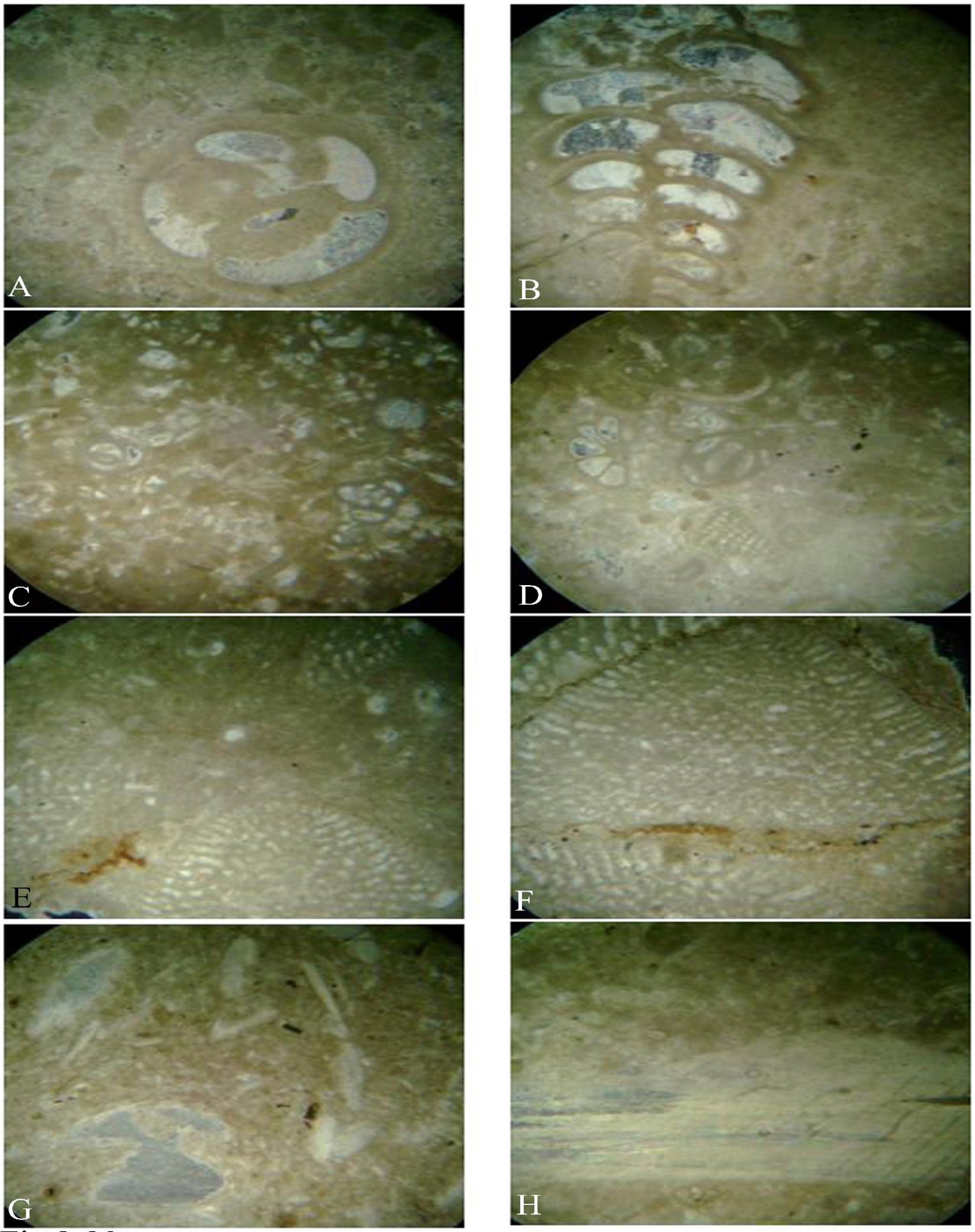



Fig.2-20

A: *Milliolid* in Milliolid-Textularid Wackstone, interval 2116-2117m, Tq-1,40X, PP.

B: *Textularia* in Milliolid-Textularid Wackstone microfacies Limestone Unit, interval 2117-2118 m, Tq-1,40X, PP.

C: *Milliolid* and Bioclasts in Milliolid-Textularid Wackstone microfacies, interval 2118-2119 m, Tq-1,40X ,PP.

D: *Milliolid* , *Textularia* and Bioclast in Milliolid-Textularid Wackstone microfacies, interval 2118-2119, in Tq-1,40X, PP.

E: Orbitulina Bioclastic Wackstone – Packstone microfacies Chambers of Orbitulina filled by calcite cement, interval 2129-2130m, Tq-1,40X,PP.

G: Shell Fragment and Bioclast filled by spary calcite cement in Rudist Bioclastic Wackstone-Packstone, interval 2136-2137m in Tq-1, 40X, PP.

H: Rudist Fragment partially recrystallized cement in Rudist Bioclastic Wackstone-Packstone, interval 2151-2152m, Tq-1, 40X, PP.

**b-Porphyrotopic Foraminiferal Clayey Dolo Wackstone ($DL_2$)**

It is characterized by floating rhomb of medium to coarse crystalline dolomite associated with basinal planktonic forams, clay laminated Wackstone. It is occasionally stylolitic filled by oil stain. Dolomitization and dissolution removed some bioclast and rhomb of dolomite. Dolomite cement fills some pores especially moldic type. Poor amount of porosity with Mesopore size and vug, moldic and intercrystalline pore types present in this microfacies, this microfacies observed in limestone of Tq-1(Fig.2-21,B).

**c-Pelliodal –Bioclastic Dolo Wackstone- Dolo Packstone ($DL_3$)**

Pelloids are circular to elliptical grains composed of micritic calcite and lacking the internal structure with dark color, relatively well rounded and sorted particles with different size, generally the term of Pelloid was applied to all particles of various origins which consist of cryptocrystalline carbonate (Flugel, 1982).

Pelloid represents the main nonskeletal grains with bioclasts in this microfacies it is distributed in micritic matrix which is partially dolomitized. Sometime Pelloid irregular due to dolomitization of micritic material.

Dolomitization and dissolution causes increasing porosity, while spary dolomite and dolomite cement fill some pores. Occasionally stylolitization affect this microfacies and oil stain remain in stylolite, this microfacies observed in both dolomite and limestone units of Tq-1(Fig.2-21, C and D).

**d-Orbitulina Dolo Wackstone- DoloPackstone ($DL_4$)**

This Microfacies represent by ghost of large benthonic foraminifera (Orbitulina) which appear as slightly argillaceous mudstone in micritic matrix which partially to completely dolomitized to cloudy fine to medium crystalline mosaic dolomite planer-e to s, sometime with complete Orbitulina(little alteration) with other Bioclasts in fine to very fine dolomite mosaic.

The dolomitization in this microfacies caused increasing of intercrystalline pores. Ghost of remains of chamber arrangement of Orbitulina changed by dissolution to small circular moldic pores in uniform arrangement. Some pores filed by coarse crystalline of mosaic dolomite. oil remains in some portions of this microfacies, present in dolomite unit of Tq-1(Fig.2-21, E).

**e-Bioclastic Foraminiferal Dolo Boundstone ($DL_5$)**

Bioclasts are present as ghosts of different sand size fossils, and commonly replaced by dolocement. Forams are Textularids and laminated algal fragment in medium crystalline dolomite mosaic of planer-s.

Bioclasts are commonly replaced by dolocement .Dissolution dissolved some bioclasts and dolomite crystal and created vugs and moldic pores. Occasionally stylolitic and the stylolites seams showing oil stain.

Moldic, vug and intercrystalline pores are dominant as mesoporosity and poor amount. Algal interlocking within pelliodal boundstone with micritic matrix. Dolomite and occasionally spary calcite replaces bioclasts. Intercrystalline, moldic, vug pores and fractures with mesoporosity. It is observed in dolomite unit of Tq-1 and TT-09 and limestone unit of Tq-1(Fig.2-21, F).

## 2.4.2.3: Dolomite Micro Facies

These microfacies which completely affected by dolomitization processes. It shows skeletal grain completely obliterated or remain as ghost. Micritic ground mass completely replaced by dolomite crystal. This microfacies give the best reservoir unit in Upper Qamchuqa reservoir in Taq Taq oil field.

Dolomite microfacies include the following types based on crystal size and distribution:

Coarse ($D_1$), medium ($D_2$) and fine ($D_3$) crystals, medium-fine ($D_4$) and polymodal ($D_5$).

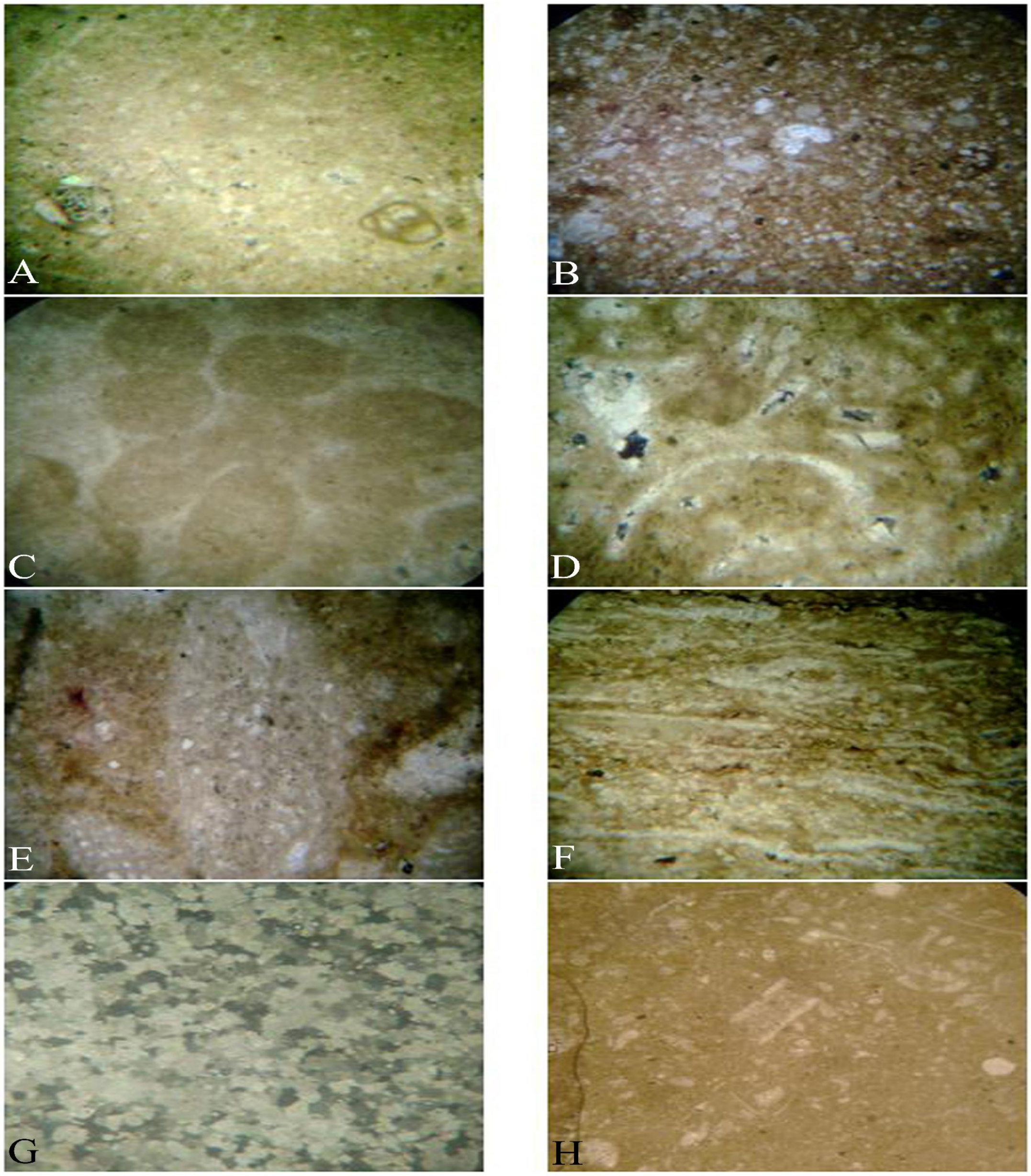



Fig.2-21

A: Floating *Milliolid* in Milliolid-Textularid DoloWackstone microfacies, interval 2103-2104m,Tq-1.

B: Floating rhomb of dolomite in basinal sediments in Porphyrotopic foraminiferal clayey DoloWackstone microfacies, interval 2149-2150m, Tq-1, limestone unit, 40X,PP.

C: Pelloid in micritic matrix in pelliodal-Bioclastic DoloWackstone-DoloPackstone microfacies, depth 2050.07m in Tq-1, 40X, PP.

D: Bioclast replaced by dolomite cement in Pelloidal-Bioclastic DoloPackstone microfacies. Interval 1981.56-1982.43m, Tq-1, 40X, PP.

E: Ghost of *Orbitulina* in micritic matrix, dolomitize by cloudy fine to medium crystalline mosaic in Orbitulina DoloWackstone- DoloPackstone microfacies, interval 2042-2043m, Tq- 1,40X, PP.

F: Ghost of Bioclasts and small size forams in laminated Algal fragment with in medium crystalline dolomite in Bioclastatic Foraminiferal DoloBounstone microfacies, 2052.48m in Tq-1, 40X, PP.

G: Medium crystalline dolomite mosaic, Planer-e to s, dolomite unit, depth 2082.93m in TT-06, 40X, PP.

H: Ghost of Algae (Dacycladacean) in medium crystalline dolomite mosaic, dirty cloudy fabric, Dolomite Unit, interval 1978.96- 1979.83m in Tq-1,20XN.

**1-Coarse Crystalline Dolomite Mosaic, Planer-e to s ($D_1$)**

Coarse crystal of dolomite mosaic planer-e (Euhedral) to planer-s (Subhedral) With high degree of dolomitization. The main diagenesis processes effect this microfacies are; dolomitization which increased intercrystalline pores, dissolution which dissolved dolomite crystals and developed pores and enlarged of intercrystalline and moldic pore existing pores and make vug pores, cementation which destroyed pores, spary dolomite (some cloudy cement clear rim dolomite), calcite, anhydrite and siliceous cement filled some pores. Some intercrystalline pores filled by oil and residual oil remain around crystals .Dominant types of porosity are intercrystalline, moldic and vug pores with mesoporosity size in good amount. It is observed in dolomite unit of Tq-1 and TT-09 (Fig.2-16, A and 2-17, D).

**2-Medium Crystal Dolomite Microfacies ($D_2$)**

This facies can divided into the following subfacies:

**a-Medium crystalline dolomite mosaic planer-e ($D_{2a}$)**

Dolomite crystals have medium size and euhedral shape with high degree of dolomitization. Dominant types of diagenesis are dolomitization which increased intercrystalline pores, some of them stained by oil . and dissolution which makes excellent vug and moldic pores by remove of shell and skeletal grain, while dolomite and calcite cement fill pores and act as cementation diagenesis .stylolite and fracturing filled by oil staining, occasionally pyrite mineral present at surface of stylolite. Excellent intercrystalline, vug and moldic porosity, mesoporosity size, present in dolomite unit of Tq-1, TT-06, TT-07andTT-09 (Fig.2-16 , 2-17G,2-23 E).

**b-Medium Crystalline Dolomite Mosaic, Planer e-s ($D_{2b}$)**

Medium crystal dolomite mosaics have euhedral to Subhedral shape with skeletal grain of algae, dirty cloudy fabric with ghost of dacyculardarcy or algae. Dolomitization increased intercrystalline pores in this microfacies, dissolution is pores. Stylolite filled by oil with some intercrystalline pores which filled by oil.

Intercrystalline, moldic and vug pores are present in this microfacies with mesoporosity size and good amount porosity. It is observed in dolomite of Tq-1, TT-06 and TT-07 and limestone units of Tq-1(Fig.2-21, H , 2-23, B, C and D).

**c-Medium Crystalline Dolomite Mosaic with ghost of Orbitulina ($D_{2c}$)**

Medium crystal dolomite mosaic remain which indicates high degree of dolomitization and ghost of Orbitulina. Dolomitization increased intercrystalline pores and dissolution which makes vug and moldic pores have positive effect in this microfacies while dolomite cement filled some pores have negative role in reservoir character.

Intercrystalline, vug and moldic pores with mesoporosity in this microfacies which have good amount. It is present in dolomite unit of Tq-1 and TT-07 (Fig.2-22, A).

**d-Medium Crystalline Dolomite Mosaic with ghost of Bioclasts ($D_{2d}$)**

Dolomite mosaic with crystals have medium size with ghost of bioclasts either replaced by dolocement or left out with moldic pores, sometime give pseudo Pelliodal fabric represent this microfacies.

Dolomitization and dissolution that increased intercrystalline pores and makes vug and moldic pores. Dolomite cement fills same pore intercrystalline, moldic and vug with mesoporosity size. It is present in dolomite unit of Tq-1, TT-06 and TT-07 (Fig.2-22, B).

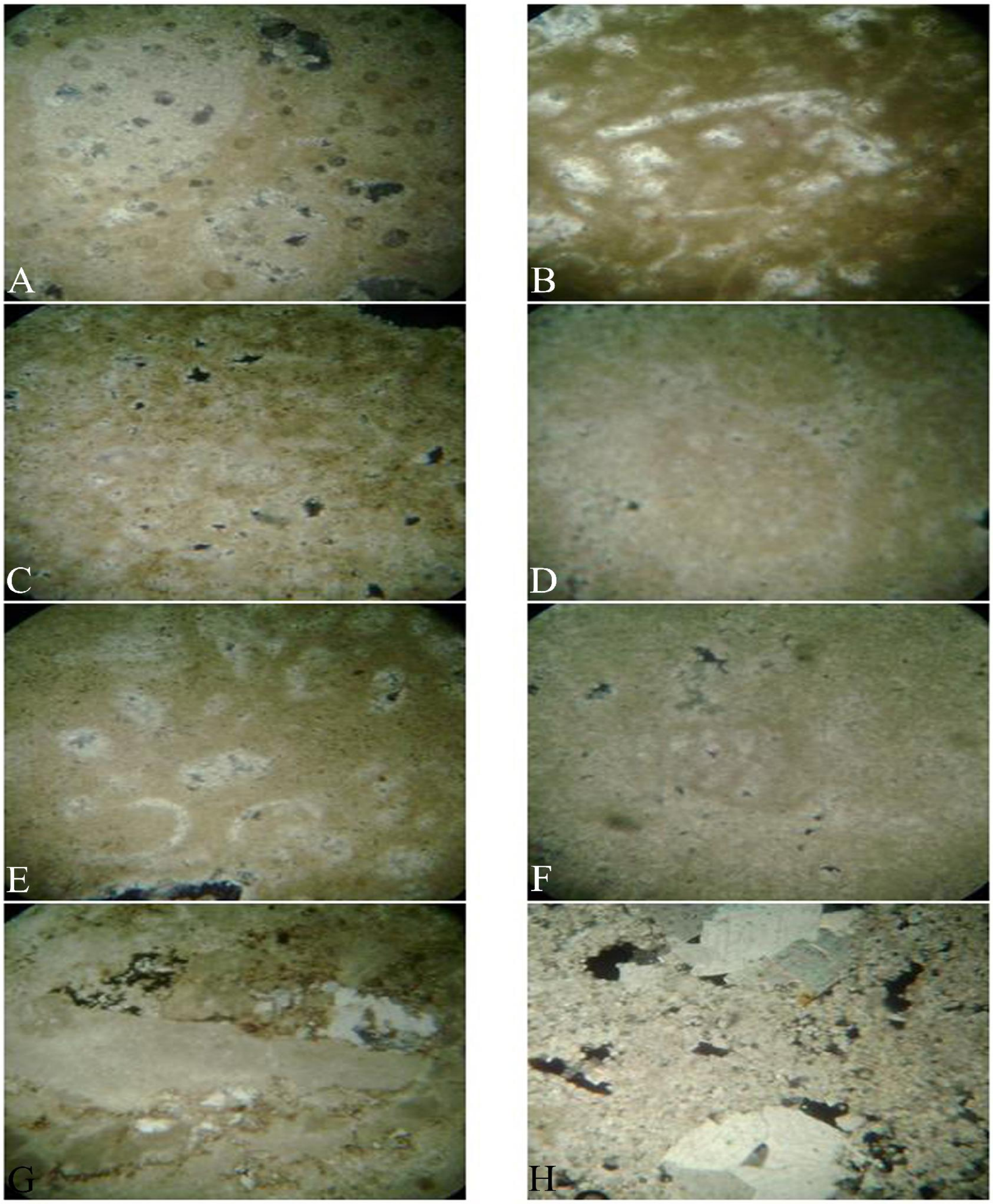



Fig.2-22

A: Ghost of dolomitized *Orbitulina* in Medium crystalline Dolomite mosaic, Dolomite unit, interval 2035-2036m, Tq-1, 40X, PP.

B: Medium to Fine Crystalline Dolomite Mosaic with Ghost of Bioclasts filled by Dolomite cement, depth 2054.96, Tq-1,40X, PP.

C: Ghost of dolomitized Stromatolite (Algae) in fine crystalline Dolomite, interval 1972-1973m, Tq-1, 40X, PP.

D: Ghost of *Orbitulina* in fine crystalline Dolomite mosaic, interval 2020-2025 in Tq-1, 40X, PP.

E: Ghost of Bioclasts and Forams in Fine Crystalline Dolomite mosaic, depth 1986m in Tq-1, 40X, PP.

F: Ghost of *Textularia* in fine crystalline dolomite mosaic, interval 2047-2048m, Tq-1,100X, PP.

G: Fine crystalline Dolomite Mosaic, with patchy spots of Medium crystalline of Dolomite, fractured stainined with oil, depth 2018 m in TT-09, 40X,PP.

H: Polymodal (coarse medium and fine Crystalline Dolomite) ,depth 2036m in TT-07, 40X, PP.

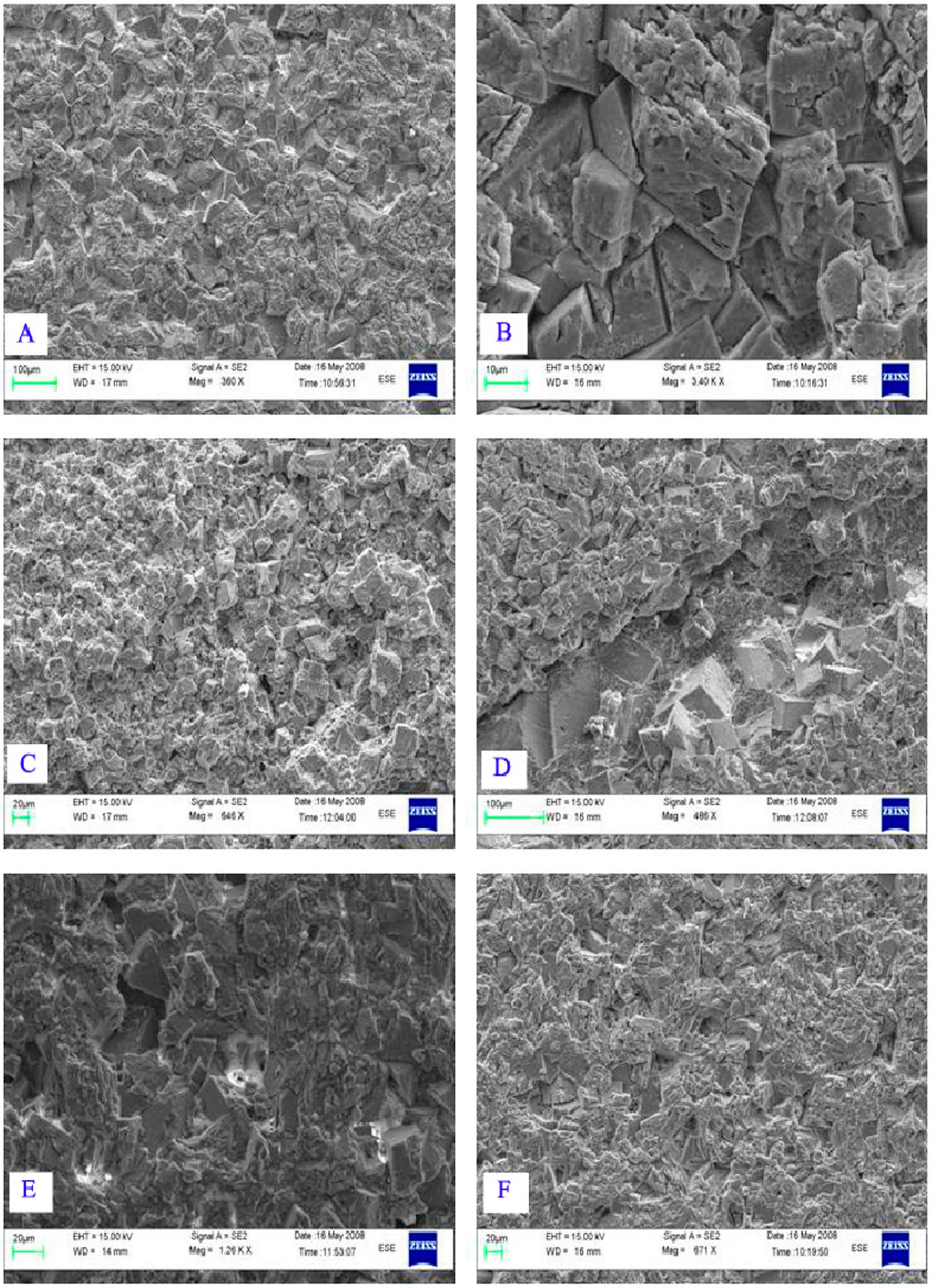



Fig.2-23

A: Medium crystalline dolomite mosaic, showing planer-e crystals, depth 2041.7 m, TT-07, SEM-360X.

B: Medium crystal of dolomite mosaic, showing planer-e crystals in crystalline dolomite mosaic planer-e to s microfacies, dolomite unit , depth 1980m, Tq-1, SEM – 340 KX.

C: Medium and Fine crystals of dolomite mosaic in Medium to fine planer-e to s type, depth 2084.26m, TT-06, SEM-645X.

D: Coarse crystals of dolomite cement fill fractures in Medium Crystalline Dolomite mosaic planer –e to s , depth 2085.48m ,TT-06, SEM-486X.

E: Fine crystalline dolomite mosaic, Euhedral planer-e to s type, dolomite unit, depth 2077.65m ,TT-06,SEM-1.26 KX.

F: Fine subhedral crystal dolomite mosaic, Dolomite Unit, depth 1985m Tq-1, SEM- 671X.

### 3-Fine Crystalline Dolomite Microfacies

Have the following subdivisions:

**a-Fine Crystalline Dolomite Mosaic ($D_{3a}$)**

Dolomite mosaic with crystal of dolomite has small size with non clear shape under microscope, have euhedral or planer-e shape which can be seen clearly under SEM (Fig.2-23, E).Dolomitization which increased intercrystalline porosity, dissolution makes vug pores and cementation; spary dolomite and dolomite fill some pores. This microfacies have intercrystalline and vug pores which have mesopore size with poor amount .This microfacies observed in dolomite unit of Tq-1 and TT-06 .

**b-Fine Crystalline Dolomite Mosaic with Ghost of Stromatolite ($D_{3b}$)**

Fine crystal dolomite mosaic with ghost of stromatolite and algal fragment, is the common feature of this microfacies Dolomitization increased intercrystalline pores and dissolution makes vug pores, cementation diagenesis represented by dolomite; anhydrite and calcite cement which fill some pores. Occasionally stylolitic which filled by oil stain.

Fenesteral, intercrystalline and moldic are types of porosity, have Mesopore size in good amount. It is present in dolomite unit and limestone unit of Tq-1 and dolomite unit of TT-06 and TT-07 (Fig.2-22, C).

**c-Fine Crystalline Dolomite Mosaic with Ghost of Orbitulina ($D_{3c}$)**

Crystal of dolomite in this microfacies has fine size with ghost remain of forams and irregular fabric *Orbitulina* which is affected by affect of dolomitization. It contains pyrite mineral as accessory material.

Dolomitization in this microfacies which increased intercrystalline pores, dissolution dissolved dolomite crystals and developed pores. Cementation which destroys pores, especially dolomite which filled some pores. Occasionally stylolitic filled by oil stain. Intercrystalline, moldic and vug pores have

Mesopore size with poor amount. It is observed in dolomite unit of Tq-1 and TT-09 (Fig.2-22, D) and (Fig.2-23, F).

**d- Fine Crystalline Dolomite Mosaic with Ghost of Bioclasts ($D_{3d}$)**

Fine crystalline dolomite mosaic sometime with ghost of bioclasts and forams.The main diagenesis affect this micro facies are; dolomitization which increased intercrystalline pores, dissolution which dissolved dolomite crystals and developed pores, fracturing which enhance permeability, and cementation which destroyed pores, spary dolomite filled some moldic pores , fractures and occasionally stylolites.

Moldic and fractured pores are of Mesopore size and good amount of porosity, present in dolomite unit of Tq-1, TT-06 and TT-07(Fig.2-22,E).

**e-Fine to very Fine Crystalline Dolo Mudstone ($D_{3e}$)**

Fine to very fine crystalline dolomite with rare partly replaced fine sand size bioclasts and small benthic forams (Textularid) are the common component of this microfacies. Dolomitization and dissolution are two positive diagenesis factors which affect this microfacies and causes development of porosity. Dolomite cement acts as negative of diagenesis which fills same moldic pores.

Moldic pore is dominant types of porosity in this microfacies have mesopore size and poor amount, observed in dolomite unit of TT-07 (Fig.2-22, F).

**4-Fine to Medium Crystalline Dolomite Mosaic ($D_4$)**

This microfacies is characterized by fine to medium crystalline dolomite mosaic with dark clay, fractured, stylolitic with patchy spots of medium crystalline dolomite. Dolomitization causes increasing of intercrystalline pores, dolomite cement fill some pores which refer to cementation type of diagenesis**,** occasionally stylolitic and fractured.

Intercrystalline pores with mesopore size and poor amount. It is present in dolomite unit of Tq-1 **(**Fig.2-22, G).

**5-Polymodal Dolomite of Fine, Medium and Coarse Crystalline Mosaic ($D_5$)**

Medium, fine and coarse crystal dolomite mosaic mixed together in bimodal or polymodal combination represent this microfacies.

Dolomitization dominant types of diagenesis affect this microfacies which causes development of intercrystalline porosity as well as spary dolomite cement fills some pores. Dissolution effect develop vug and moldic pores and occasionally stylolitic.

Intercrystalline, moldic and vug porosities types of porosity with mesopore size with excellent amount. It is observed in dolomite unit of TT-06, TT-07 and TT-09(Fig.2-22, H).

In general, dolomite microfacies have good reservoir quality especially fine and medium crystal dolomite mosaic; have intercrystalline, vug and moldic pores. This microfacies affected by dolomitization and dissolution lead to development of reservoir characters.

Dolomitic limestone microfacies have moldic and vug pores, this microfacies have important roles in reservoir development especially in those facies present in dolomite unit.

Limestone microfacies have poor amount of porosity, most of pores in this microfacies filled by cement, have poor reservoir quality and present in limestone unit which consider as non reservoir unit.

Microfacies in studied wells with depth listed in appendix no.1

# Chapter Three

# Well Log Analysis

## 3.1: Preface

Well log is a record of characteristics of a formation traversed by a measurement in the well bore. It provides a means to evaluate the formation characteristics and hydrocarbon production potential of a reservoir (Torres, 2002).

Petrophysical log interpretation is one of the most useful and important tools available to petroleum geologist. Logs help define physical rock characteristics such as lithology, porosity, pore geometry and permeability, logging data are used to identify productive zone to determine depth and thickness of zones, to distinguish between oil, gas or water in reservoir and to estimate hydrocarbon reservoir(Asquith and Krygowski, 2004).

In this chapter it is attempted to use different types of log (Gamma Ray, Caliper, Spontaneous Potential, Resistivity, Density, Neutron and Sonic) as well as image logs to identify petrophysical parameters of Upper Qamchuqa reservoir in Taq Taq oil field

Below is general review of the basics of these logs and their application to the studied reservoir.

## 3.2: Caliper Log

Caliper tools measure size and shape. The simplest and most widely used caliper measures a vertical profile of hole diameter. The tool works by pressing spring loaded arms against the open hole and receiving a single at the surface that indicates the relative positions of the arms (Fertl, 1980).

The caliper log records the mechanical response of formation to drilling. A hole that of the same size as the bit which drilled it, is called "on gauge", with a much greater than the bit size are "caved" or" washed out" that is borehole walls cave in, are broken by the turning drill pipe, or are eroded away by the circulating borehole mud by typical shale, or coal or organic shale (Rider, 1996).

Caliper may show hole diameter smaller than the bit size, if the log has a smooth profile, a mud cake build up is indicated. This useful indicator of permeability, only permeable beds allow mud cake to form, the limit of mud cake indicates clearly the limits of the potential reservoir (Rider, 1996).

In TT-06, the caliper reading log show greater diameter of hole as compared with bit size which indicate washed out especially in interval 2071-2112m and 2202-2228m that is borehole walls cave in, brocked by the turning drill pipe and originally fractured as well as drilling mud type which used in this well, causes absence of mud cake building, interval 2112-2202m showed washed out but not high as compared with previous intervals. (Fig.3-1).

In Tq-1, the caliper reading log show that the hole diameter is smaller than the bit size which means mud cake build up in dolomite unit in interval 1958 – 2098m show permeable zone, then gradually close to bit size and greater than bit size "washed out" below 2100m in limestone unit .

In TT-07 and TT-09, caliper log shows greater diameter of hole if compared with bit size; indicate of "washed out" in upper Qamchuqa formation in both wells.

In new drilled wells (TT-06, TT-07 and TT-09) because drilling mud not used with penetration (ionic solution used) so mud cake not build up in Upper Qamchuqa interval especially in permeable zones.

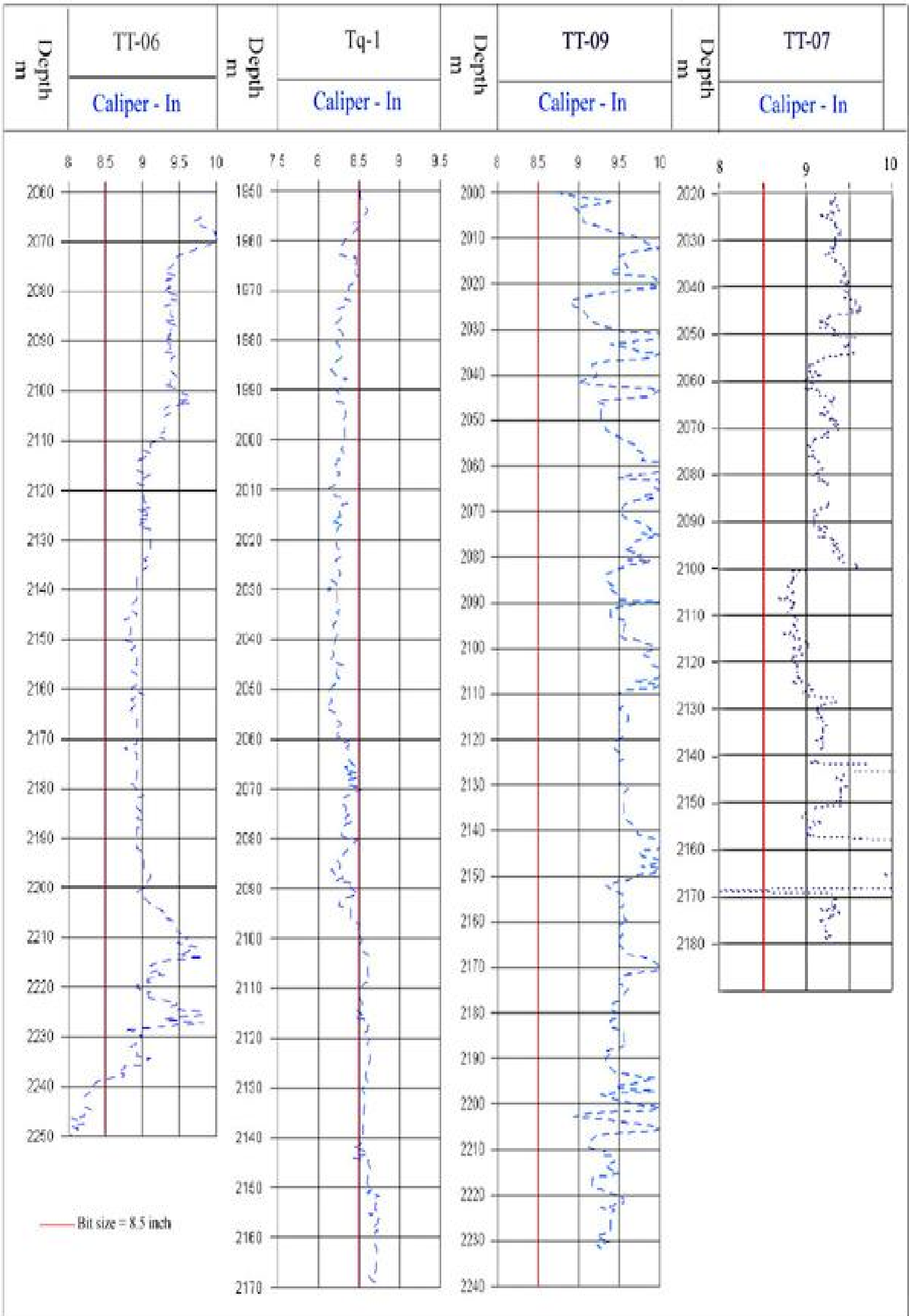



Fig.3-1: Caliper reading log of the studied wells, Upper Qamchuqa Reservoir in Taq Taq Oil Field.

## 3.3: Spontaneous Potential (Sp) Log

The Sp log is a measurement of the natural potential differences or self potential between an electrode in the borehole and references electrode at the surface. The principle uses of Sp log are to calculate formation water Resistivity and to indicate permeability (Rider, 1996).

The Sp response of shale is a relatively constant and follows a straight line called shale base line. The Sp value of the shale base line is assumed to be zero and sp curve deflection is measured from this base line. The presence of shale in permeable formation reduces the Sp deflection in water bearing zone, the amount of Sp deflection is related to the amount of shale in formation (Asquith and Krygowski, 2004).

In hydrocarbon bearing zone, the Sp deflection is reduced, this effect is called hydrocarbon suppression, is qualitative phenomena and can not be used to determine hydrocarbon saturation of the formation (Hilchie, 1978 in Asquith and Krygowski, 2004).

### 3.3.1: Quantitative Uses of Sp

#### 3.3.1.1: Indication of Shale Base line and Static Sp (Ssp)

The definition of Sp zero is made on thick shale intervals where the sp does not move (shale base line).The theoretical maximum deflection of the Sp opposite permeable bed is called the static spontaneous potential (Ssp), it represent the Sp value that would be observed in an ideal case within a permeable, water bearing formation with no shale. Ssp can be used for quantitative evaluation of Formation Water Resistivity (Rw) (Rider, 1996).

$Ssp = -k \log Rmf/Rw$---------------------------------------------- (3-1)

Ssp: Static Spontaneous Potential (m.v.)

Rmf: Mud filtrate Resistivity, ohm-m

Rw: Formation water Resistivity, ohm-m

K: temperature dependent efficiency, k= (0.133+Tf),Tf: Formation temperature

### 3.3.1.2: Shale Volume Calculation

The volume of shale in sand can be used in the evaluation of shale sand reservoir and as mapping parameter for both sandstone and carbonate facies analysis. The Sp log can be used to calculate the volume of shale in permeable zone by the following formula (Asquith and Krygowski, 2004).

Volume of shale = 1- PSP/SSP------------------------------------- (3-2)

PSP: Pseudostatic spontaneous potential (maximum sp of shaley formation)

SSP: Static spontaneous potential of nearby thick clean sand .

### 3.3.2: Qualitative Use of Sp (Permeable Recognization)

If there is slight deflection of the Sp, the bed opposite deflection is permeable, all deflections (with some rare exceptions) on the Sp indicate a permeable bed (inverse no true).Qualitatively the greater Sp deflection, the greater salinity contrasts between the mud filtrate and the formation waters being more saline than the mud filtrate, deflection to positive value however occur with fresh formation water or at least those fresh than the mud filtrate (Rider, 1996).

Where Resistivity of mud filtrate (Rmf) is greater than resistivity of formation water (Rw), the Sp deflects to the left shale base line (negative deflection), this condition called normal Sp, where Rmf is less than Rw, the Sp deflects to the right shale base line (positive deflection) called reversed Sp, this condition is produced by a formation contain fresh water, where Rmf=Rw there is no deflection on shale base line (Asquith and Krygowski, 2004).

In TT-06, the Sp log show negative deflection (normal Sp) from beginning Upper Qamchuqa Formation downed below, indicate permeable zone (Fig.3-2).

In Tq-1, there is negative deflection of Sp curve which show permeable interval except in 206.5m and 2070m show shale base and lower boundary of Upper Qamchuqa reservoir 2170 m, shale of Upper Sarmord Formation.

In TT-09 and TT-07 , the Sp log have negative deflection, indicate permeable zone in Upper Qamchuqa Formation.

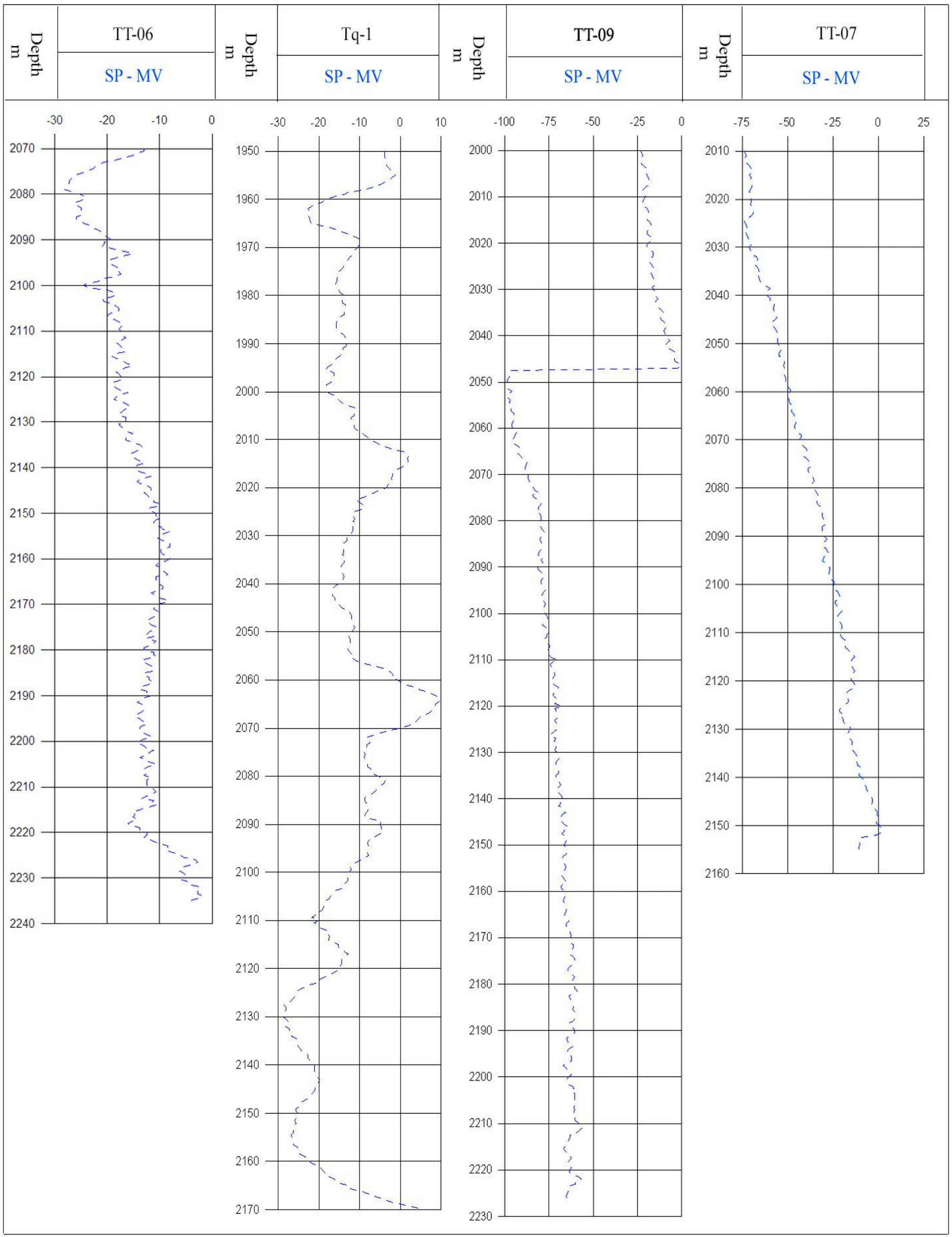



Fig.3-2: Spontaneous Potential log (Sp) of Upper Qamchuqa reservoir in the studied wells Tq Taq Oil Field.

## 3.4: Gamma Ray Log

The gamma ray log is a record of formation radioactivity, the radiation emanates from naturally occurring uranium (U), thorium (Th) and potassium (K). In petroleum borehole logging the commonest natural radioactivity (by volume) is found in shale (clay), high gamma ray value frequently mean shale.

A typically shale analyzed by spectral gamma ray tool shows that each three element, uranium (U), thorium (Th) and potassium individually (K) (Rider, 1996).

### 3.4.1: Quantitative Use of Gamma Ray Log

#### 3.4.1.1: Shale Volume Calculation

Because shale is usually more radioactive than sand or carbonate, gamma ray log can be used to calculate volume of shale in porous reservoir. The volume of shale expressed as a decimal fraction or percentage is called $V_{shale}$ shale (Asquith and Krygowski, 2004), gamma ray reading log shown in (Fig.3-3).

Calculation of gamma ray index is the first step needed to determine the volume of shale from gamma ray log:

$I_{GR}=(GR_{log}-GR_{min})/(GR_{max}-GR_{min})$-------------------------------- (3-3)

$I_{GR}$: gamma ray index

$GR_{log:}$ gamma ray reading from log, API (at any depth)

$GR_{min}$: minimum gamma ray reading (clean sand or carbonate), API

$GR_{max}$: maximum gamma ray reading, API (Shale)

The calculated $I_{GR}$ is then used on the appropriated chart or determined mathematically using (Larionov, 1969) equitation:

Consolidated older rocks:

Unconsolidated –Tertiary rock

$Vsh=0.083[2^{(3.7*GIR)}-1.0]$ ------------------------------------------ (3-4)

For older rocks:

$Vsh =0.33[2^{(2*IGR)}-1.0]$ -------------------------------------------- (3-5)

Volume of shale in Upper Qamchuqa Reservoir calculated in all studied wells and listed in appendices no 2, 3, 4 and 5.

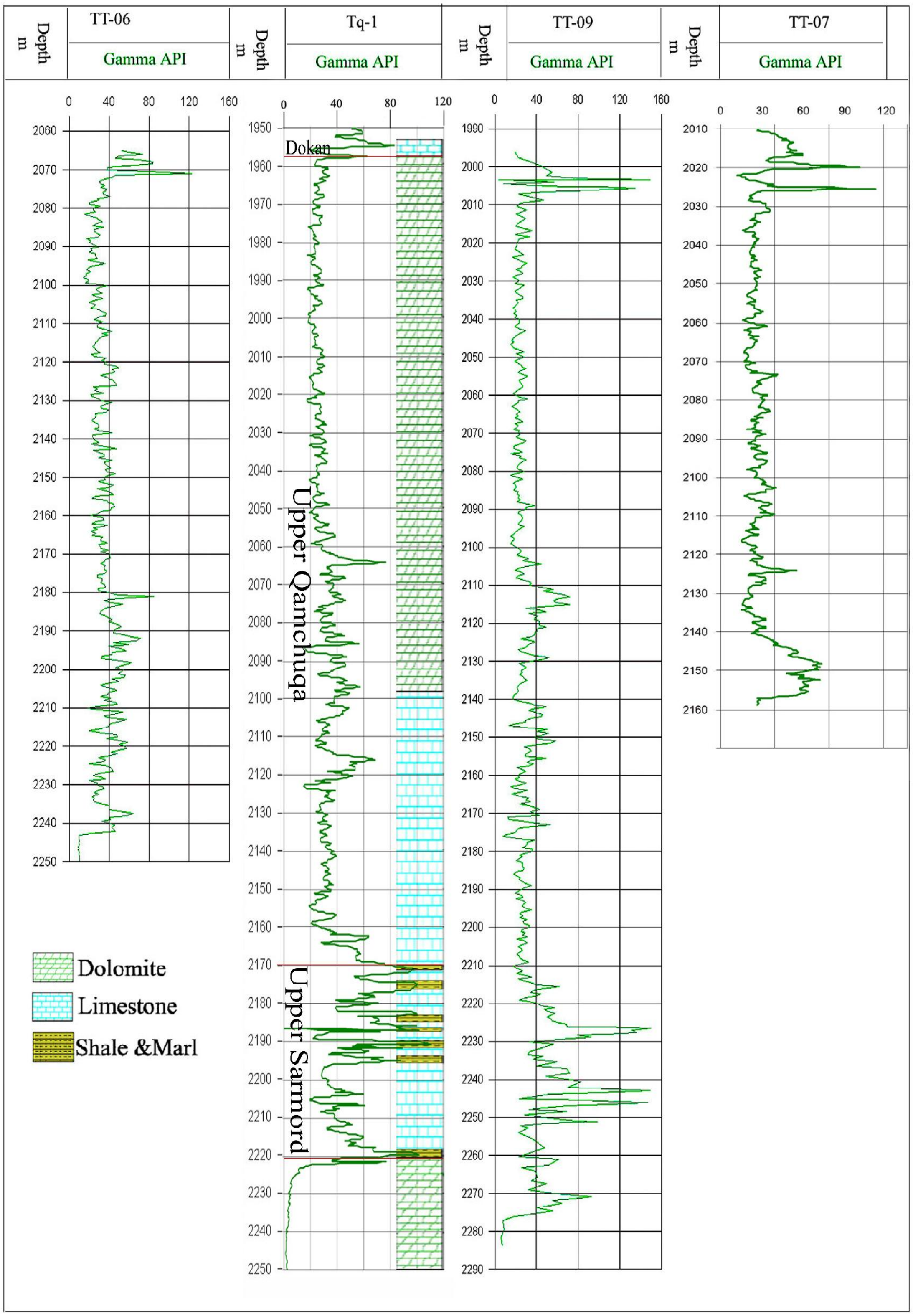



Fig.3-3: natural gamma ray log of studied wells of Upper Qamchuqa reservoir in Taq Taq Oil Field.

## 3.5: Resistivity Logs

The Resistivity log is the measurement of formation resistivity that is resistance to the passage of an electric current. When a formation is porous and contains salty water the overall resistivity will be low, when the same formation contains hydrocarbon its resistivity is very high (Rider, 1996).

Resistivity logs are primarily used to differentiate between hydrocarbon and water bearing zone, because a rock matrix is non conductive, hydrocarbon like the rock matrix is non conductive, there for as hydrocarbon saturation increase, the rock resistivity increase (Baker Hughes, 1992).

There are two basic types of resistivity logs used, Induction and Latero resistivity logs. The Laterolog generally provides three resistivity measurements:

Deep Laterolog (LLD), investigates about 10 ft into formations, measure true formation resistivity ($R_t$), Shallow Laterolog (LLS), investigates 3 to 6 ft into the formations, measure the resistivity of invaided zone ($R_i$) and Microspherical focused log(MSFL), measure resistivity in the flushed zone ($R_{xo}$) (Torres, 2002). In Taq Taq oil field, Latero resistivity logs are used in studied wells, table (1-2). During drilling operation the formation around the borehole contaminated by mud filtrate, and then the resistivity log can not be real the accurate value especially in large borehole, the value must be corrected to formation temperature, all resistivity values; formation water resistivity ($R_w$), mud filtrate resistivity ($R_{mf}$) and mud resistivity ($R_m$) must be corrected to formation temperature (Schlumberger, 1997).

### 3.5.1: Formation Water Resistivity ($R_w$)

The total contained water in an otherwise hydrocarbon bearing reservoir rock is best called "formation water". The measurement of resistivity of formation water is essential for accurate assessment of water saturation. Formation water resistivity ($R_w$) is closely related to salinity, salinity varies both vertically and laterally across basin (North, 1985).

Formation water resistivity ($R_w$) can be developed during geologic time, and its value can change in wide spread from well to another in same reservoir because the influence of salinity, temperature and contamination with fresh water and change in depositional environment (Tiab and Donaldson, 1996).

There are some methods to estimate the formation water resistivity from spontaneous potential log or from formation water analysis in laboratory by known salinity of formation water, NaCl concentration in formation water at specific interval and temperature and using chart Gen-9 to change salinity to resistivity (Schlumberger, 1998).

Formation water resistivity ($R_w$) of the Upper Qamchuqa reservoir in Tq-1 measured by NOC (Catalog estimation) and applied to other wells after correction to formations temperature which is shown below:

Table.3-1: Formation Water Resistivity corrected to Formation temperature in studied wells.

| Well no. | Tq-1 | TT-06 | TT-07 | TT-09 |
|---|---|---|---|---|
| Formation Depth(m) | 1985 | 2095 | 2035 | 2030 |
| Formation Temperature ( C) | 73 | 69 | 70 | 65 |
| Formation water resistivity (ohm-m) | 0.042 | 0.0433 | 0.043 | 0.045 |

### 3.5.2: Formation Resistivity Factor (F)

Archie's experiments shows that the resistivity of a water filled formation ($R_o$) could be related to the resistivity of the water ($R_w$) filling the formation through constant called the formation resistivity factor (F) which could be related to the porosity of the formation.

$F= a/Ø^m$ ---------------------------------------------------- (3-6)

$R_o= F*R_W$ ---------------------------------------------------- (3-7)

F: formation resistivity factor

Ø: porosity

a: tortuosity factor = 1.0

m: Cementation exponent, who's value varies with the grain size, grain distribution and the complexity of the paths between pores (tortusity).

The value of "F" is very important reservoir indicator. It is increased as porosity and permeability decrease. (F) value from 10 to 40 for most porous rock and over 1000 for dense limestone. The increase in "F" value with increase in cementation factor (m).The value for cementation factor (m) lies between 1.2 to 2.2, It is lowest value for shaley or dirty sandstone and highest value for limestone (North, 1985).

The general value of cementation factor which results from formation factor porosity relation of Tq-1, based on electrical resistivity measurement of core samples measured in North Oil Company is equal to 1.81 to Upper Qamchuqa Reservoir in Taq Taq Oil Field as shown in fig (3-4), this value applied in equation (3-6) to calculate of the formation resistivity factor (F) to studied wells which are listed in appendices no.2, 3, 4 and 5.

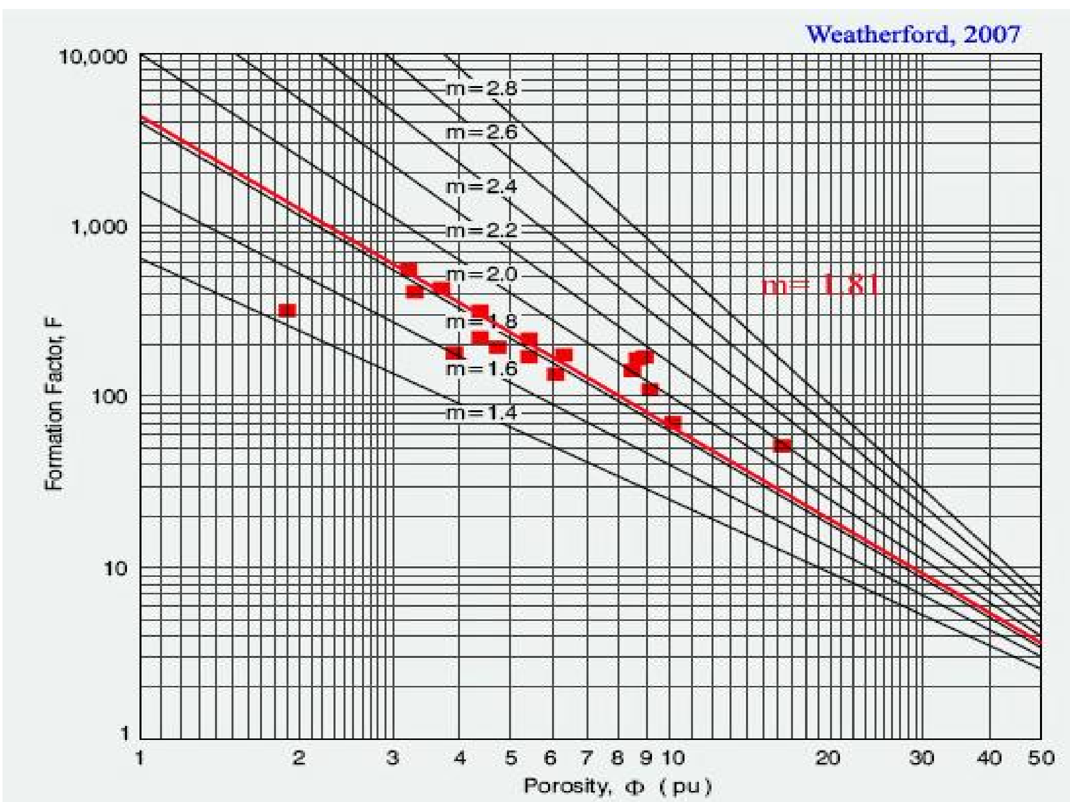



Fig.3-4: Porosity-formation factor relation ship to calculate cementation Factor in Upper Qamchuqa reservoir, for Tq-1 well, Taq Taq Oil Field.

## 3.6: Porosity Log

Porosity logs "Sonic, Density and Neutron" are largely responsive to porosity; they are also affected by formation matrix, lithology, and type of fluid present in the pores. The type of porosity and degree and an extent the type of shaliness (Schlumberger, 1974).

Because the different porosity devices respond to different formation and fluid characteristics, combinations of two or all three of the devices can be used to solve for porosity and lithology to differentiate between intergranular porosity and vugy or fractured porosity, to locate gas caps and to identify some minerals (Baker Hughes, 1992).

Three main types of log are used to porosity determination and identification which are Sonic, Density and Neutron logs.

### 3.6.1: Sonic Log

The sonic log provides a formations interval transit time, designated ($\Delta t$),is a measure of formations capacity to transit sound waves. Geologicaly this capacity varies with lithology and rock texture, notably porosity (Rider, 1996).

Porosity determination from an acoustic log is based upon the measurement of the travel time of an acoustic wave in the formation, when the travel time for the formation of interest is known porosity can be calculated. The variations in acoustic travel time ($\Delta t$) are measured in ($\mu$ sec/ft) and referenced to the value in limestone (Baker Hughes, 1992).

The interval transit time ($\Delta t$) is dependent upon both lithology and porosity; therefore a formation matrix interval transit time must be known to derive sonic porosity by Wyllie time-average equitation (Wyllie et al, 1958: in Asquith and Krygowski, 2004).

$Ø_s = (\Delta t_{log} - \Delta t_{ma}) / (\Delta t_{fl} - \Delta t_{log})$ ------------------------------------------------ (3-8)

Øs: Sonic derived porosity

$\Delta t_{log}$: interval transit time in the formation, µsec/ft.

$\Delta t_{ma}$: interval transit time in the matrix (limestone=156 µsec/ft, dolomite=143 µsec/ft)

$\Delta t_{fl}$: interval transit time in the fluid in the formation (fresh water=189 µsec/ft, salt water=185 µsec/ft).

The formula for calculating sonic porosity can be used to determine porosity in consolidated sandstone and carbonates with intergranular porosity or intercrystalline porosity (sucrosic dolomites). However when sonic porosities of carbonates with vugy or fracture porosity are calculated by Whille formula, porosity value are too low. This happens because of the sonic log only record matrix porosity rather than secondary porosity (Asquith and Krygowski, 2004).

The interval transit time of formation is increased due to presence of hydrocarbon and the sonic porosity is too high and must be corrected by the following empirical correction for hydrocarbon effect (Hilchie, 1978: in Asquith and Krygowski, 2004).

Ø= Øs*0.7 (Gas) ------------------------------------------- (3-9)

Ø= Øs*0.9 (Oil) ---------------------------------------------- (3-10)

Ø: Corrected porosity

Øs: Sonic porosity

### 3.6.2: Density Log

The density log is a continuous record of formations bulk density. This is the overall density of a rock including solid matrix and the fluid enclosed in the pore. Density (ρ) is measured in $gm/cm^3$ or ($kg/m^3$) (Rider, 1996).

Two separate density values are used by density log; the bulk density (ρb or RHOB) and matrix density ($\rho_{ma}$) as measured by logging tool. The bulk density is the density value of the entire formation (solid and fluid part) (Asquith and Krygowski, 2004).

The main uses of the density log are porosity determination, identification of mineral in evaporate deposits, detection of gas and determination of hydrocarbon density (Baker Hughes, 1992).

Formation bulk density ($\rho b$) is a function of matrix density, porosity and density of the fluid in the pores (salt water mud, fresh water mud or hydrocarbons).

To determine density porosity, either by chart or by calculation, the matrix density, type of fluid in the formation must be known (Asquith and Krygowski, 2004).

$Ø_D = (\rho_{ma} - \rho_b)/(\rho_{ma} - \rho_{fl})$------------------------------------------------------ (3-11)

$Ø_D$ : Density derived porosity

$\rho_{ma}$ : Matrix density(limestone density=2.71gm/cm$^3$ , dolomite density=2.87gm/cm$^3$)

$\rho_b$ : Bulk density(log reading, gm/cm$^3$)

$\rho_{fl}$ : Fluid density(salt water density=1.15 gm/cm$^3$, fresh water density=1.0 gm/cm$^3$)

Oil does not significantly affect density porosity, but gas does (gas effect), (Hilchie, 1978: in Asquith and Krygowski, 2004) suggests using a gas density of 0.7 gm/cm$^3$ for fluid density in the density formula if gas density is unknown.

The value of density porosity must be corrected in shale formation by the following relation;

$Ø_{D\text{-shale corrected}} = Ø_D - V_{sh} * Ø_{Dsh}$ (Schlumberger, 1972) ----------------------- (3-12)

$Ø_D$ : Density derived porosity

$V_{sh}$ : Volume shale

$Ø_{Dsh}$ : log values read from the density log at the shale point.

### 3.6.3: Neutron Log

Neutron logs are porosity logs that measure the hydrogen concentration in a formation. In clean formation(shale free) where the porosity is filled with water or oil, the neutron log measures liquid filled porosity(ØN, PHIN, NPHI) (Asquith and Krygowski, 2004).

The neutron log is used to derive porosity, the tool measures hydrogen abundance, assist to determine the porosity (Rider, 1996).

In clean water bearing formations, the only hydrogen present is in the formation water, the neutron tool therefore responds the volume of water filled pore space and gives a measure of the porosity. In gas filling formation, lower hydrogen density causes the apparent neutron porosity to decrease, therefore gas zone typically have a notorious difference between the density derived porosity and neutron derived porosity (Torres, 2002).

Whenever clays are part of the formation matrix, the reported neutron porosity is greater than the actual formation porosity. This occurs because the hydrogen that is within the clay's structure and in the water bound to the clay is sensed in addition to the hydrogen in the pore space. Because the processing software of the logging tool expects all hydrogen in the formation to reside in the pores, the extra hydrogen is interpreted as being part of the porosity. An increase in neutron porosity by the presence of clay is called shale effect (Asquith and Krygowski, 2004).

The value of neutron porosity must be corrected in shale formation by the following relation;

$Ø_{N\text{-shale corrected}} = Ø_N – V_{sh}*Ø_{Nsh}$ (Schlumberger, 1972) ----------------------- (3-13)

$Ø_N$ : Neutron porosity

$V_{sh}$ : Volume shale

$Ø_{DN}$ : log values read from the density log at the shale point.

Bulk porosity is derived from summation of neutron and density derived porosity divided by 2:

$Ø_B=Ø_D+Ø_N/2$ (Schlumberger, 1997) ------------------------ (3-14)

$Ø_B$ : Bulk porosity

$Ø_D$ : Density porosity

$Ø_N$: Neutron porosity

Secondary porosity can be resulted from subtracting sonic derived porosity from bulk porosity;

$S_{Sc}=Ø_B-Ø_S$ --------------------------------------------------------- (3-15)

$S_{Sc}$ : Secondary porosity

$Ø_B$ : Bulk porosity

$Ø_S$: Sonic porosity

Sonic derived porosity (matrix porosity) and bulk porosity (Neutron and Density derived porosity) are estimated in upper Qamchuqa reservoir in the studied wells and listed in appendices no 2, 3, 4 and 5.

## 3.7: Lithology Identification from Porosity and Gamma Ray Log

### 3.7.1: Neutron-Density Combination

Both the neutron and the density logs should be show the same formation parameters-porosity. Plotted on compatible porosity scales, they should give identical values and it should be possible to superimpose the two logs. The explanations can be taken in two stages. Firstly the scales of the two logs are made compatible (normally) on clean limestone scale. A neutron log value of zero (no porosity, 100% matrix) corresponds to a bulk density of 2.7 gm/cm3, and so on to neutron value of 100% fluid and a density of 1.0 gm/cm3.A cross plot of density log values against neutron log values will show a straight line relationship, a point on the line corresponding to a particular porosity. This is “clean-limestone line”. The second stage of the explanation is that the straight line relationship only holds good for clean limestones because matrix material has variable effects on both logs. (Rider, 1996).

A cross plot of density log values against neutron log values will show a straight line relation ship "clean limestone", while dolomite is seen differently from limestone by the density log because of different matrix density and by the neutron log (different matrix effect), the variations in matrix are translated into separation of the curves and is used to lithology identification, clean limestone shows no separation, while dolomite shows the separation moderately positive (Rider, 1996).

### 3.7.2: Shale effect

The gamma ray log usually reflects the clay content of a formation. Clean sand and carbonates normally exhibit low level of natural radio activity while shale usually shows higher radio activity (Hughes, 1992).

Pure shale is recognized on neutron-density combination when the neutron value is high relative to the density value; it gives a large positive separation to the logs, the neutron well to the left of the density. If shale becomes diluted by matrix grains such as quartz or calcite with low hydrogen indices. The neutron log value decreases rapidly, small separation means slightly shaley formations tend to be related to low neutron values, while pure shale shows large positive separation and high neutron value (Rider, 1996).

**Application**

In Tq-1, neutron log separated from density curve "increasing in density reading, dolomite matrix greater than limestone matrix" in the beginning of Upper Qamchuqa reservoir in interval 1958-2098m which indicate dolomite unit and interval 2098-2170m neutron and density curves overlies" no or few separation" which indicates limestone unit, gamma ray log increased in 2060 m and gradually become higher downward to Upper Sarmord Formation.

The intervals 2170-2195m and 2217-2221m show localized high separation of neutron curve from density curve, gamma ray log record high value of radiation and interval transit time record high value which indicates shale of Upper Sarmord Formation separating Upper Qamchuqa from Lower Qamchuqa Formations (Fig.3-5).

In TT-06 like Tq-1, neutron curve separated from density curve at the beginning of dolomite unit "positive separation" from 2071m to 2239m, shows dolomite unit and both neutron and density curves are overly each other of only 4m drilled at bottom of section indicating beginning of limestone unit, and gamma ray log reading increased gradually to downward (Fig.3-6).

TT-07 in has positive separation of neutron and density from upper boundary of Upper Qamchuqa reservoir all the way down from 2026m to 2170m which indicates complete section of dolomite (Fig.3-7).

In TT-09, the neutron reading curve separated from density curve as positive separation which indicates dolomite unit from 2007m to 2171m with 55m of limestone unit until 2226m which neutron curves overlies density curve, Upper Sarmord Formation appear in higher separation of neutron log ,high reading of gamma ray and interval transit time in shale formation in 2226-2253m and 2270-2273m, like Tq-1 separated Upper Qamchuqa from Lower Qamchuqa Formation(Fig.3-8).

### 3.8: Unconformity Identification

Usually high gamma ray values often occur as narrow, isolated peak, this peak generally is associated with uranium concentration, indicates extreme conditions of depositions frequently occur around unconformity (Rider, 1996).

Upper boundary of Upper Qamchuqa Formation with Dokan Formation in studied wells is recorded by isolating, narrow peak, high gamma ray value which can indicate unconformity surface which also previously recorded in Bai Hassan oil field(Alperyadi- 2002 ) and in Khabaz oil field (Qadir, 2008) as unconformity surface between Upper Qamchuqa Formation and Dokan Formation. (Fig.3-5, 6, 7 and 8).

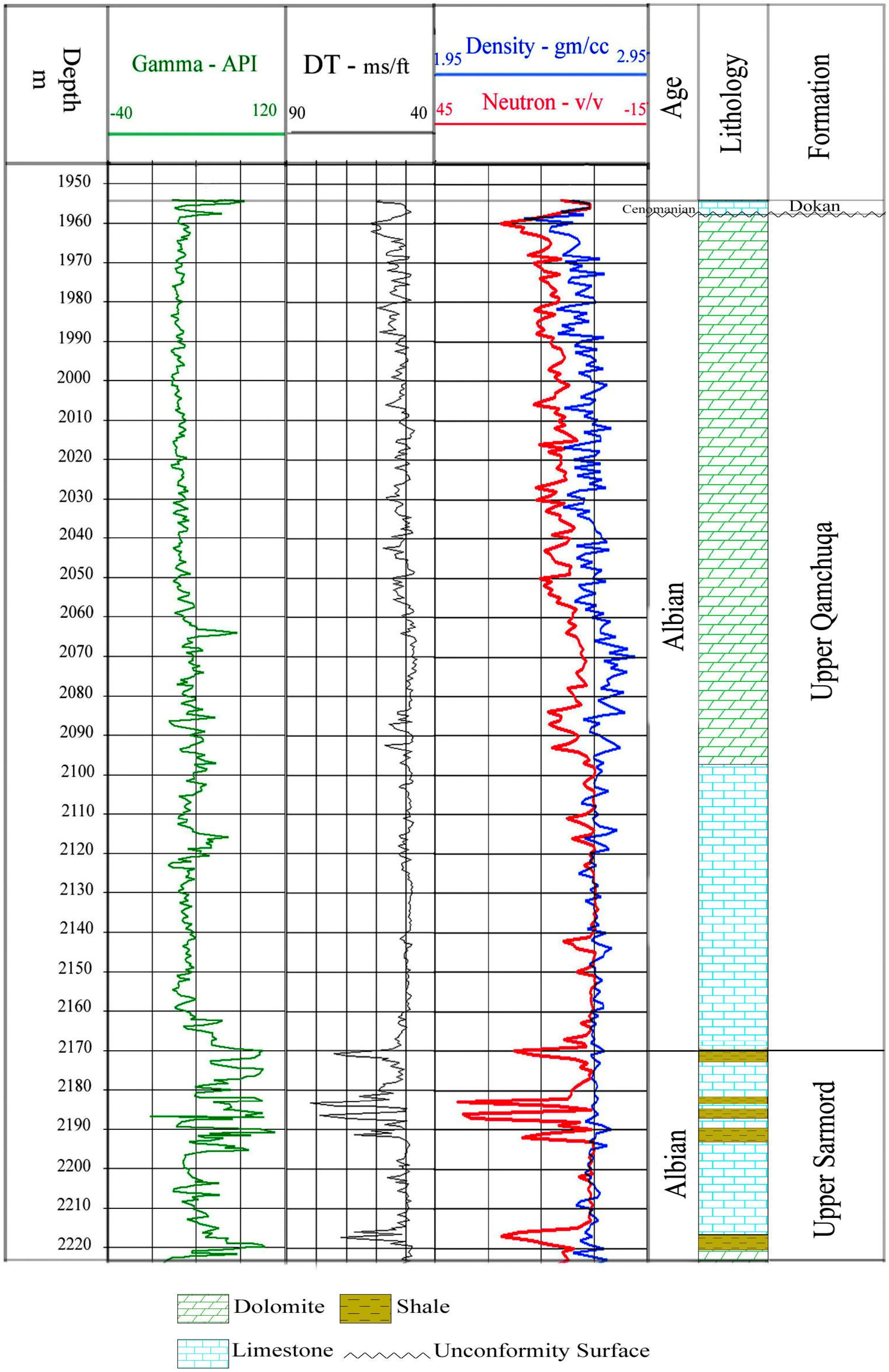



Fig.3-5: Neutron-Density combination with Gamma and Sonic log to explain lithology in Tq-1 of Taq Taq Oil Field

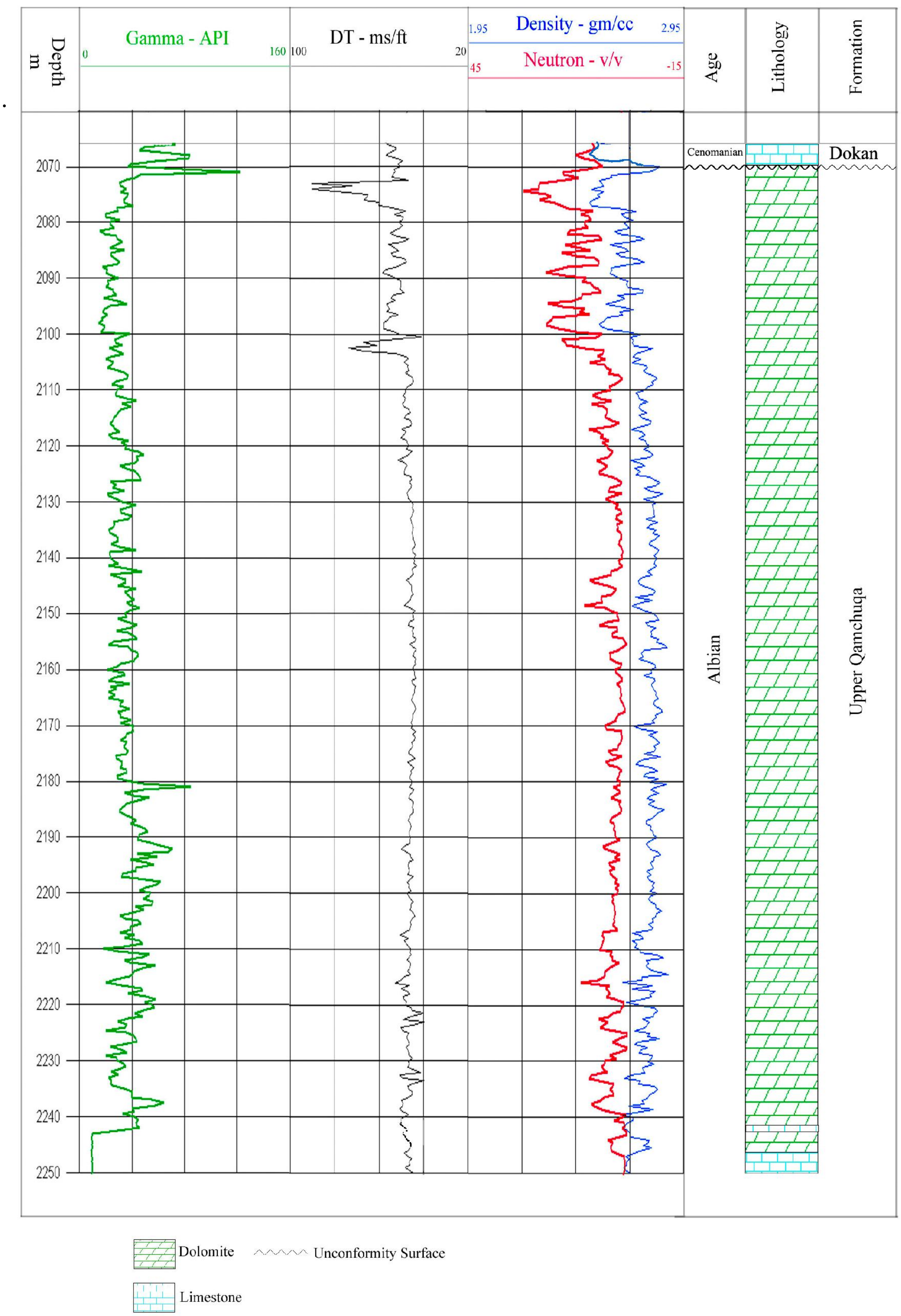



Fig.3-6: Neutron-Density combination with Gamma and Sonic log to explain lithology in TT-06 of Taq Taq Oil Field.

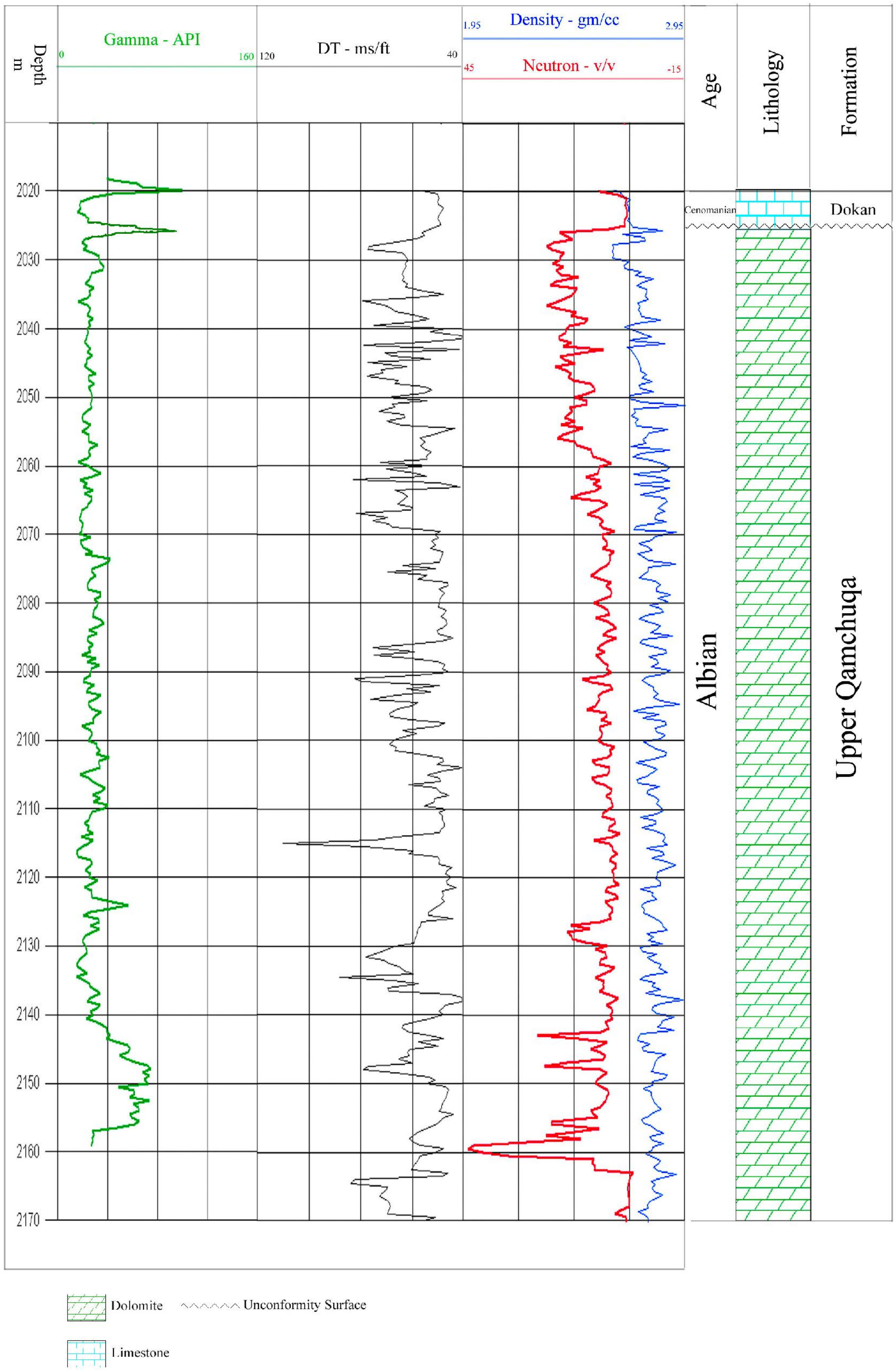



Fig.3-7: Neutron-Density combination with Gamma and Sonic log to explain lithology in TT-07 of Taq Taq Oil Field.

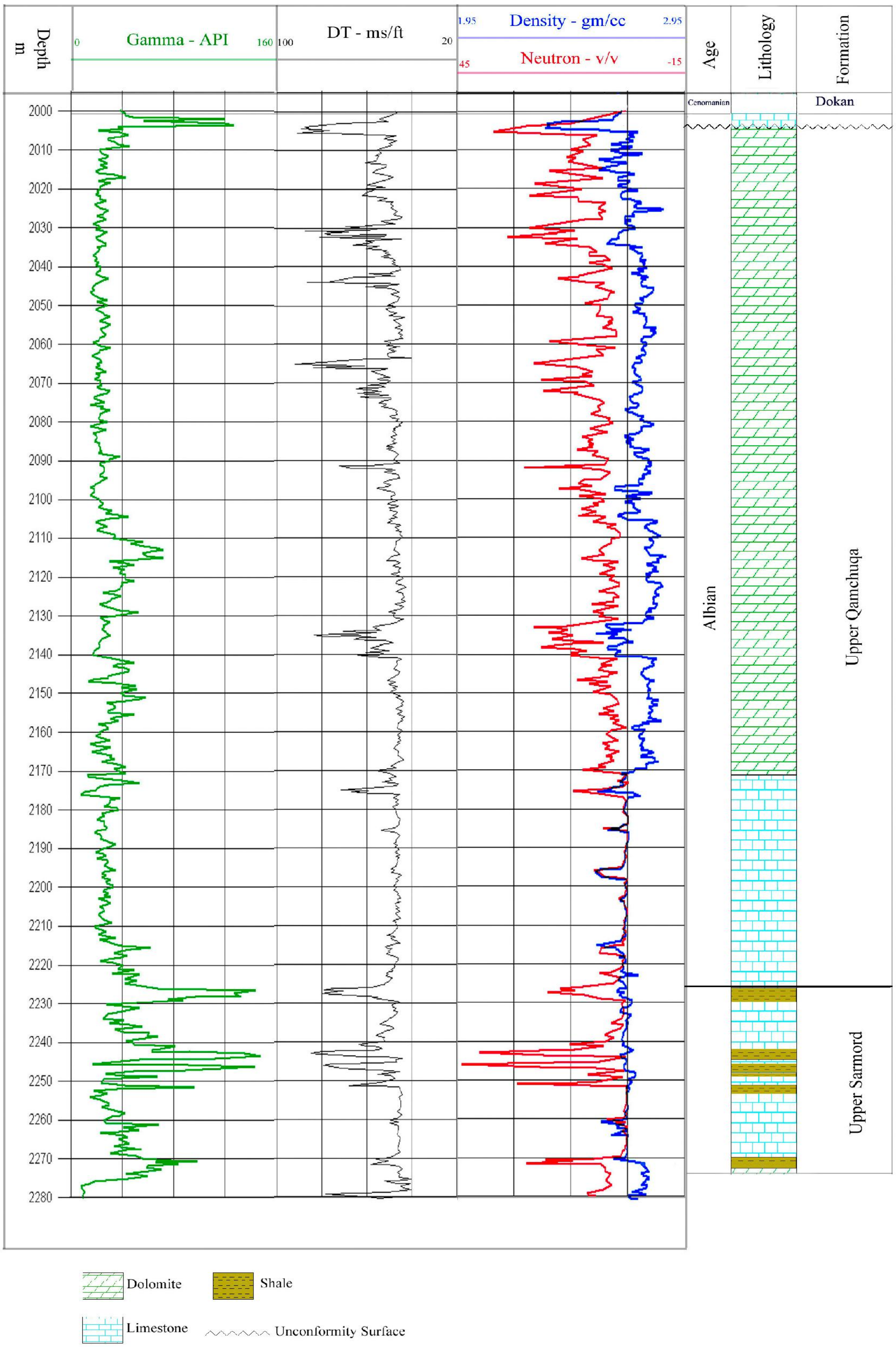



Fig.3-8: Neutron-Density combination with Gamma and Sonic log to explain lithology in TT-09 of Taq Taq Oil Field.

## 3.9: Cross Plots

Cross plots are charts based on the slope and intersect of two porosity logs response (dependent on matrix lithology and pore fluid), therefore if one assumes rock and fluid properties, an average lithology affecting the porosity measurements can be determined(Hughes,1992).

### 3.9.1: Neutron-Density Cross Plot

The neutron log is used to measure the amount of hydrogen in formation, which is assumed to be related to porosity, the density log is to measure electron density and from that formation bulk density, when the two logs are used together, lithology can be determined (Asquith and Krygowski, 2004).

There are three lithology lines displayed on the cross plot, sandstone (silica), limestone (calcite) and dolostone (dolomite), the lithology lines are marked with porosity values usually in percent (Fig.3-9) and (Fig.3-10).

The log values for a particular interval or depth are plotted on the cross plot to create a point and the location of the point with respect to the lithology lines is an indication of the lithology and porosity of the points.

If the point fall directly on the lithology line, the lithology of the point corresponds to the lithology of the line and the porosity of the point corresponds to the porosity of the line at that location,

When if the point falls between two lines it can be assumed to be a mixture of the lithologic of those two lines that contain a greater percentage of the mineral of the line to which it is closet (Krygowski, 2003).

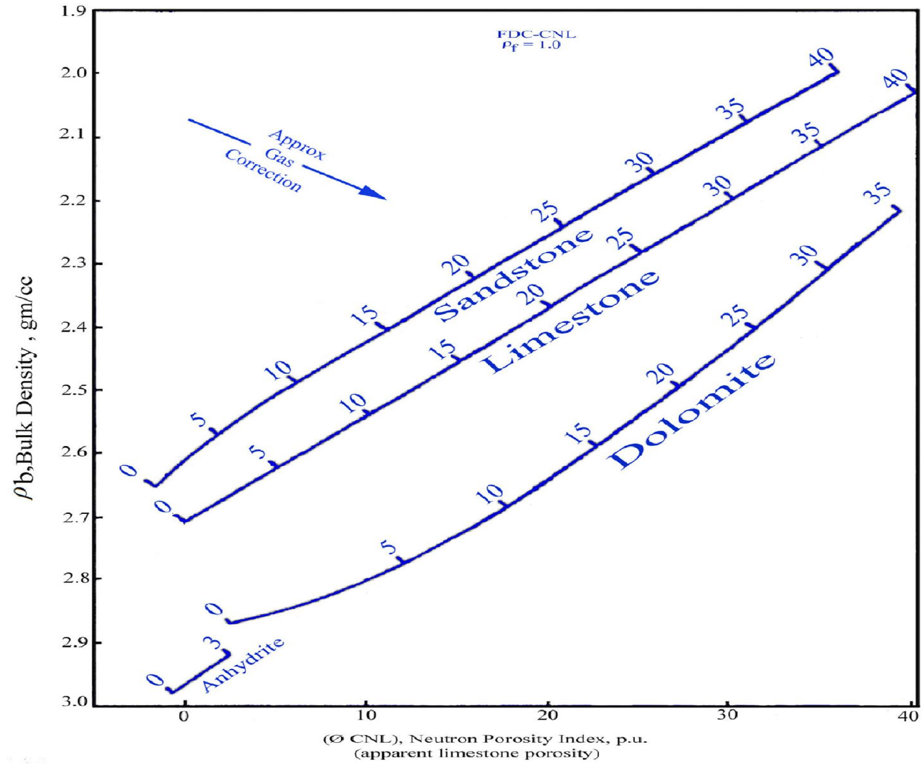



Fig.3-9: Neutron-Density Cross plot, fresh water drilling fluid.

(Schlumberger, 1982).

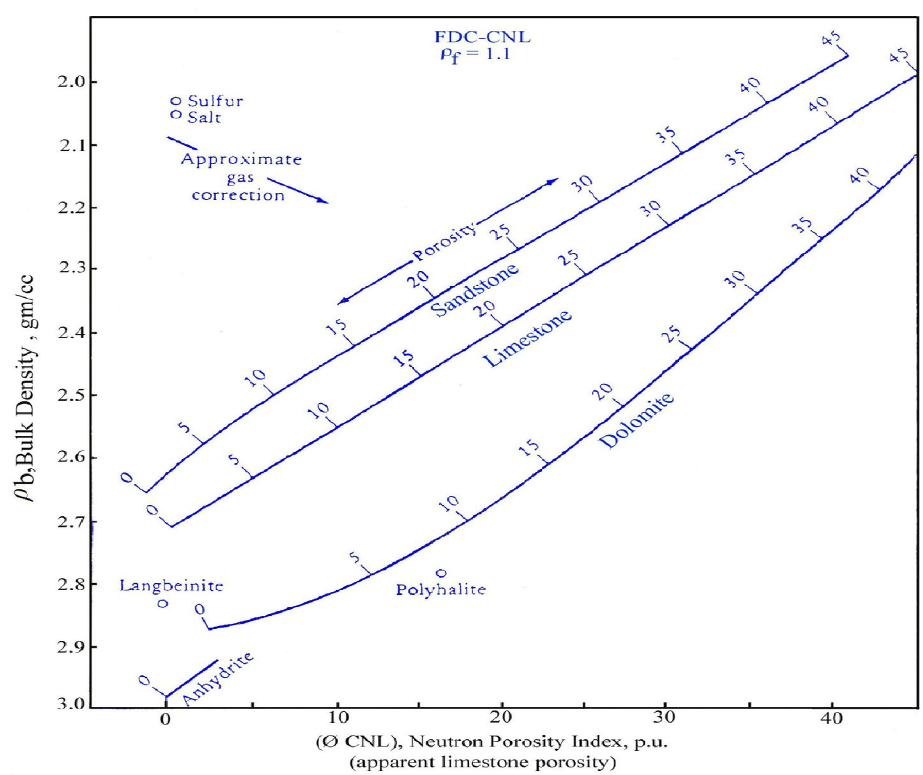



Fig.3-10: Neutron-Density Cross plot, salt water drilling fluid

(Schlumberger, 1982).

**Application**

The cross plotted data of Tq-1 well in dolomite unit falls close dolomite line and some of them closed to limestone line but remain between them which indicate dolomite and dolomitic limestone lithology with average porosity (0-18%) (fig.3-11), in limestone unit the plotted data fall to the limestone line which show limestone lithology and the some data indicated dolomitic limestone with porosity(0-7%) especially limestone lithology have poor porosity value (Fig.3-12).

In TT-06, plotted data fall to dolomite line which indicated dominant dolomite lithology and some of the samples close to limestone but remain as dolomitic limestone with few data represent some meters of limestone show limestone lithology and fall to limestone line(Fg.3-13), the porosity range between(0-20% ) and (0-3%) in limestone plotted data.

In TT-07, the plotted data fall to dolomite unit and closed to limestone but remain between them which indicates dolomite and dolomitic limestone lithology with porosity range (0-20%) (Fig.3-14).

The cross plotted data in TT-09 well for dolomite unit falls close to the dolomite line and some of them falls close to limestone line but remain between them which indicate dolomite and dolomitic limestone lithology with average porosity ( 0-18%) (fig.3-15), in limestone unit the plotted data fall to the limestone line which show limestone lithology and some data indicated dolomitic limestone with low porosity value range(0-4%) (Fig.3-16).

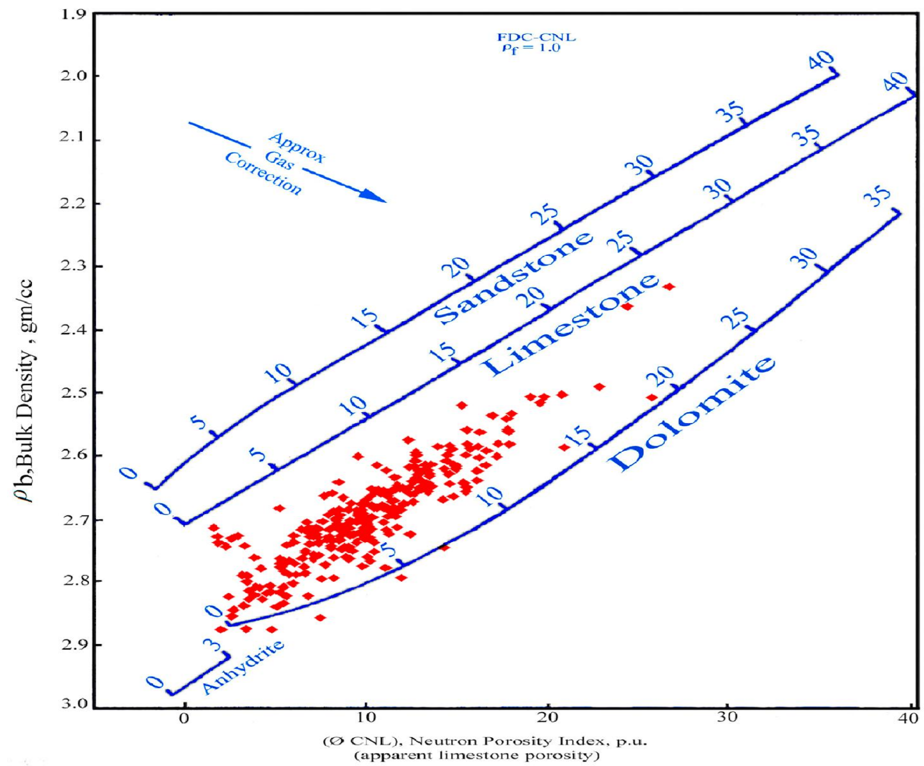



Fig.3-11: Neutron-Density Cross plot, Dolomite unit, Tq-1

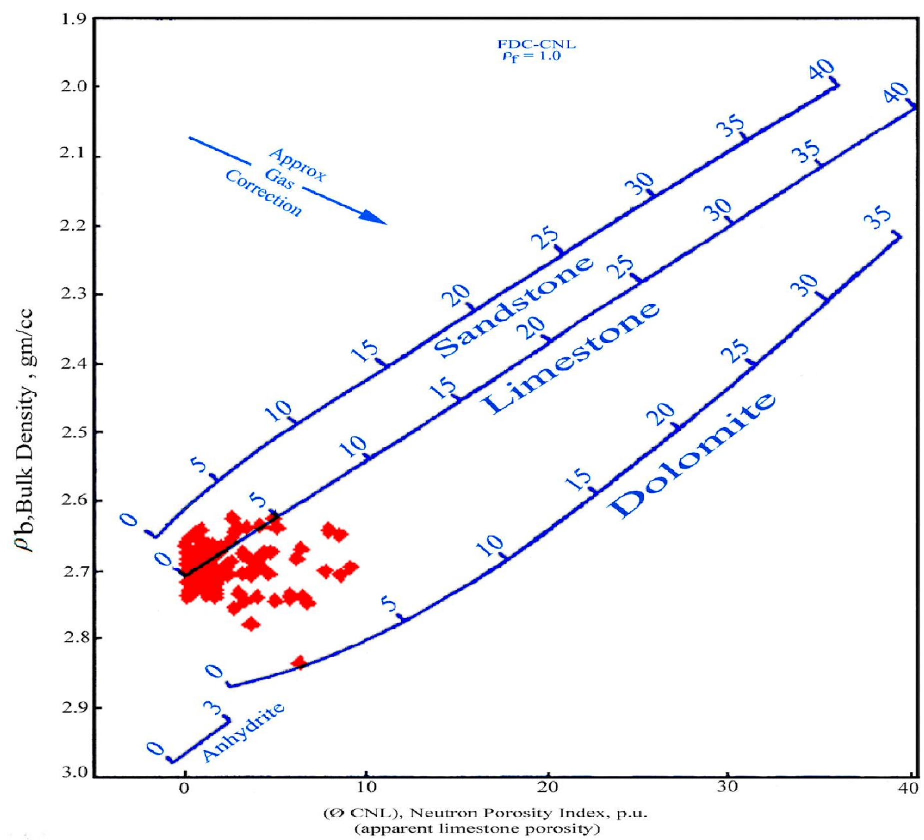


Fig.3-12: Neutron-Density Cross plot, Limestone unit, Tq-1

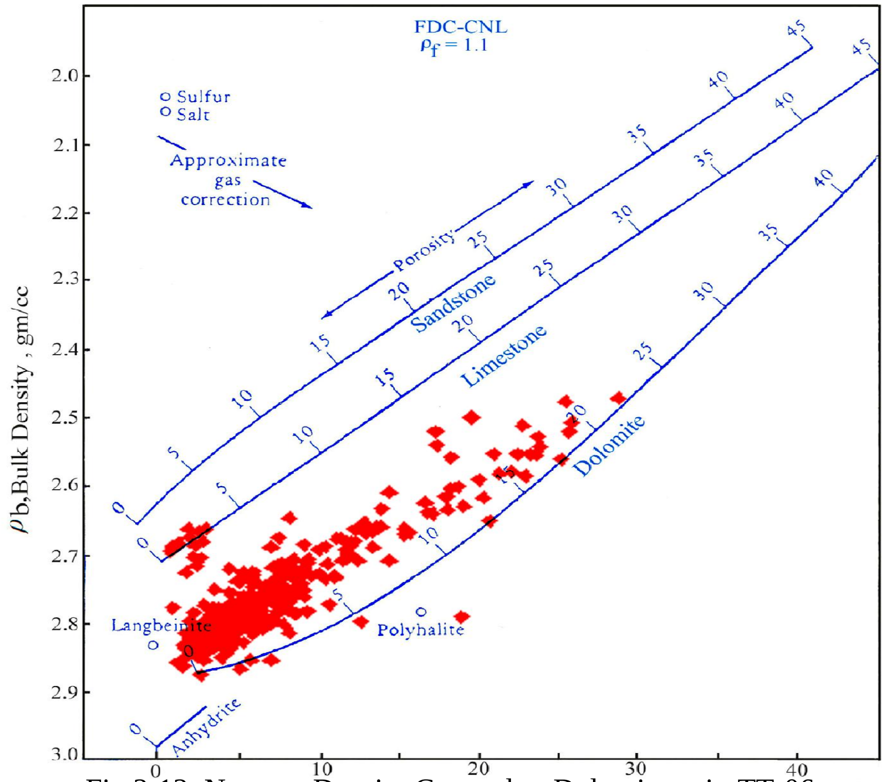



Fig.3-13: Neutron-Density Cross plot, Dolomite unit, TT-06

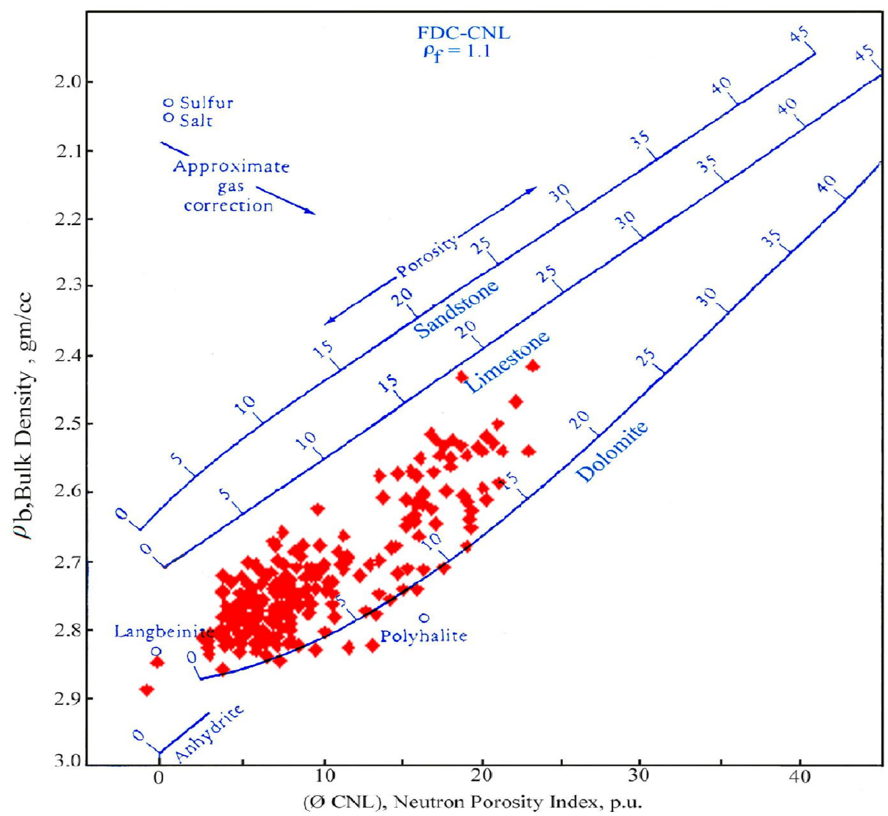


Fig.3-14: Neutron-Density Cross plot, Dolomite unit, TT-07

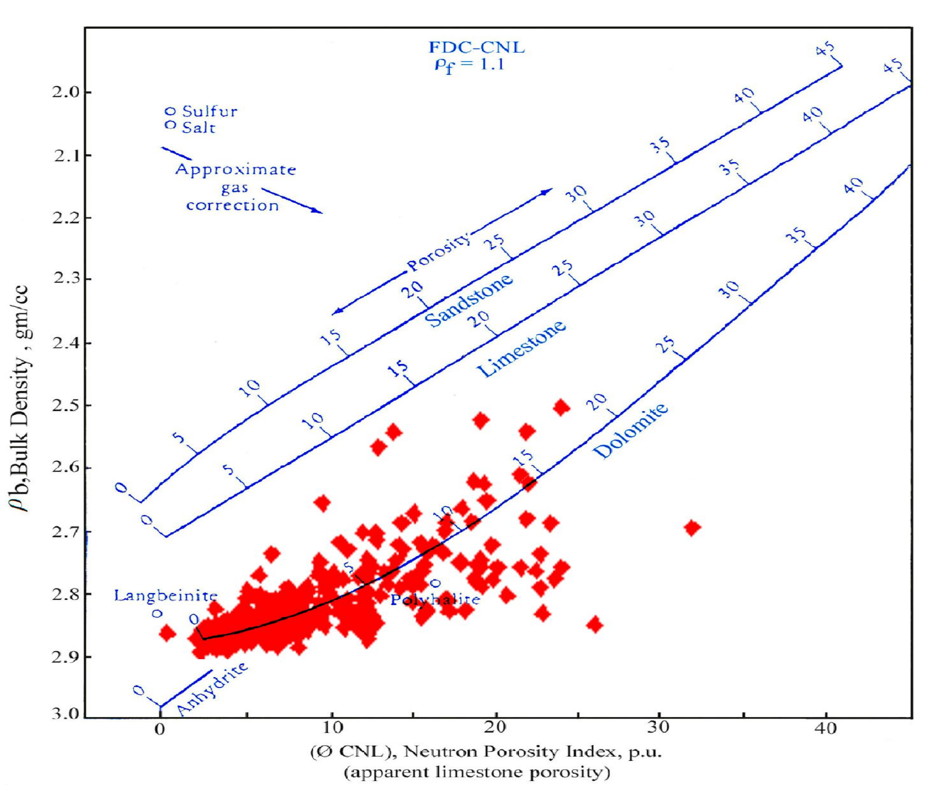



Fig.3-15: Neutron-Density Cross plot, Dolomite unit, TT-09.

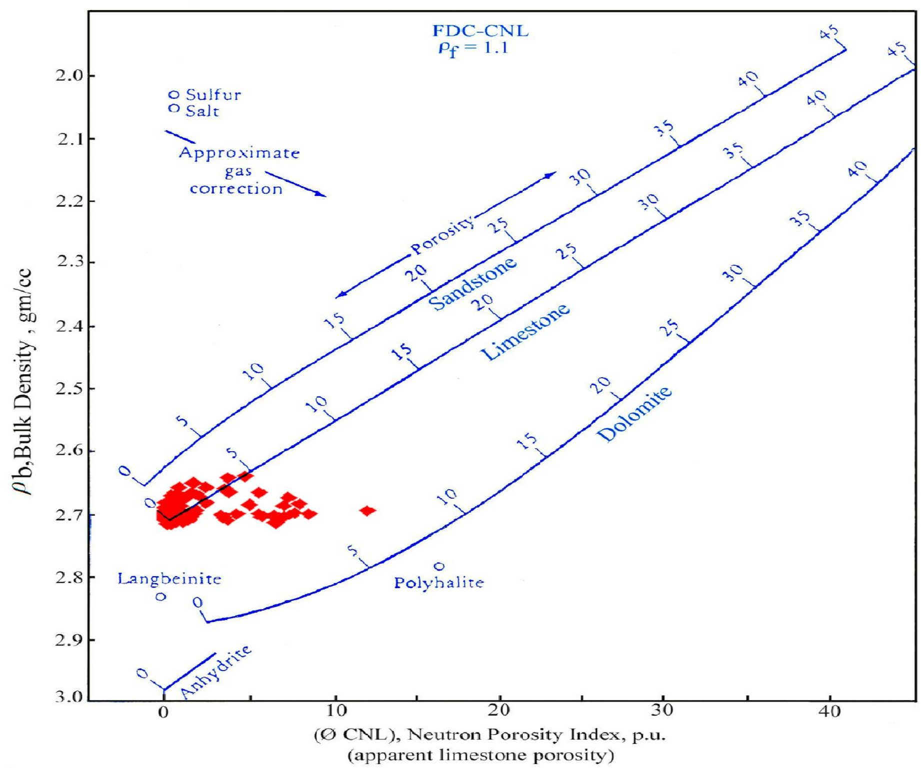


Fig.3-16: Neutron-Density Cross plot, Limestone unit, TT-09

### 3.9.2: M-N Cross Plot

Another method for determining the lithology of a formation is the M-N plot (Fig3-17), by using values from the Density, Neutron, and Sonic logs this plot can show what kind of main lithologies define the formation or if the formation lies within shaliness region (medium N values and low M values).The value of is M and N values are derived from the following two equations (Schlumberger, 1997)

$M=(\Delta t_{fl} - \Delta t) / (\rho_b - \rho_{fl}) * 0.01$------------------------------------------(3-16)

$N=(Ø_{Nf} - Ø_N)/ (\rho_b - \rho_{fl})$ ----------------------------------------------(3-17)

$\Delta t_{fl}$ : interval transit time in the fluid in the formation

$\Delta t$ : interval transit time in the formation(from log)

$\rho b$ : formation bulk density(from log)

$\rho fl$ :fluid density

$Ø_{Nf}$ : neutron porosity of the fluid of the formation(usually 1.0)

$Ø_N$: neutron derived porosity.

M and N values are largely independent of matrix porosity and quantities of M and N are related to lithology and have no relation to cementation exponent (m) and saturation exponent (n) (Asquith and Krygowski, 2004), M and N measured to all studied wells and listed in appendices no 2, 3, 4 and 5.

(Rider, 1996) showed two lithology triangles in M-N plot:

Gypsum-Anhydrite-Dolomite lithology triangle, typically envelop for points from shale free evaporate zone and Calcite-Dolomite-Silica lithology triangle for points from shale free carbonate zone with no secondary porosity.

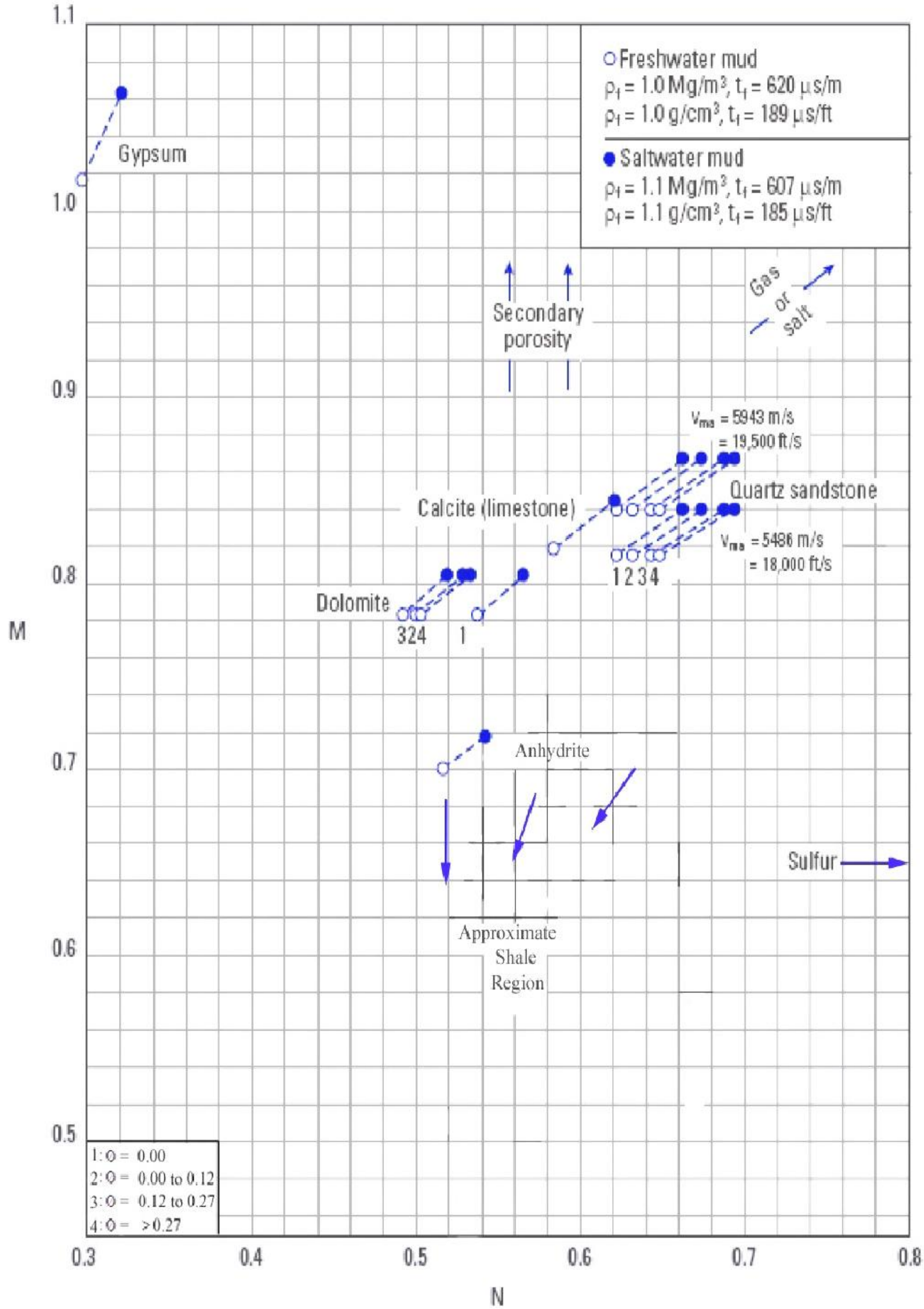



Fig.3-17: M-N Cross Plot for lithology and mineralogical composition identification (Schlumberger, 1998).

**Application**

in Tq-1, the cross plotted data in all parts of dolomite unit located in dolomite region and toward secondary porosity but in limestone unit located in calcite region and some of them between them indicated composition of calcite and dolomite, or in calcite –dolomite-silica lithology triangle, for points from shale free carbonate zone with no secondary porosity(Fig.3-18).

In TT-06, plotted data located in dolomite area with extension toward secondary porosity in dolomite unit with the some data which is located in calcite unit indicate limestone unit (Fig.3-19).

In TT-07, plotted data of dolomite unit located in dolomite region and moved toward secondary porosity (Fig.3-20)

In TT-09, cross plotted data fall in dolomite area which closed to secondary porosity in dolomite unit while plotted data in limestone unit located in calcite area (Fig.3-21).

Cross plotted data in M-N plot in all studied well shows that the dolomite unit composed mainly of dolomite mineral and have secondary porosity especially in upper part and limestone unit show calcite mineral and some dolomite mineral with no indication of secondary porosity.

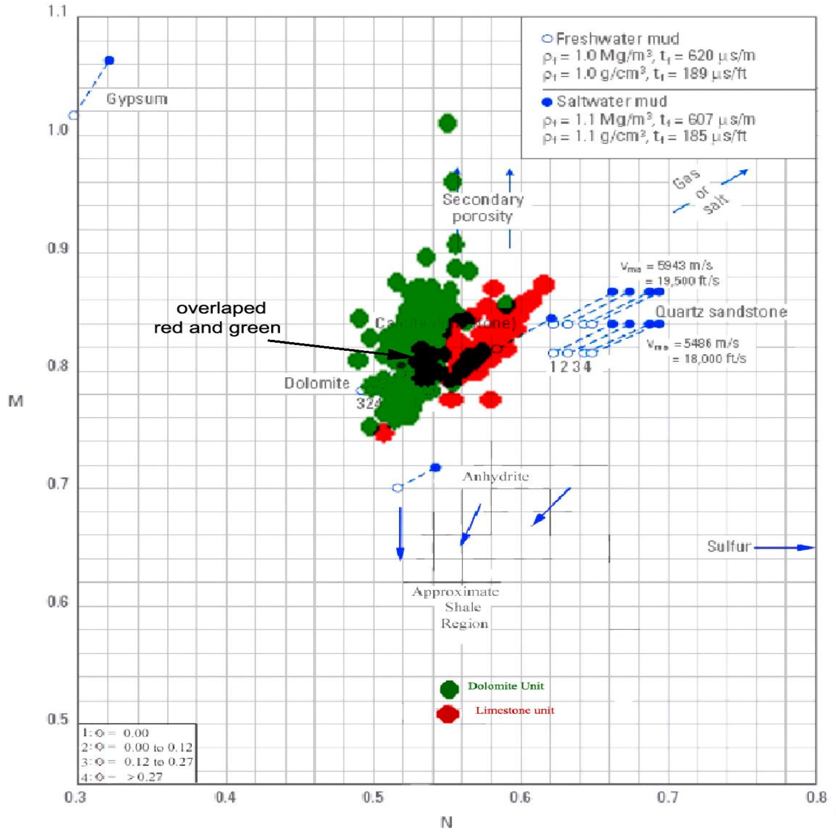



Fig.3-18: M-N cross plot of Tq-1, Taq Taq Oil Field.

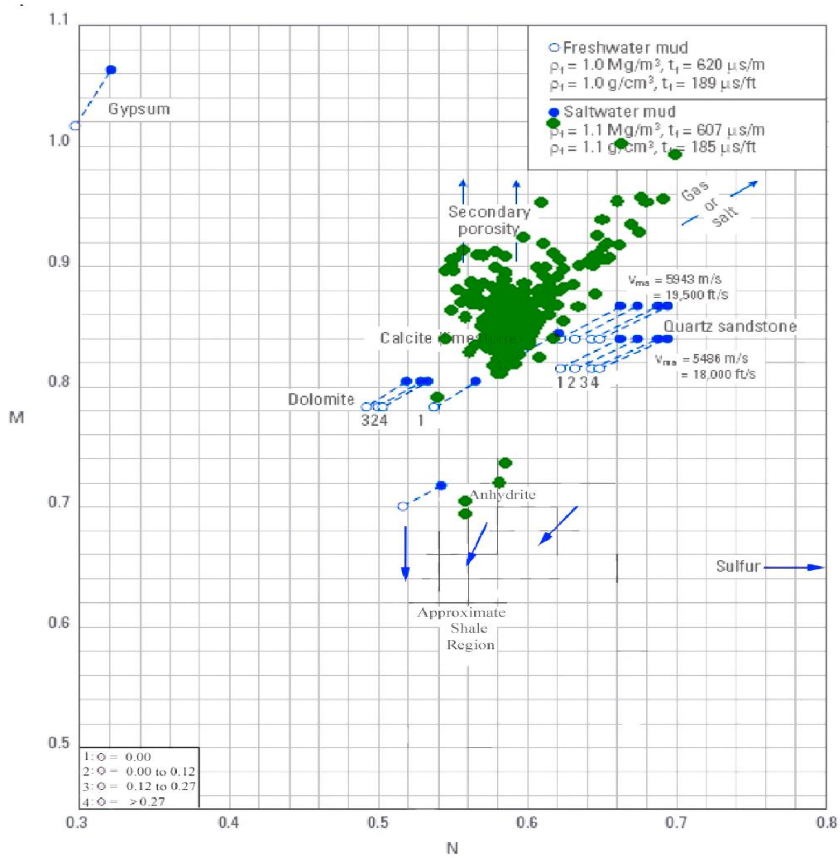



Fig.3-19: M-N cross plot of TT-06, Taq Taq Oil Field

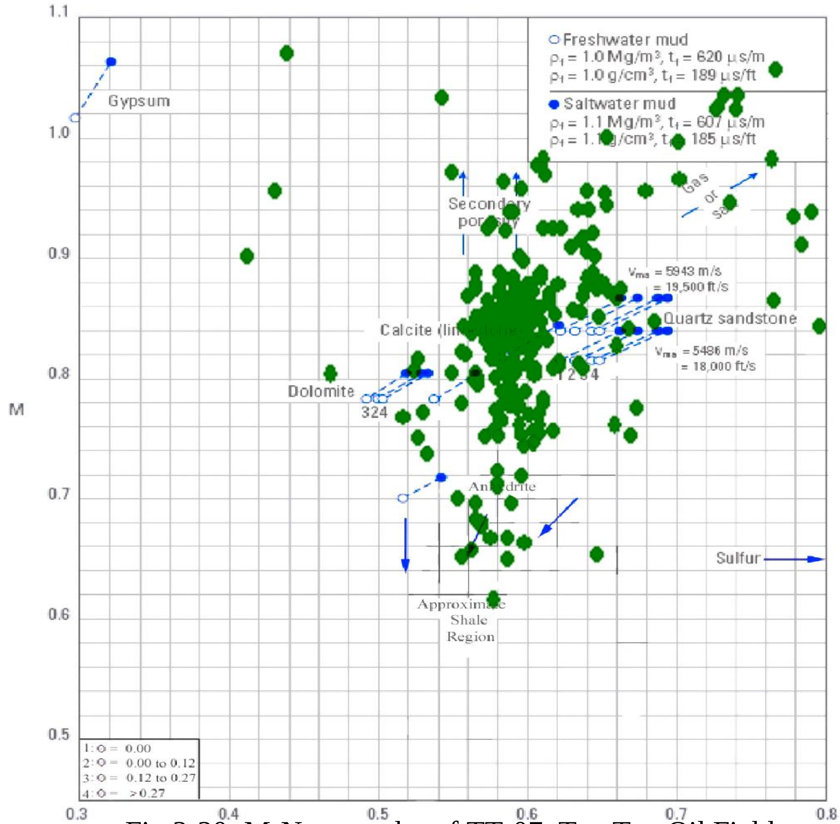



Fig.3-20: M-N cross plot of TT-07, Taq Taq Oil Field.


Fig.3-21: M-N cross plot of TT-09, Taq Taq Oil Field.

## 3.10: Image Log

This log utilize microresstivity electrodes located on pads to provide electronic images of the well bore, have high vertical and lateral resolution, and they provide critical information about bedding dip, faults, unconformities, vugy and fracture porosity(Asquith and Krygowski, 2004).

There are two types of imaging tool, first the acoustic imaging tool, generally called the borehole televiewer or BHTV, use the detailed acoustic response of the formation at the borehole wall to create an image, the second is Electrical Borehole images, have microresistivity electrodes arranged around well bore on pads that are passed against the borehole wall (Rider, 1996).

The microresistivity image of the borehole wall is created from the current measured by the array of button, microresistivity changes related to lithological and petrophysical variations in the rock, which are converged mainly by high resolution current component, are interpretated on the image in terms of rock texture, strartigraphic and structural features and fractures (Schlumberger, 2002).

Image log used in this study is electrical micro imaging –EMI or XRMI (six arm microresistivity borehole imaging tool) which designated by Halliburton.

This tool represents a further advancent in the evaluation of electric borehole imaging, electrode arrays are mounted on six independent arms, providing excellent pad contact and produces very high resolution images for strartigraphic and structural analysis (Seleir etal, 1994).

Application of EMI in reservoir evaluation explained in detail in next chapter.

# Chapter Four
# Reservoir Characterization

## 4.1: Preface

Any rock possessing both the porosity and the permeability necessary both tocontain and to yield oil , gas , or both in commercial quantities (North , 1985).

Abundant types of reservoirs are clastic, carbonate and fractured reservoirs.

Carbonate reservoirs are the result of depositional and diagenetic processes may be heterogeneous and exhibit lateral and vertical variation in porosity and permeability, their development and production present geologist and engineers with a different set of problems (Selley, 1985, Reijers and Hus, 1986 and Layman and Ahr, 2005).

To determine reservoir volume and producibility, quantitative estimates are required of the lithofacies (calibrated to porosity and permeability), geometry, orientation, spatial distribution, and proportion connectedness of permeable and impermeable rock bodies (Bridge and Tye, 2000).

## 4.2: Reservoir Parameters

To evaluate reservoir character and identification of capacity and producibility of the hydrocarbon one must explain porosity and permeability and other parameters and their relation with reservoir development.

### 4.2.1: Formation Temperature

The temperature of the earth usually increases with depth, when a well is drilled into the earth, shows persistent rise in temperature with depth, which is usually expressed in terms of temperature gradient or called "Thermal Gradient" that is in $C^o$ increase per kilometer of depth(Rider,1996).

Temperature Gradient and Formation Temperature Calculation

TG=BHT-TS/TD -------------------------------------- (4-1)

TG: Temperature Gradient ( $C^o$/m or km , $F^o$/ft)

BHT: Bottom Hole Temperature ($C^o$ or $F^o$)

TS: Surface Temperature ($C^o$ or $F^o$)

TD: Total depth (m or ft)

The average temperature gradients of Qamchuqa Formation in the Taq Taq oil field are calculated from Borehole temperature recorded in log header of studied wells equal to 0.021 C°/m.

Formation temperature is also important in log analysis, because the resistivites of the drilling mud (Rm), the mud filtrate (Rmf), and the formation water (Rw) varies with temperature, those values can be corrected to formation temperature by Arp's Formula (Asquith and Krygowski, 2004).

$R_{TF}= R_{temp}\,(T_{emp} + 21.0)/\,(TF+21.0)$ Arp's Formula -------------------------- (4-2)

$R_{TF}$: Resistivity at formation temperature (ohm-m).

$R_{temp}$: Resistivity at temperature other than formation temperature (ohm-m).

$T_{emp}$: Temperature at which resistivity was measured ($C^o$).

TF: Formation temperature ($C^o$).

### 4.2.2: Formation Pressure

Pressure is the force per unit area acting on a surface, measured in $kg/cm^2$ or psi, the several types of subsurface pressure classified as, overburden pressure includes lithostatic and fluid pressure, hydrostatic and hydrodynamic pressures represent two types of fluid pressure (Selley, 1998).

The formation pressure is the pressure under which the subsurface formation fluids, and gases are confined, in most geological basins the pressure at which pore fluids are found increasly from the normal (is hydrostatic pressure due to the weight of the fluid column above the formation) to moderately over pressured (any pressure above the normal for a particular depth) (Rider, 1996).

The two types of fluid pressure are hydrostatic and hydrodynamic; the hydrostatic pressure is imposed by a column of fluid at rest, for a column of water with salinity of 88,000 ppm of dissolved salts the hydrostatic gradient is about 0.465 psi/ft,

The second type of fluid gradient is the hydrodynamic pressure gradient, or fluid potential gradient, which is caused by fluid flow, when a well is drilled; pore fluid has a natural tendency to flow into the well bore which is inhibited by the density of the drilling mud (Selley, 1998).

Subnormal pressures are those pressures that are less than the hydrostatic pressure, while that pressure is greater than hydrostatic pressure is supernormal pressure.

Hydrostatic Gradient is equal to 1.29 psi /m which can be used to calculate of the pressure in Upper Qamchuqa Reservoir pressure in studied wells.

Theoretical pressure= Hydrostatic Gradient (1.29 psi /m) * Depth (m)

Hydrostatic pressure in Upper Qamchuqa reservoir recorded in Tq-1 which is equal to 2809 psi in 1958-1985 m (measured by DST method), while theoretically is equal to 2545.2 psi in same interval of reservoir.

By comparison of theoretical pressure value and recorded pressure in Tq-1 appear that there is anomaly pressure (supernormal pressure).

### 4.2.3: Porosity

Porosity can be defined as the ratio of voids to the total volume of rock; it is represented as a percentage by the Greek letter phi, Ø. (Asquith and Krygowski, 2004).

Porosity is the first of the two essential attributes of a reservoir, pore spaces or voids within a rock generally filled with connate water, but contains oil or gas within a field (Selley, 1998).

Porosity = volume of pore/total volume of rock

Selley, (1998) classified pores to three morphological types;

Cantery pores are those that communicate with others by more than one throat passage.

Cul-de-Sac pore or dead-end pores have only one throat passage connecting with others.

Closed pores have no communication with other pores (Fig .4-1).

Cantery and Cul-de-Sac pores constitute effective porosity; in that hydrocarbon can emerge from them. In Catenary pores hydrocarbon can be flushed out by a natural or artificial water drive, Cul-de-Sac pores are unaffected by flushing, but may be yield some oil or gas by expansion as pressure drops, closed pores are unable to yield hydrocarbon.

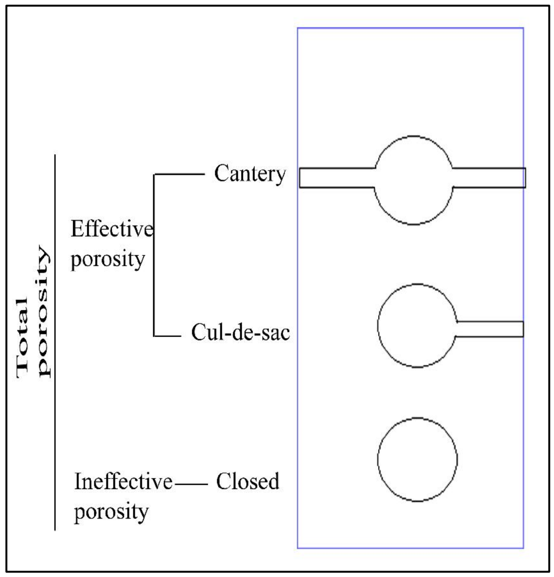



Fig .4-1: Morphological types of pores, (Selley 1998).

Lucia, (1999) designated three major pore types in carbonate rocks;
Interparticle porosity, consist of pores between grains and/or crystals, whereas all other pore space are vuggy. Separate vugs are interconnected only through the Interparticle pore network, although touching vugs from an interconnected pore system. In the absence of vuggy porosity, Interparticle porosity can be used to predict permeability for given rock.

Choquette and Pray (1970), Lucia (1995), Selley (1998) and House (2007)
Used the following terms of types of pores;

**Primary porosity**: is the main or original porosity system in a rock, formed when sediment is deposited, divided into two subtypes, Interparticle (intergranular) pores, are initially present in all sediments, intraparticle pores are generally found with in skeletal grains of carbonate sand.

**Secondary porosity**: pores are often caused by solution , is a subsequent or separate porosity system in rock, often enhancing overall porosity of a rock, this can result in chemical leaching of minerals or the generation of fractures system, this can replace the primary porosity or coexist with it, have the following subtypes:

**Moldic pores**: is fabric selective that is only the grains or only the matrix has been leached out, originate from dissolution of mineralogical metastable grains. The pores thus are integrated in frame consist micrite, cement, or just preserved micritic rims of the grains that resisted dissolution. (Fig 4-2, C)

**Vug pores**: are pores whose boundaries cross-cut grains, micrites and/or earlier cement, tend to be larger than Moldic pores (Fig .4-2, A, D and E).

**Intercrystalline pores**: pores occurring between the crystal faces of crystalline rocks, dominant type of secondary porosity occurs in secondary dolomite that have been formed by the replacement of calcite (Fig 2-4, A and E).

**Fracture pore**: porosity associated with fracture system or faulting,
can create secondary porosity in rock that otherwise would not be reservoirs for hydrocarbon due to their primary porosity being destroyed (Fig .2-4, F).

Different types of pores with in each microfacies and their causes of producing, pore types and amount of them described in detail in chapter two.

### 4.2.4: Permeability

Is the property of a medium of allowing fluids to pass through it without change in the structure of the medium or displacement of its parts (North, 1985), or is the second essential requirement for a reservoir rock. It is the ability of fluids to pass through a porous material. Measured by mellidarcy unit and generally referred by letter (K) (Selley, 1998).

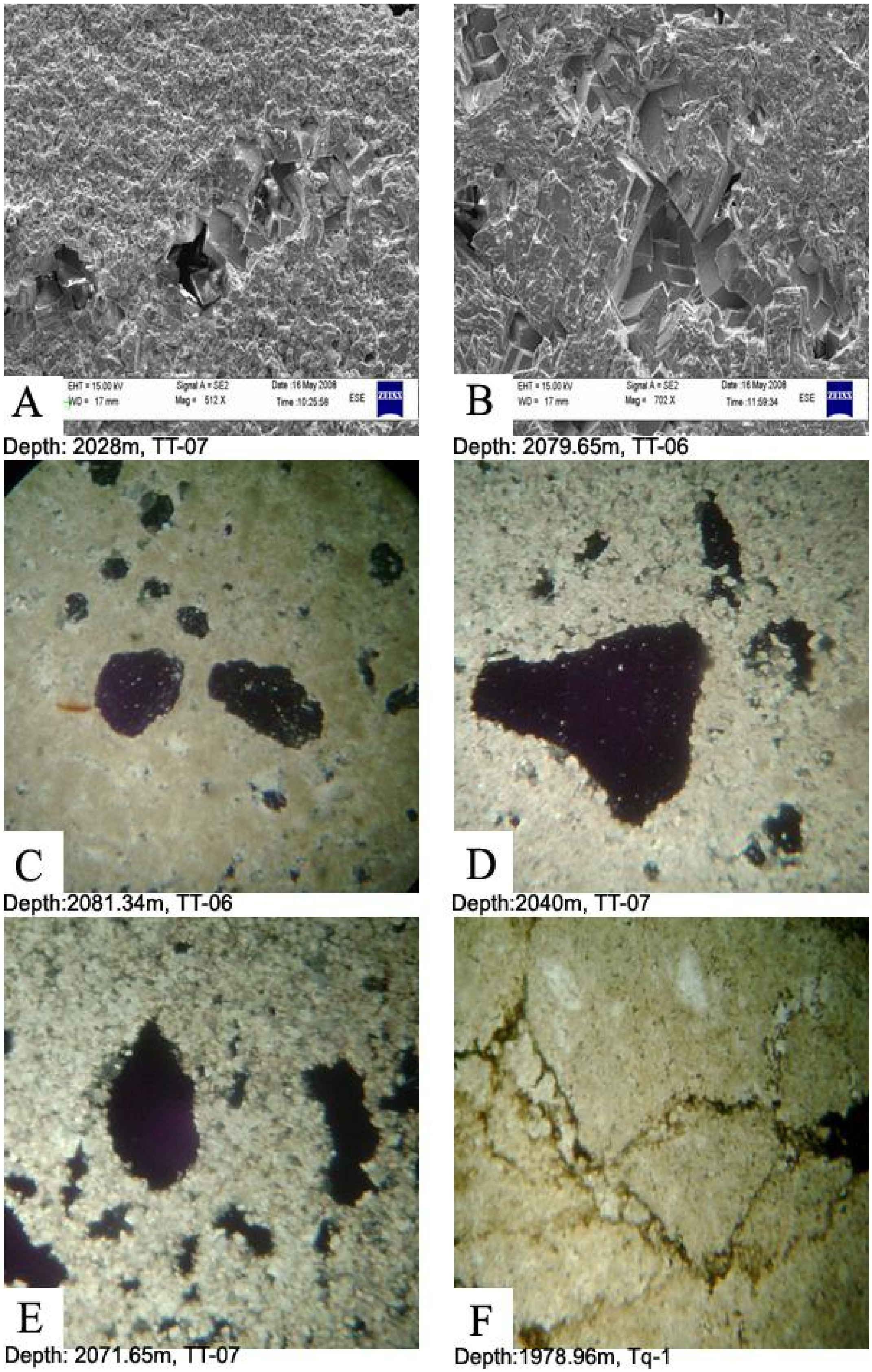



Fig.4-2: Different types of porosity in Upper Qamchuqa Reservoir in Taq Taq Oil Field.

The permeability of a reservoir with homogenous pore distribution frequently increases proportionally with bulk porosity, heterogeneous pore distribution, however results in reservoir permeability that depends largely on the interrelation of individual pores, which is characterized by pores of a multigenetic origin, (Reijers and Hus, 1986).

## 4.3: Calculation of Reservoir Porosity and Permeability

### 4.3.1: Porosity Calculation

Porosity values in Upper Qamchuqa Formation in Taq Taq Oil field obtained from porosity log calculation" Sonic log" which measured primary porosity and from Density and Neutron log which measured total or bulk porosity .

The sonic log responds basically to intergranular or intercrystalline (primary) porosities while density and Neutron log respond to the total porosity (primary and secondary; vug, mold and fracture) and the differences between the calculated porosity from either of these two logs and sonic log will give a secondary porosity index which indicate of fracture porosity only when it is known that no other type of secondary porosity is present (Millard, 1980) and (Rider, 1996).

Those porosity data which is measured by log data used as basic a parameter to classify and division of reservoir into different units and estimation of hydrocarbon saturation, water saturation, bulk volume of oil and water (movable and residual).Final resulted porosity calculation and plotting (primary and bulk porosity) data from log data with fracture index in different lithologic unit of Upper Qamchuqa showed in fig (4-3) and listed in appendices no 2, 3, 4 and 5.

### 4.3.2: Permeability Calculation

Numerous ways of calculating permeability from wire line log have been tried, the most popular has been the porosity-permeability transform, relate permeability to water saturation , porosity and capillary pressure , as well as several stastical methods used to calculating permeability in reservoir rocks(Lucia etal, 2001).

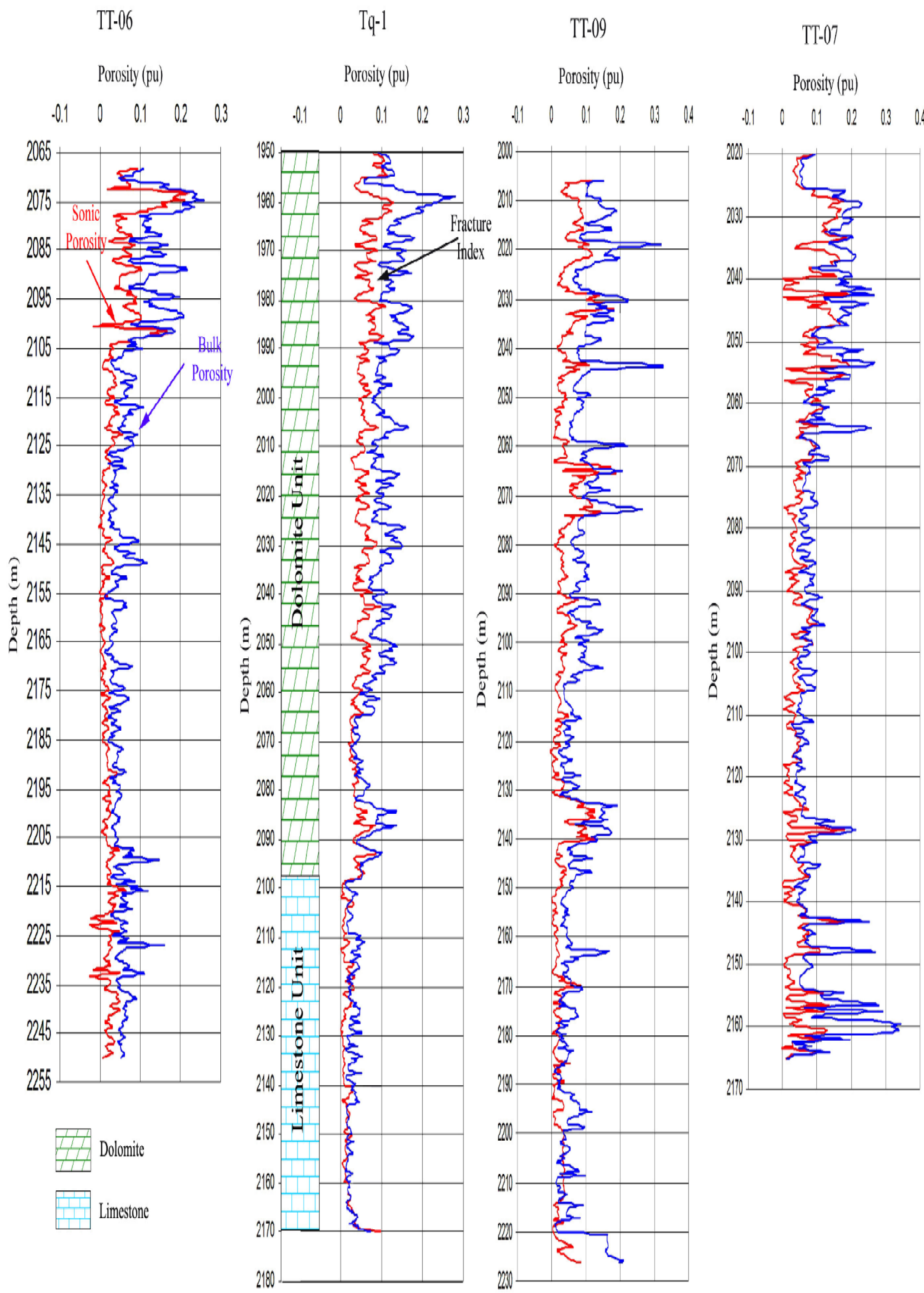



Fig .4-3: Porosity (primary and Bulk) on logs of the studied wells, showing fracture index.

Some methods of calculating permeability are shown below:

$K = (93 * Ø^{2.2} / Sw_{irr})^2$   Timur , 1968 ---------------------------------- (4-3)

In (Asquith and Krygowski, 2004).

K: permeability   Ø: porosity   $Sw_{irr}$: irreciudible water saturation

But because this equation require $Sw_{irr}$, it was impossible to obtain reasonable value for the permeability value.

(Mohaghegh, et al, 1995), derived permeability equation based on log reading data, as show in following:

$K = 38.2542 * GR^{-0.5874} * BD^{-40.9438} * DI^{0.4066}$ ---------------------------- (4-4)

GR: Gamma Ray   BD: Bulk Density   DI: Deep Induction Log

The suitable equation of calculation reservoir permeability is based on log reading data used by some modification on (Mohaghegh, et al, 1995)equation with addition of effect Neutron porosity and acoustic travel time to equation used to calculation of permeability in Qamchuqa formation,

$K = (-38 * GR^{-0.58} + BD^{-0.0044} * LD^{0.28} * DHT^{0.003} * N^{0.4})^{2.0}$ ---------------- (4-5)

K: Permeability, M.D

GR: Gamma Ray, API

BD: Bulk Density, gm/cc

LD: Deep Laterolog, ohm-m

DHT: Acoustic Travel Time (Sonic), μ.s/ft

N: Neutron Porosity, Pu

Resulted data compared with laboratory permeability measurement for cores from TT-07, which is shown in Fig (4-4).

The resulted permeability data from above equitation to studied well of Upper Qamchuqa Reservoir shown in Fig (4-4) and listed in appendices no 2, 3, 4 and 5. In this chapter, the aim of the calculation of permeability by equation is to drown porosity-permeability relation in R35 method to show fluid flow and pore size determination which explained in section 4.7.

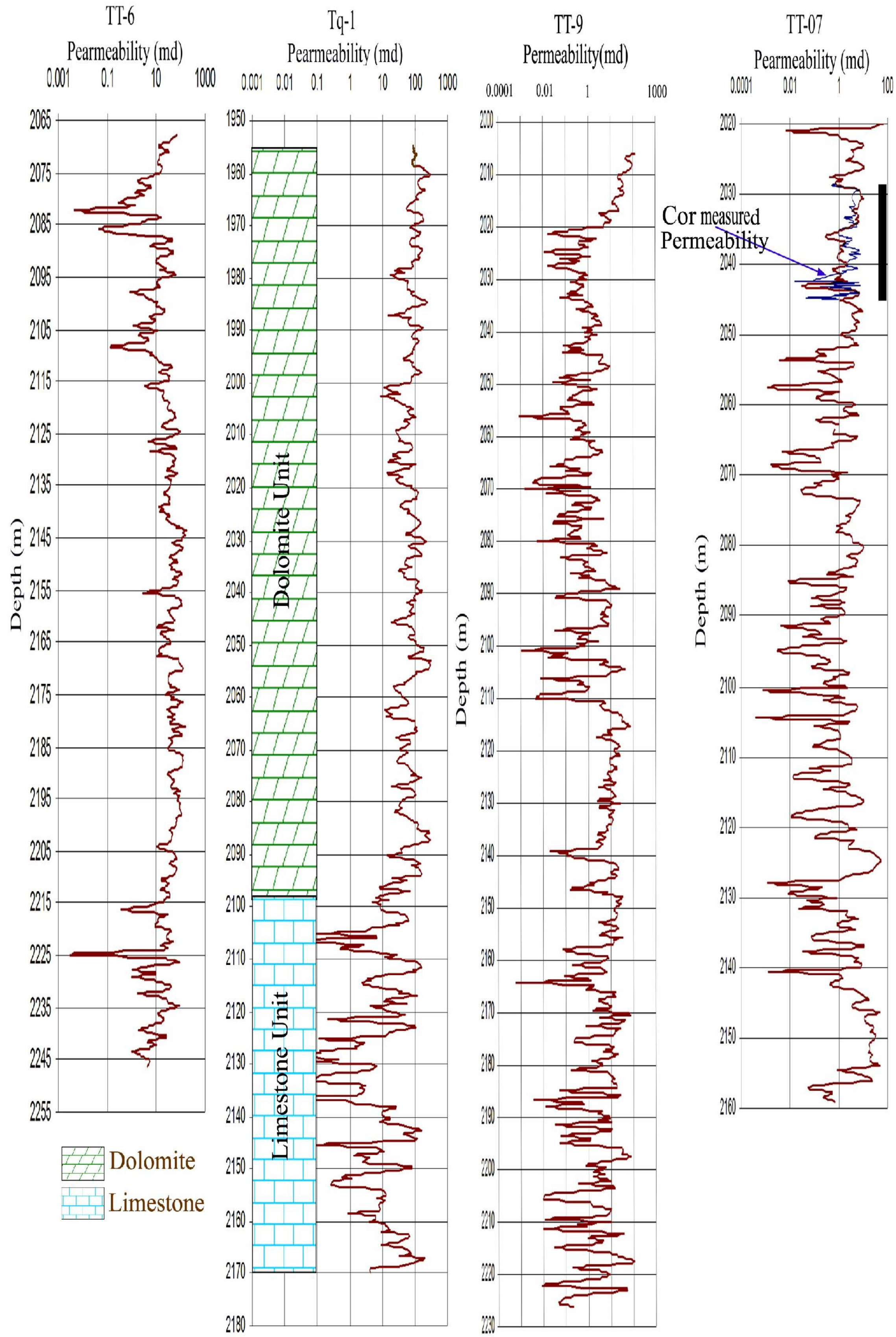



Fig .4-4: Permeability log deflections of the studied wells.

## 4.4: Reservoir Fluids Saturation and Movability

### 4.4.1: Fluid Saturation

Saturation of any given fluid in pore space is the volume of fluid to the total pore space volume, saturation is the percentage or fraction of total capacity to hold fluids (porosity) that actually holds any particular fluid (Dresser Atlas, 1975).

Saturation and hydrocarbon movability has been determined to show which permeable zones have potential interest, drive a fairly accurate value of water saturation and give same valuable information about hydrocarbon movability.

#### 4.4.1.1: Water Saturation

Is the amount of pore volume in a rock that is occupied by formation water, it is represented as decimal fraction or as percentage and has the symbol (Sw).

$$\text{Water Saturation (Sw)} = \frac{\text{Formation water occupying pores}}{\text{Total pore space in the rock}}$$

Water saturation (Sw) of a reservoirs uninvaided zone is calculated by the Archie's (1942) formula: in (Asquith and Krygowski, 2004).

$Sw= (a*Rw/Rt*Ø^{m})^{1/n}$ --------------------------------------------------(4-6)

Sw: Water saturation of the uninvaided zone

Rw: Resistivity of formation water at formation temperature (ohm-m)

Rt: True formation resistivity (ohm-m)

Ø: Porosity

a: Tortuosity Factor =1.0

m: Cementation Exponent =1.81

n: Saturation Exponent =2.0

Water Saturation of formation's flushed zone ($Sx_o$) is also based on the Archie's equation, but two variables are changed; Mud Filtrate Resistivity (Rmf) in place of Formation Water Resistivity (Rw) and Flushed Zone Resistivity ($Rx_o$) in place of uninvaided zone Resistivity (Rt).

$Sx_o = (a*Rmf/Rx_{o*}\ Ø^m)^{1/n}$ ---------------------------------------------- (4-7)

$Sx_o$ : Water Saturation of Flushed Zone.

Rmf: Resistivity of the Mud Filtrate at Formation Temperature (ohm-m).

$Rx_o$ : Shallow Resistivity (ohm-m).

Water Saturation of the Flushed zone ($Sx_o$) can be used as indicator of hydrocarbon movability, if the value of $Sx_o$ is much greater than Sw, then Hydrocarbons in the flushed zone have probably been moved or flushed out of the zone nearest the borehole by the invading drilling fluids (Asquith and Krygowski, 2004).

Water saturation in uninvaided and flushed zone of all studied wells except water saturation in flushed zone of TT-06 (not estimated because bad reading of MSFL and bad value of $Rx_o$ as mentioned in top of log in TT-06) listed in appendices no 2, 3, 4 and 5.

#### 4.4.1.2: Hydrocarbon Saturation

Is the amount of pore volume in a rock that is occupied by hydrocarbon, is usually determined by the difference between unity and water saturation,

$Sh = 1 - Sw$ ------------------------------------------ (4-8)

Sh: Hydrocarbon Saturation

Residual Hydrocarbon Saturation is the difference between unity and water saturation in flushed zone,

$Sh_r = 1 - Sx_o$, ----------------------------------------- (4-9)

The equation gives the saturation in unmoved or residual Hydrocarbons of invaided zone (Rider, 1996).

Hydrocarbon saturation and residual hydrocarbon saturation for all studied wells estimated except residual hydrocarbon in TT-06 for bad recoding, and listed in appendices no 2, 3, 4 and 5.

### 4.4.2: Bulk Volume of Water and Oil, BVW &BVO

The product of formation water saturation (Sw) and it is porosity is the bulk volume of water, and bulk volume of oil, Hydrocarbon saturation multiply by the porosity, (Spain, 1992)

BVW=Sw x Ø------------------------------------------------------- (4-10)

BVW: bulk volume of water

Sw: water saturation of uninvaided zone.

Bulk volume of Oil (BVO) =Sh x Ø------------------------------ (4-11)

Bulk volume of water in flushed zone $BVX_O$=Sxo x Ø.

The values of (BVW, BVO, BVXO), are indicating for all studied wells, bulk volume of water represent the amount of water that hold in sediment during deposition and lithification before hydrocarbon migrating to reservoir rock, which is known as connate water (Tiab and Donaldson,1996 ).

Bulk volume of water in uninvaided zone and flushed zone except in TT-06 with Bulk volume of oil of all studied wells estimated and listed in appendices no 2, 3, 4 and 5.

### 4.4.3: Ratio Method and Hydrocarbon Movability

The ratio method identified hydrocarbons from the difference between water saturations in the flushed zone ($Sx_o$) and the uninvaided zone (Sw) when the uninvaided zone from of Archie’s equation is dividing the flushed zone (Asquith and Krygowski, 2004).

$(Sw/ Sx_o)= [(Rx_o/Rt )/ (Rmf/Rw)]^{1/2}$ --------------------------------  (4-12)

$Sw/ Sx_o$: Movable Hydrocarbon Index

If the Movable hydrocarbon Index is equal to or greater than 1.0 , then hydrocarbons were not moved during invaition, this is true regardless of weather or not a formation contains hydrocarbons, whenever the ratio $Sw/ Sx_o$ is less than 0.6 for carbonate , Movable Hydrocarbons are indicated (Schlumberger,1972).

Comparison of Sw and $Sx_o$ in hydrocarbon zone is considered to give movable hydrocarbons ($Sx_o$ - Sw) is equal to the fraction of movable Hydrocarbons in the formation. The percentage volume in terms of the reservoir in given by multiplying in term of the porosity, i.e. percentage of volume of reservoir with movable hydrocarbons (Rider, 1996).

Movable Hydrocarbon = $(Sx_o\text{-}Sw)*Ø$. --------------------------- (4-13)

Movable hydrocarbon index of all the studied wells except TT-06 is estimated and listed in appendices no 2, 3, 4 and 5, (Fig.4-5).

## 4.5: Porosity Cut off

Porosity Cut off value is to determine the value above which is relatively porous unit and below it relative neglible porosity unit. The cut-off limit of the formation is (0.1md) which indicates the boundary between good porous part and poor porous (Kupecz, 1995).

To determining porosity cut off, drawing the relationship between the porosity (linear scale) and permeability (log scale), (Fig.4-6),the reading are taken from the core analysis, laboratory measurement of TT-07and drawing best fit line to determine Øcut-off , which is corresponding to the (0.1md) permeability value. Porosity cut-off is equal to 9.3 %( 0.093) to porosity units of all studied wells. Fig (4-7) show porosity Cutt of line of TT-07.

### 4.5.1: Porosity Units

Based on porosity measured data and from log analysis of the Upper Qamchuqa Reservoir classified into four (4) porosity units (U1, U2, U3 and U4) from top to bottom using total porosity , average effective porosity ,average pay (reservoir)porosity , net pay and net/gross ratio of each unit measured.

**Average reservoir porosity=∑porosity values≥ porosity cut off÷ number of samples with values ≥ porosity cut off.**

**Net Reservoir =total feet of pay having porosity ≥ porosity cut off.**

**Net /gross ratio = total feet of pay / total thickness. (Kupecz, 1995).**

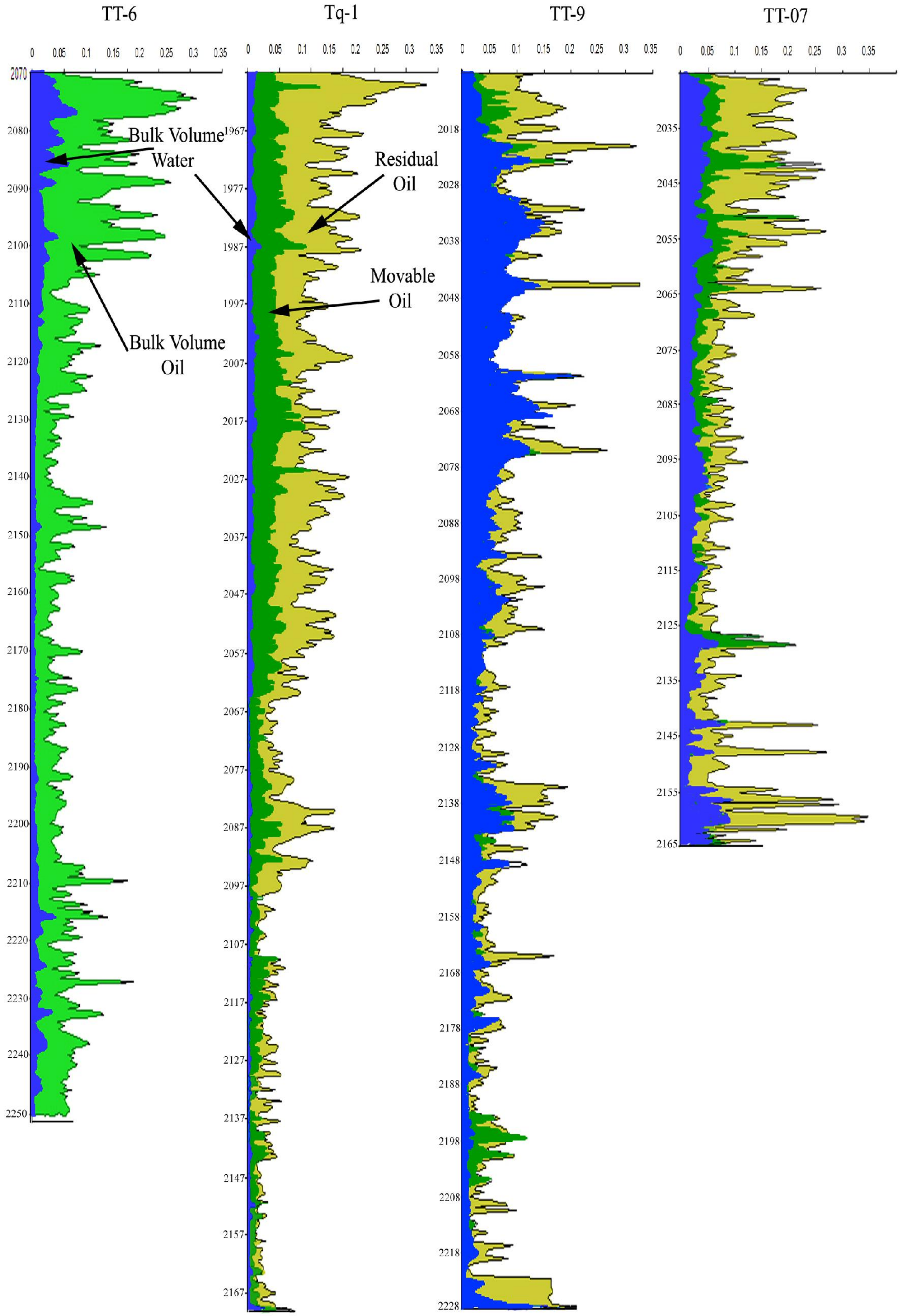



Fig .4-5: Bulk Volume of Water, Movable and Residual Hydrocarbon in the studied wells.

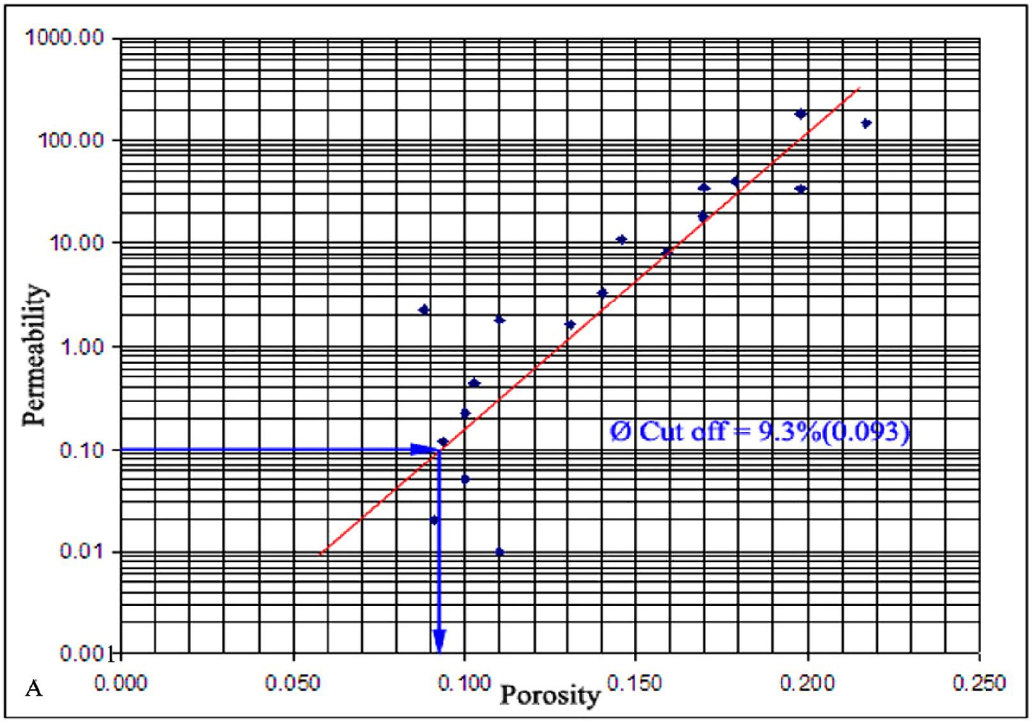



Fig.4-6: Porosity Cut off applied to all porosity units of studied wells.

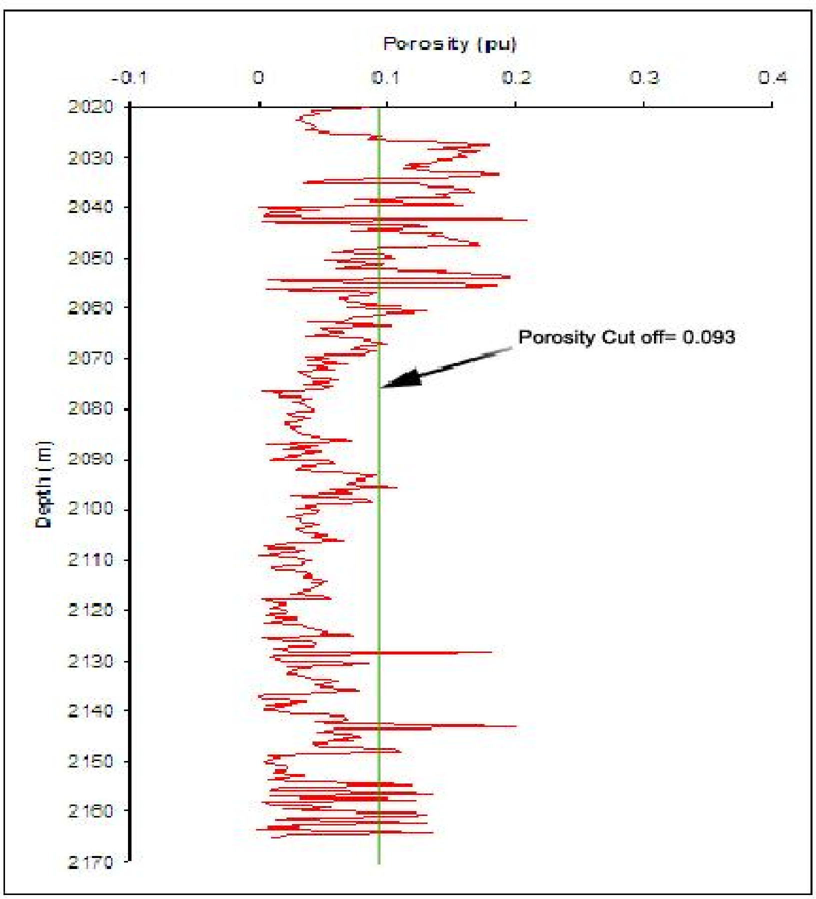



Fig.4-7: Porosity Cutt of applied to all porosity units of TT-07.

#### 4.5.1.1: Porosity Unit Division and Properties in TT-06

**First Porosity Unit (U1)**

Started depth from 2071m to 2108m. Thickness of this unit is 37 m. It is consist of crystalline dolomite of different size in the dolomite unit. Average porosity of this unit is 16% and average pay porosity of this unit 16.2%. Thickness of pay zone (net pay) is 18 m which represent 75.7% of total thickness of porosity unit. This unit represents the best productive part of the Upper Qamchuqa reservoir in TT-06, table (4-1) and (Fig.4-8).

**Second Porosity Unit (U2)**

Started from 2108m to 2203m. Thickness of this unit is 95 m. it is consist of dolomite crystals in dolomite unit. Average porosity of this unit is 5% and average pay porosity of this unit 11%. Thickness of pay zone (net pay) is 1.5m which represents 1.6% of total thickness of porosity unit.

**Third Porosity Unit (U3)**

Started from 2203m to 2250m. Thickness of this unit is 47 m. it is consist of dolomite crystals in dolomite unit. Average porosity of this unit is 6% and average pay porosity of this unit 12%. Thickness of pay zone (net pay) is 3m which represent 6.3% of total thickness of porosity unit.

#### 4.5.1.2: Porosity Unit Division and Properties in Tq-1

**First Porosity Unit (U1)**

Started from 1957 to 1988.5m. Thickness of this unit is 31.5 m. It is consists of crystalline dolomite of different size with dolomitic limestone in Dolomite unit. Average porosity of this unit is 15% and average pay porosity of this unit 15.6%. Thickness of pay zone (net pay) is 31m which represent 97% of total thickness of Porosity unit. This unit is considered as best productive porosity unit in Upper Qamchuqa reservoir.

**Second Porosity Unit (U2)**

Started from 1988.5m to 2072m. Thickness of this unit is 83.5 m. It is consist of crystalline dolomite of different size with dolomitic limestone in Dolomite unit. Average porosity of this unit is 9% and average pay porosity of this unit12%. Thickness of pay zone (net pay) is 4.5m which represent 18% of total thickness of porosity unit.

**Third Porosity Unit (U3)**

Started from 2072m to 2098m. Thickness of this unit is 26 m. It is consist of coarse crystalline dolomite in lower part of dolomite unit. Average porosity of this unit is 6% and average pay porosity of this unit 12%. Thickness of pay zone (net pay) is 3m which represent 11.5% of total thickness of porosity unit.

**Forth Porosity Unit (U4)**

Started from 2100m to 2170m. Thickness of this unit is 70 m. It is consist of Limestone and Dolomitic limestone in limestone unit. Average porosity of this unit is 3% and average pay porosity is 0.0%, i.e. all porosity values located under porosity cut off.

### 4.5.1.3: Porosity Unit Division and Properties in TT-09

**First Porosity Unit (U1)**

Started from 2006m to 2041m. Thickness of this unit is 35 m. It is consist of crystalline dolomite of different size in Dolomite unit. Average porosity of this unit is 13% and average pay porosity of this unit 14.3%. Thickness of pay zone (net pay) is 28.5m which represent 81.43% of total thickness of porosity unit.

**Second Porosity Unit (U2)**

Started from 2041m to 2122.5m. Thickness of this unit is 81.5 m. it is consist of dolomite mosaic in dolomite unit. Average porosity of this unit is 9% and average pay porosity of this unit 13%. Thickness of pay zone (net pay) is 28m which represent 34% of total thickness of porosity unit.

**Third Porosity Unit (U3)**

Started from 2122.5m to 2153.5m. Thickness of this unit is 31 m. it is consist of dolomite crystals in dolomite unit. Average porosity of this unit is 8% and average pay porosity of this unit 14.4%. Thickness of pay zone (net pay) is 9m which represent 29% of total thickness of porosity unit.

**Forth Porosity Unit (U4)**

Started from 2153.5m to 2225m. Thickness of this unit is 71.5 m. Limestone unit make this unit, average porosity of this unit is 5% and average pay porosity of this unit 14%. Thickness of pay zone (net pay) is 8m which represent 11% of total thickness of porosity unit.

#### 4.5.1.4: Porosity Unit Division and Properties in TT-07

**First Porosity Unit (U1)**

Started from 2025m to 2060m. Thickness of this unit is 35 m. is consisting of crystalline dolomite of different size in Dolomite unit. Average porosity of this unit is 16.6% and average pay porosity of this unit17.7%. Thickness of pay zone (net pay) is 31.5m which represent is 90% of total thickness of porosity unit. This unit is considered best oil productive porosity unit in upper Qamchuqa reservoir in Taq Taq Oil Field.

**Second Porosity Unit (U2)**

Started from 2060m to 2140m. Thickness of this unit is 80 m. it is consist of dolomite mosaic in dolomite unit. Average porosity of this unit is 7% and average pay porosity of this unit 13%. Thickness of pay zone (net pay) is 13.5m which represents 17% of total thickness of reservoir unit.

**Third Porosity Unit (U3)**

Started from 2140m to 2165m. Thickness of this unit is 25 m. It is consist of dolomite crystals in dolomite unit. Average porosity of this unit is 9% and average pay porosity of this unit20%. Thickness of pay zone (net pay) is 10m which represents 40% of total thickness of reservoir unit.

All porosity units in all studied wells are shown in fig (4-8).

Table:4-1: Porosity parameters values in studied wells

| TT-06 | Interval m | Thickness m | Average Porosity% | Average Pay Porosity% | Net Pay m | Net/Gross% |
|---|---|---|---|---|---|---|
| U1 | 2071-2108 | 37 | 16 | 16.2 | 18 | 75.7 |
| U2 | 2108-2203 | 95 | 5 | 11 | 1.5 | 1.6 |
| U3 | 2203-2250 | 47 | 5 | 12 | 3 | 6.3 |

| Tq-1 | Interval m | Thickness m | Average Porosity% | Average Pay Porosity% | Net Pay m | Net/Gross % |
|---|---|---|---|---|---|---|
| U1 | 1957-1988.5 | 31.5 | 15 | 15.6 | 31 | 97 |
| U2 | 1988.5-2072 | 83.5 | 9 | 12 | 4.5 | 18 |
| U3 | 2072-2098 | 26 | 6 | 12 | 3 | 11.5 |
| U4 | 2098-2170 | 70 | 3 | 0 | 0 | 0 |

| TT-09 | Interval m | Thickness m | Average Porosity% | Average Pay Porosity% | Net Pay m | Net/Gross % |
|---|---|---|---|---|---|---|
| U1 | 2006-2041 | 35 | 13 | 14.3 | 28.5 | 81.43 |
| U2 | 2041-2122.5 | 81.5 | 9 | 13 | 28 | 34 |
| U3 | 2122.5-2153.5 | 31 | 8 | 14.4 | 9 | 29 |
| U4 | 2153.5-2225 | 71.5 | 5 | 14 | 8 | 11 |

| TT-07 | Interval m | Thickness m | Average Porosity% | Average Pay Porosity% | Net Pay m | Net/Gross % |
|---|---|---|---|---|---|---|
| U1 | 2025-2060 | 35 | 16.6 | 17.7 | 31.5 | 90 |
| U2 | 2060-2140 | 80 | 7 | 13 | 13.5 | 17 |
| U3 | 2140-2165 | 25 | 9 | 20 | 10 | 40 |

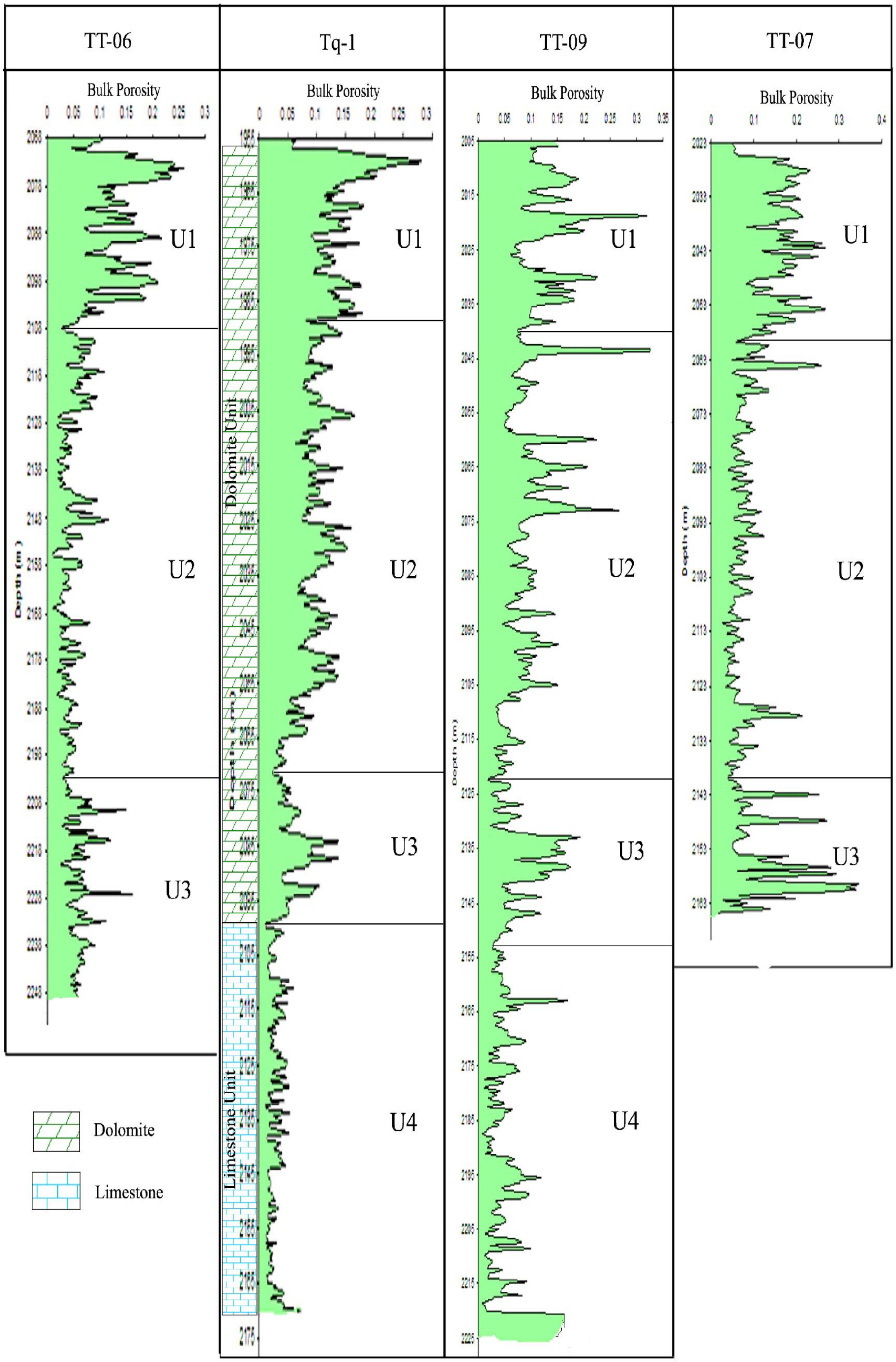



Fig (4-8): porosity units of all studied wells in Taq Taq Oil Field.

## 4.6: Water Saturation versus Porosity

If values for the bulk volume of water calculated at several depths in a formation, are constant or very close to constant this indicate that the zone is of a single rock type and at irreducible water saturation. A formation not at (Swirr) exhibit wide variations in (BVW) values.( Asquith and krygowski,2004).

To define the fluid production to be expected, good values of (Ø) and (Sw)are not sufficient, an evaluation of Swirr also needed since water production with or without hydrocarbons, is to be expected where Sw larger than Swirr.(Schlumberger,1972).

Buckles plot: is a graph of porosity versus water saturation, points of equal BVW form hyperbolic curves across this plot. Because the amount a formation water can hold by capillary pressure increase with decreasing grain size, the bulk volume of water also increase with decreasing grain size(Baker and Kuppe,2000).

With Sw and porosity plotted on linear scales, points of equal (BVW), plot as hyperbolic curves. A series of points plotting along a particular hyperbolic curve indicate that the bulk volume of water is constant and that the formation is close to irreducible water saturation. A reservoir in that condition would not produce water. As the amount of formation water increases the bulk volume water values become scattered from the hyperbolic curves and the formation has more water than it can hold by capillary pressure. The water saturation is no longer at or near, irreducible, so more water is produced relative to oil. (Asiquith and Kyrogwski, 2004).

Porosity versus Water saturation, Buckles plot in (U1) porosity unit of Tq-1, show that plotted data distributed around 0.01 hyperbolic and toward 0.005 and 0.02 which indicate change in bulk volume of water (BVW) and show movable water and irreducible . In unit (U2) porosity unit plotted data fall in 0.005 and 0.01 hyperbolic as constant value of BVW which indicate irreducible water and some data between them and moved toward 0.02 which show change in BVW and movable water. (U3) porosity unit, plotted data fall in 0.005 hyperbolic as constant line show irreducible water with some data toward 0.01 as changeable plotted data show movable water, but most part of (U4) show constant plotting on 0.005 hyperbolic show constant BVW and water in irreducible state in this unit with few movable water, fig(4-9).

TT-06, plotted data of (U1) and (U2) porosity units fall to more than two hyperbolic and distributed randomly show movable water, while in (U3) porosity unit some of them closed to 0.01 and few to 0.02 hyperbolic show movable water and most of the closed to 0.005 hyperbolic indicate irreducible water , fig (4-10).

TT-07, all plotted data of (U1) and (U3) show movable water where points are distributed in different zone between hyperbolic while some plotted data in (U2) plotted in 0.02 Hyperbolic as constant value which show irreducible water, but most of them movable water, Fig (4-11).

TT-09, plotted data on Buckles plot show that generally all data in (U1), (U2) and (U3) porosity units not closed to one hyperbolic as constant line value of BVW, while most plotted data in of (U4) closed to 0.005 and 0.01 hyperbolic which indicate irreducible water in this unit, fig (4-12).

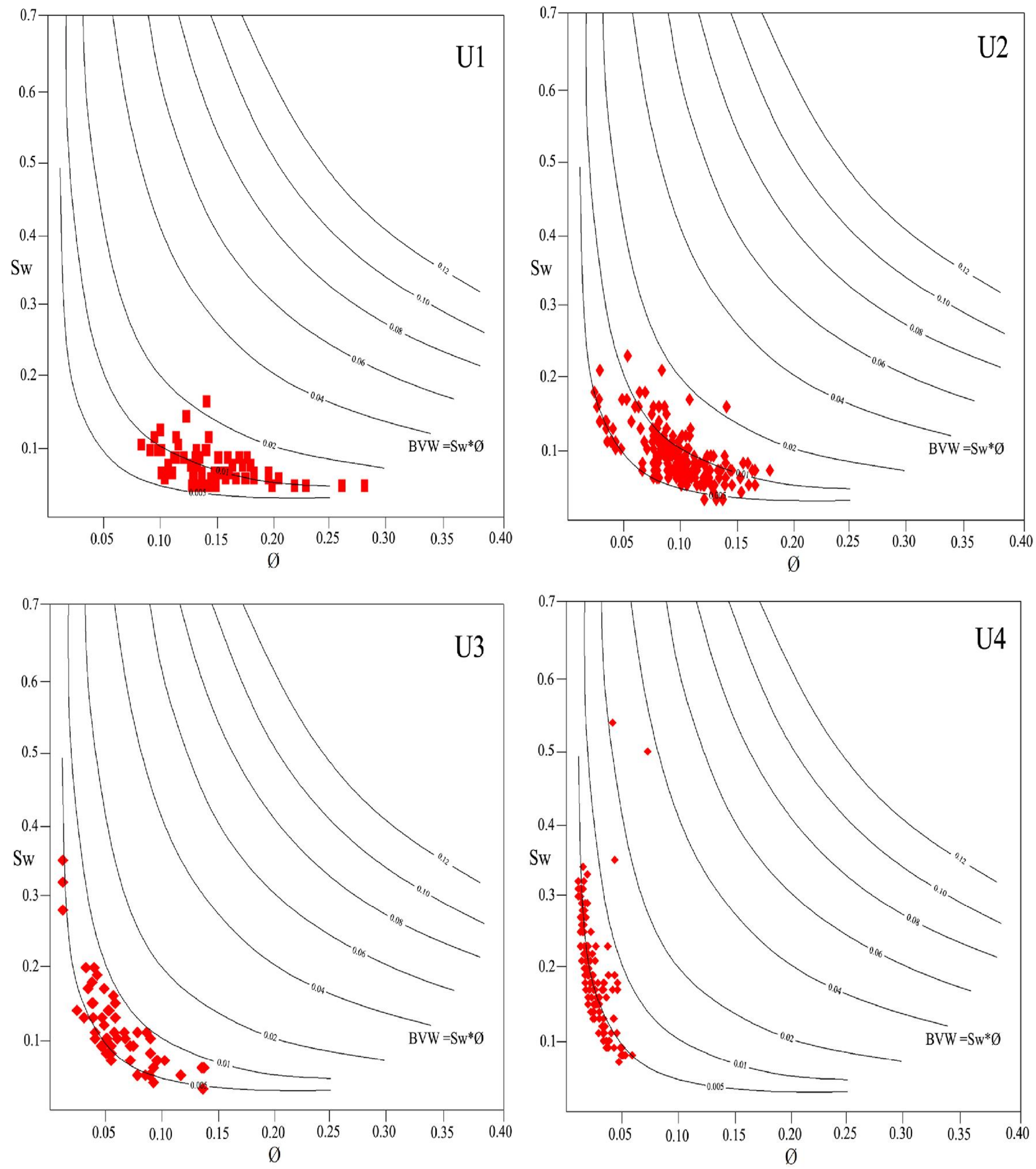



Fig.4-9: Buckles plot of Porosity versus water saturation of the four units of well Tq-1

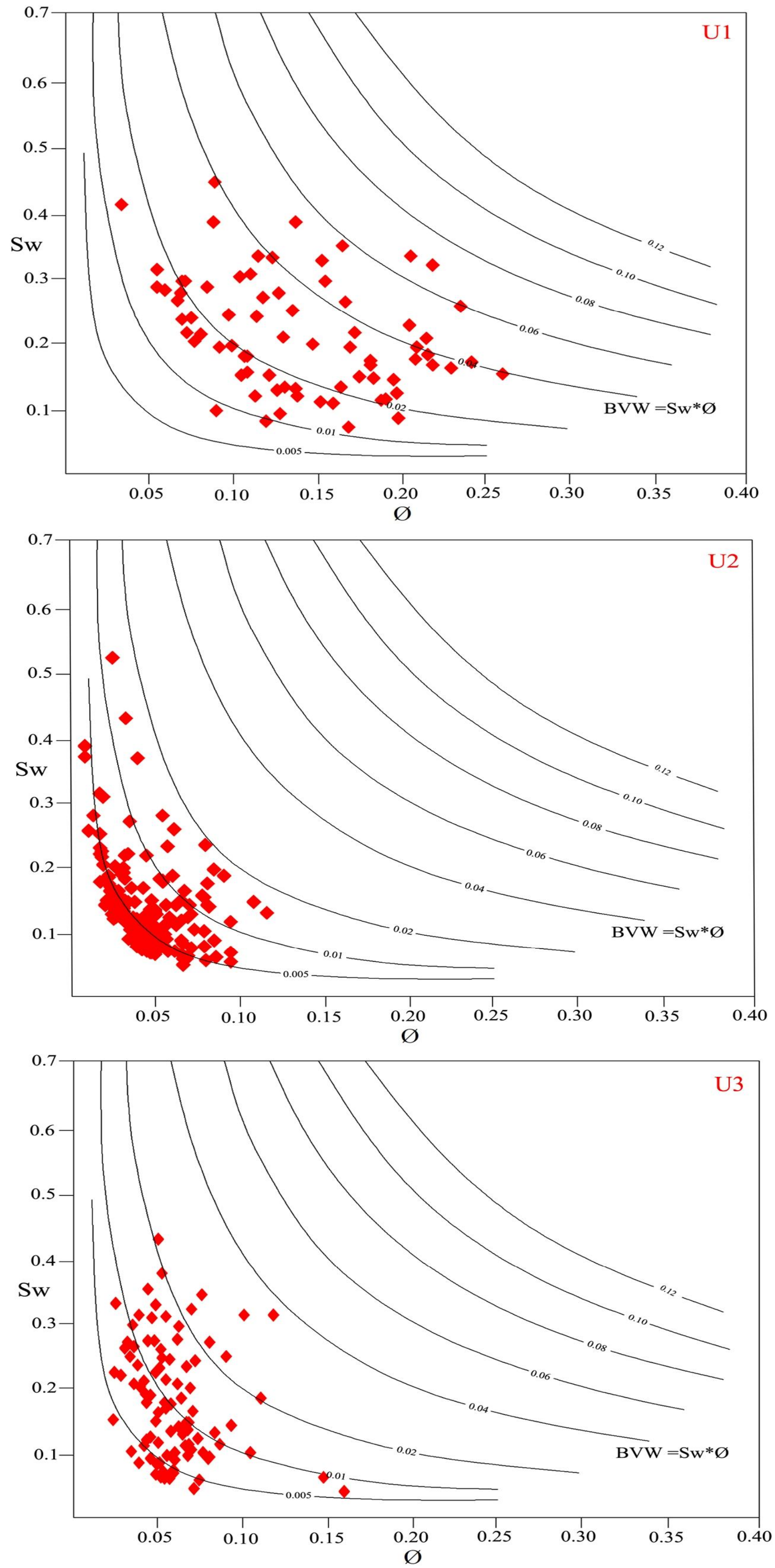



Fig.4-10: Buckles plot of Porosity versus water saturation of the four units of well TT-06

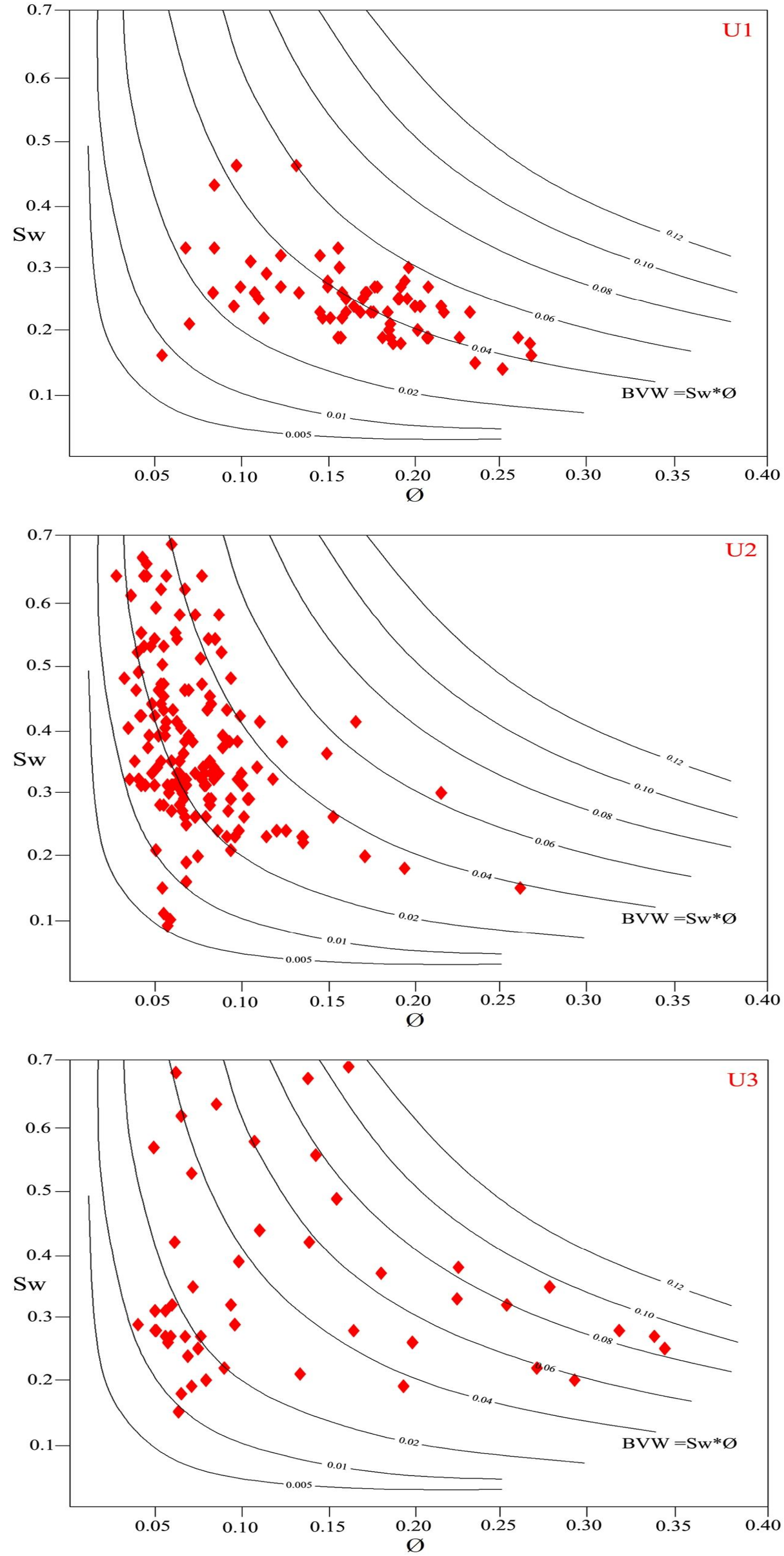



Fig.4-11: Buckles plot of Porosity versus water saturation of the four units of well TT-07.

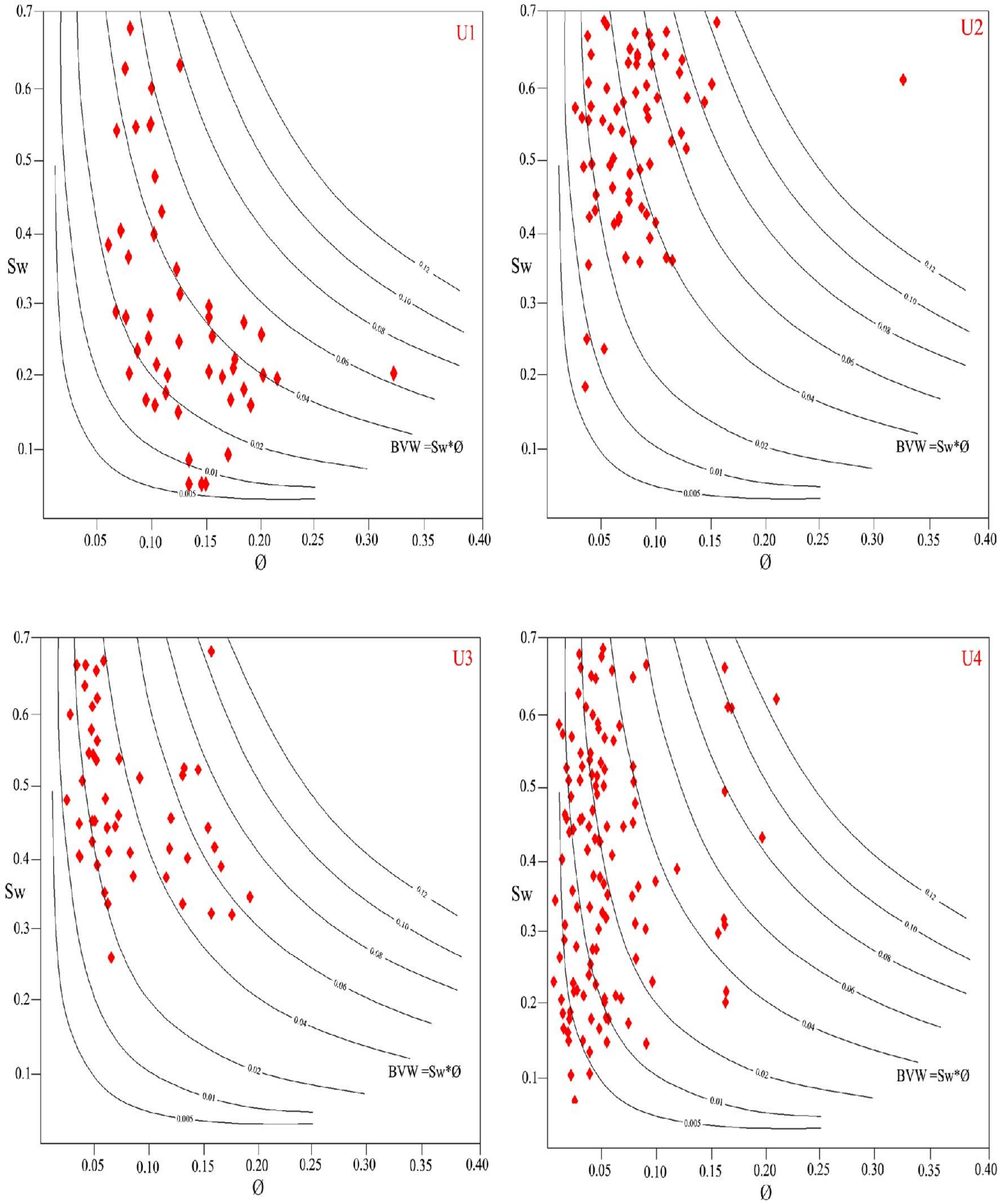



Fig.4-12: Buckles plot of Porosity versus water saturation of the four units of well TT-09.

## 4.7: Relation between Porosity and Permeability R35:

Is the relation between Porosity and air Permeability to indicate and show distribution of pore-throat size within the reservoir, (Pittman, 1992).

A graph of porosity versus permeability plotted showing the line of Isopore-throat radius, (Windland, in Pittman, 1992), the R35 method is a powerful petrophysical measurement similar to porosity and permeability with no genetic link to geologic model. (Lucia et.al, 1992; Lucia, 1995). The Windland equation is

**LogR35=0.732+0.588 log K (air)-0.864 log Ø core -------------------------** (4-14)

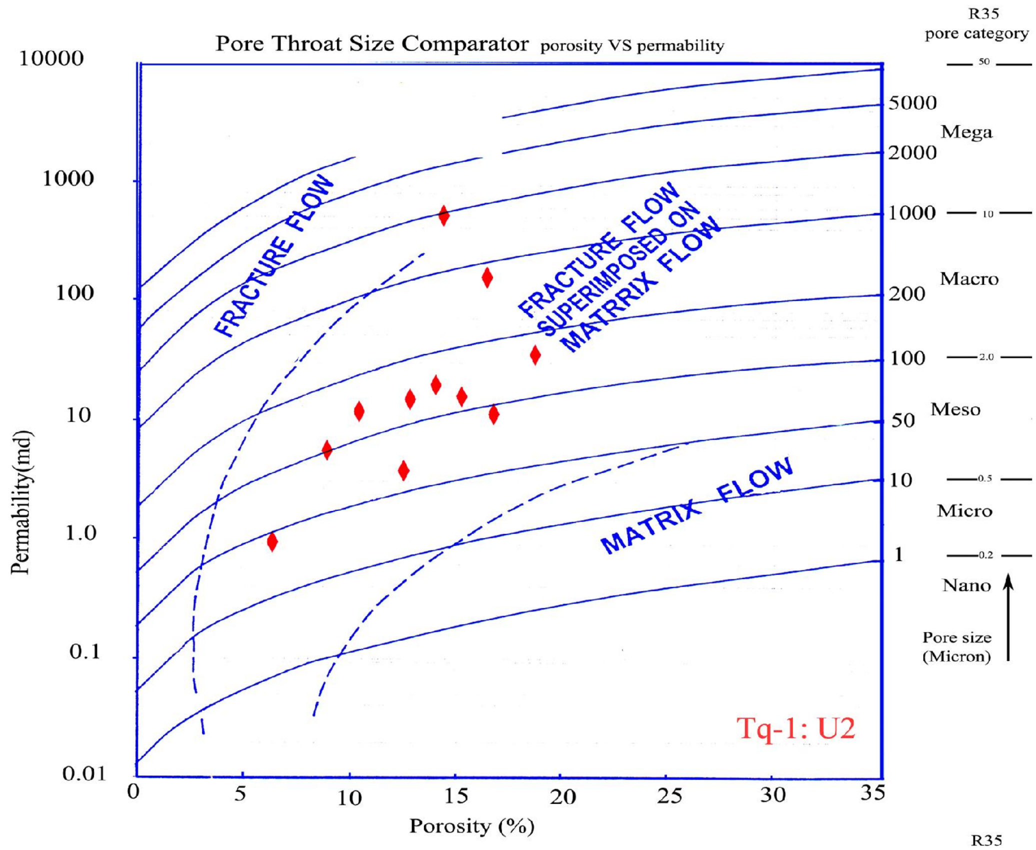
The R35 is the pore aperture radius corresponding to the $35^{th}$ , percentile of mercury saturation in a mercury porosimetry test, K(air) is the uncorrected air permeability in (md), and **Ø** is porosity in percentage, (Windland,in Pittman,1992).

R35 is not a function of pore size which is described visually, but a function of port size, which is difficult to be determined visually, (Martin, et.al., 1999).

Pore size varies within depositional rock fabric-fields, because grain size, and crystal size groups (classes), also have internal variation in sorting, packing, compaction, and digenesis that result in variation of flow, the value of R35 template is to identify the flow potential within each classes as a function of pore size, (Lucia,1999).

Plotting the relation between Kair in (md), and core porosity of Tq-1and TT-07 wells, Fig (4-13) shows that (U2) porosity unit in Tq-1 crossed data on middle field: fractured flow superimposed on matrix flow and one data on fracture flow. For unit (U1) porosity unit of TT-07, it shows fracture flow superimposed on matrix flow with two crossed data on matrix flow.

Because core data are not available in all intervals of the studied wells, this relation drowned between permeability derived from well log data by equation (4-5) and porosity derived from log (bulk porosity).



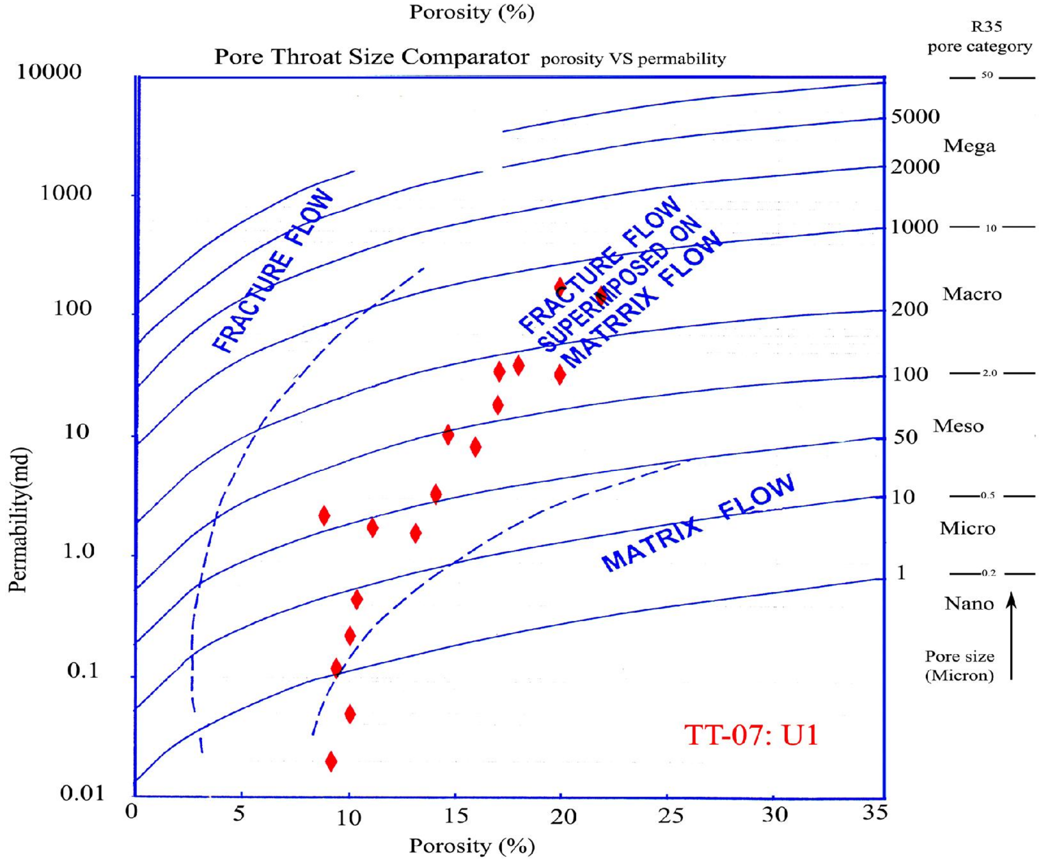



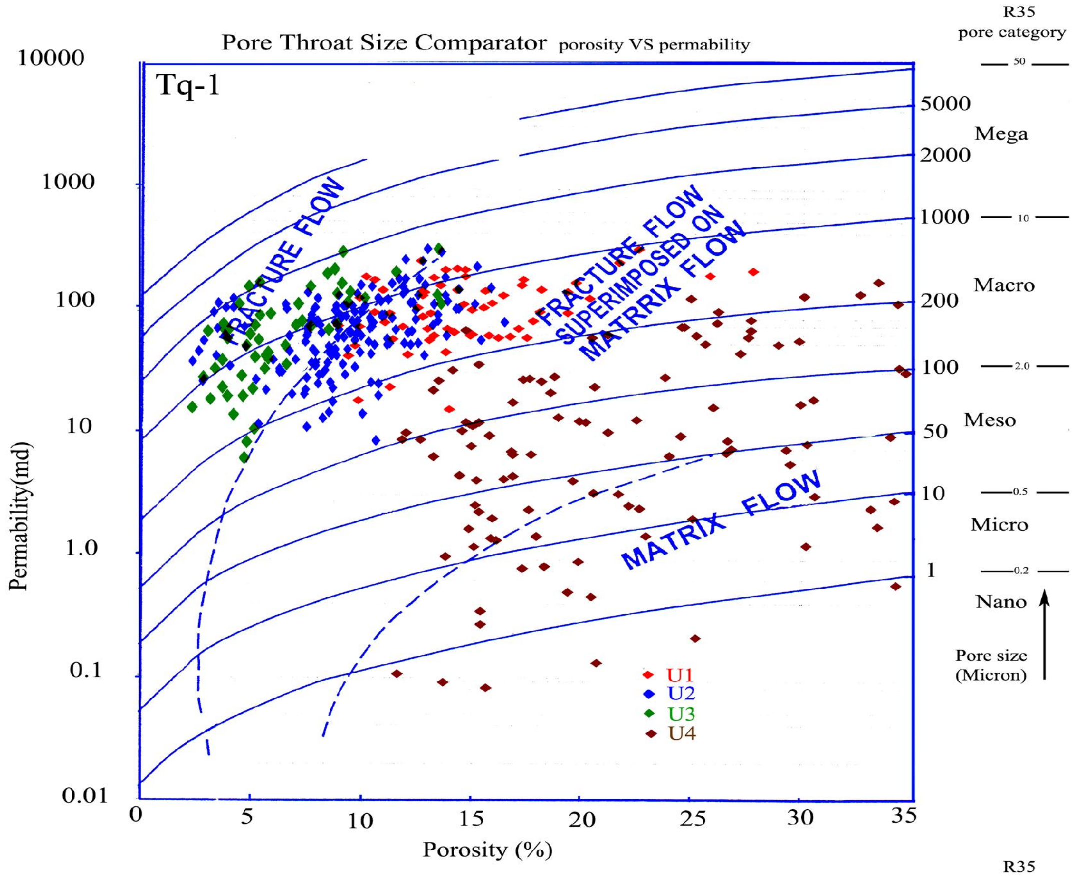

Fig.4-13: porosity and permeability relation(R35) of Tq-1 and TT-07
(core measured porosity and permeability)

Figure 4-14, shows the result of porosity-permeability relation (R35) for Tq-1 and TT-06 wells,Tq-1porosity-permeability relation of (U1) show fracture flow superimposed on matrix flow with few point in fracture flow with macro pores size is dominated, and few mega pore size. For (U2) porosity unit, it shows fracture flow and fracture flow superimposed on matrix flow with mega and macro pore size, (U3) porosity unit most plotted data fall in fracture flow with few fracture flow superimposed on matrix flow with mega and macro pore size, while (U4) porosity unit have fracture flow superimposed on matrix flow and matrix flow pore size range between macro to nano size, with meso to macro dominant class.

In TT-06, Porosity-Permeability relation in (U1) porosity unit show fracture flow superimposed on matrix flow with few points in matrix flow with macro to micro pores size is dominated. (U2) porosity unit for most parts are fracture flow and fracture flow superimposed on matrix flow with mega and macro pore size, (U3) porosity unit most plotted data fall in fracture flow and others to fracture flow superimposed on matrix flow with macro, mega and meso pore size.

Porosity-permeability relation (R35) of TT-07 and TT-09 wells is shown in Fig (4-15). In TT-07, Porosity-Permeability relation in (U1) porosity unit show fracture flow superimposed on matrix flow and matrix flow with macro, meso and micro pores size. In (U2) porosity unit most parts show fracture flow superimposed on matrix flow with few points of fracture flow and matrix flow. Pores type range from macro to meso to micro size.

In (U3) porosity unit, plotted data fall in fracture flow and others to fracture flow superimposed on matrix flow and same data in matrix flow with macro, meso and micro pore size.



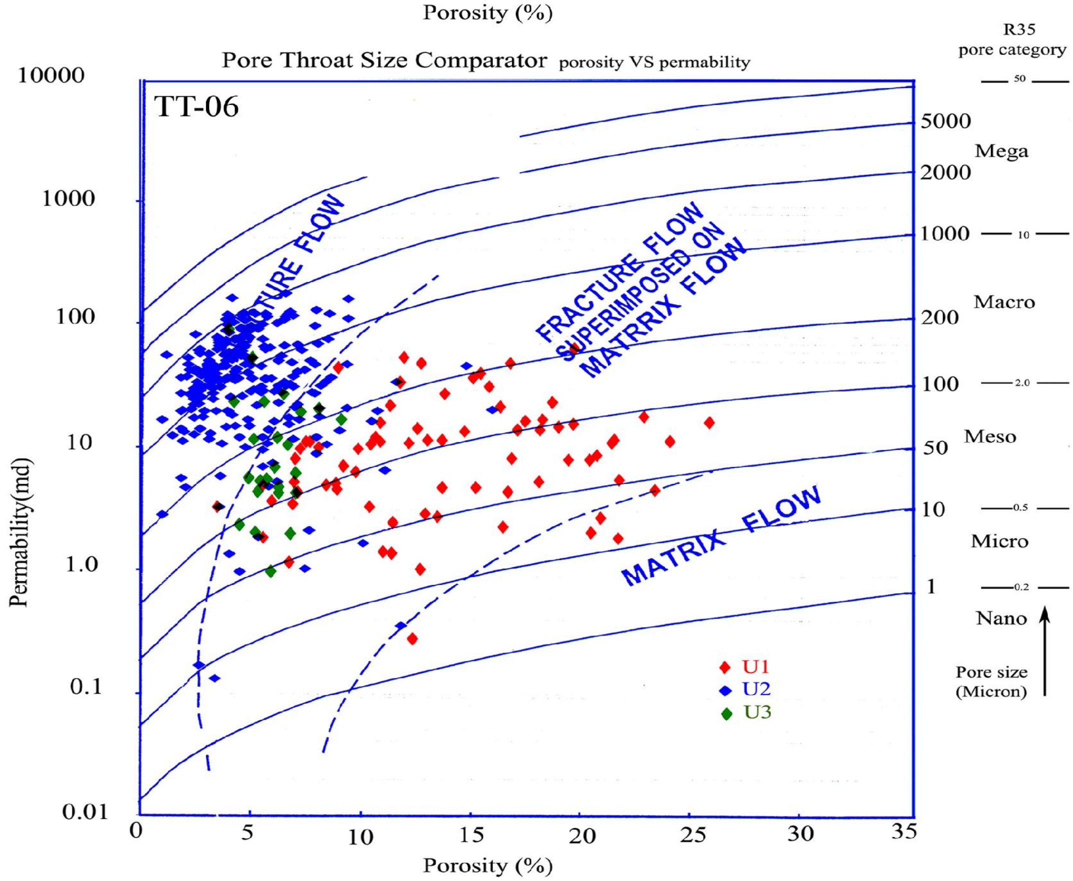




Fig.4-14: porosity-permeability relation(R35) of Tq-1 and TT-06

In TT-09, Porosity-Permeability relation in (U1) porosity unit show fracture flow superimposed on matrix flow and matrix flow with macro, meso and micro pores size, (U2) porosity unit most parts are fracture flow superimposed on matrix flow with few of fracture flow and matrix flow, pores have macro, meso, micro and nano size.

(U3) porosity unit, plotted data fall mainly in fracture flow and fracture flow superimposed on matrix flow and some data in matrix flow with macro, meso and micro pore size.

In general it is found that the general characters of each unit in all the studied wells are slightly different (Table 4-2).

Table 4-2: type of flow and pore size category in the studied wells.

| Unit | Type of flow | Pore size category range |
|---|---|---|
| U1 | fracture flow superimposed on matrix flow, fracture flow and matrix flow | Mega-Micro |
| U2 | fracture flow and fracture flow superimposed on matrix flow | Mega-Micro |
| U3 | fracture flow and fracture flow superimposed on matrix flow | Mega-Micro |
| U4 | fracture flow superimposed on matrix flow and matrix flow | Macro-Nano |

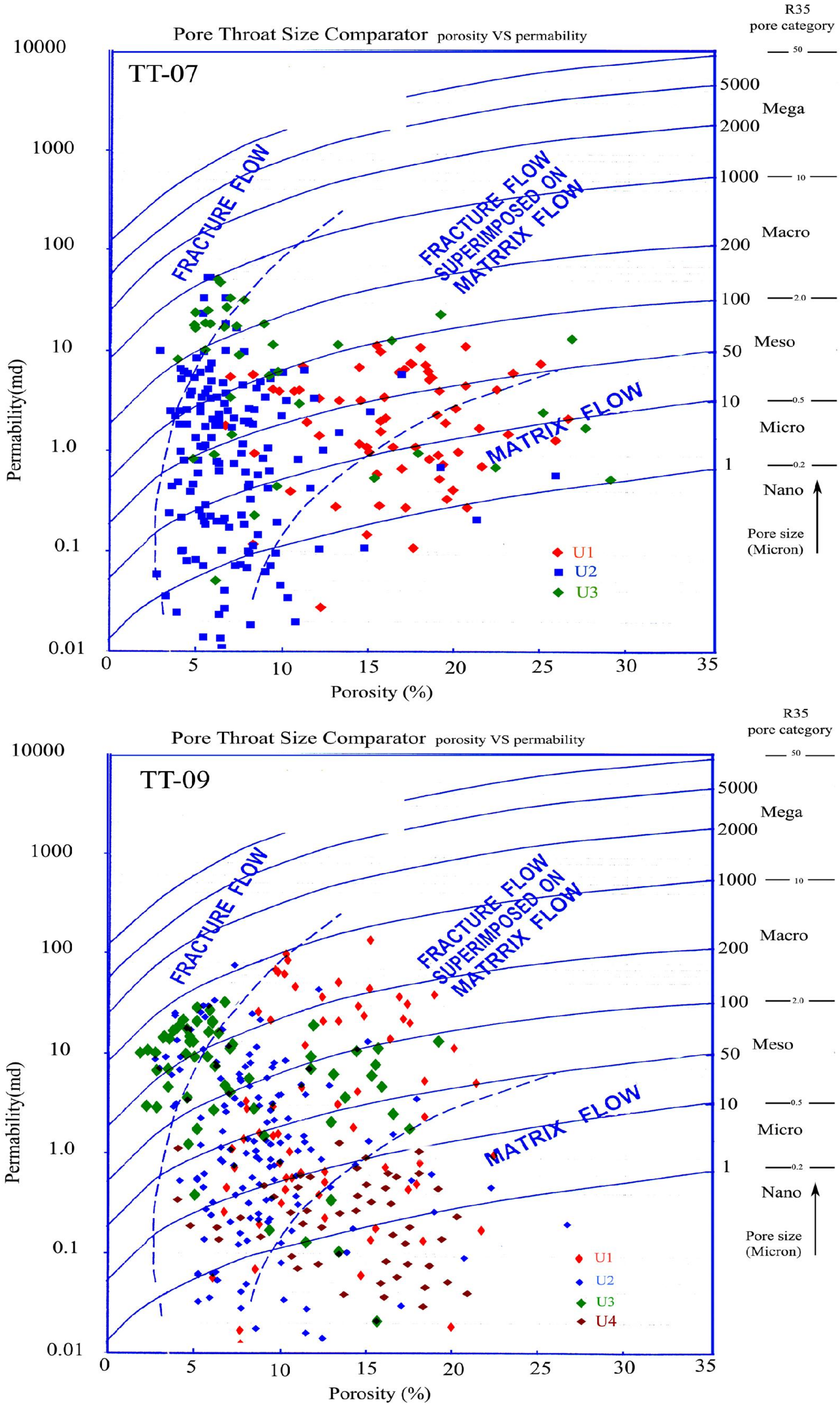



Fig.4-15: porosity-permeabilit relation(R35) of TT-07 and TT-09

### 4.8: Fracture Reservoir

Fractures represent any of series of discontinuous features in rocks such as joints, faults, fissures and bedding planes, have positive (when fractures are open and uncemented ) or negative (fractures cemented or totally mineralized) effect on the flow properties of the reservoirs that contain fractures(Torres,2002).

Nearly all hydrocarbon reservoirs are affected in some way by natural fractures in carbonate reservoir, help create secondary porosity and promote communication between reservoir compartment, however these high permeability conduits some times short-circuit fluid flow with in reservoir, leading to premature water or gas production and making secondary recovery efforts ineffective (Bratton et al, 2006).

With increasing the fracturing intensity, the system cementation exponent diminishes; tend to increase the secondary porosity and fracture width and permeability is greater when they are close to fault (Pulido et al, 2007).

Fracturing develops especially where fault and fold are intimately associated, the most common causes of fracturing are Buckle of folding due to forces parallel to layering of the rock, bending folding , is a consequence of forces perpendicular to the rock layering , Faulting which discrete numbers of fracture system with another factors like , stylolitization , weathering(North,1985).

In petroleum exploration and production, fractures are one of the most common and important geological structures, for they have a significant effect on reservoir fluid flow (Martinez et al, 2005).

The Upper Qamchuqa Reservoir in Taq Taq Oil Field in present core samples show different type of fractures with different abundance and vertical, inclined and horizontal fractures, Fig(2-6,B) , (2-8,A) and (2-10,C and E)with macro and micro size , some of them filled with cement fig(2-10,B)and others open and show free oil movement fig(2-10,A).

These fractures resulted from folding or bending of Upper Qamchuqa layers and numerous faulting which affected Upper Qamchuqa reservoir as shown in Fig(1-2,A and B).

### 4.8.1: Fractures Identification from Well Log

Natural fracture system can be identified and evaluated by several techniques with the most common being core analysis and well log analysis (Martinez et al, 2005).

The most common logs which are used in identification of fractures are gamma ray log, density and neutron logs.

**Gamma Ray Log**

In fractured reservoir an increase in the gamma ray without concurrently higher formation shaliness is frequently recognized as an increase in the deposition of uranium salts along the discontinuity surfaces of fractures or with the crack it self(Fertil, 1980).

**Density and Neutron Log**

Since the density and Neutron logs are measures of total reservoir porosity in fluid saturated formations, therefore in the presence of fractures the density and neutron logs will decrease the recorded bulk density and neutron porosity (Torres, 2002).

**Fracture Index**

The fracture index of Upper Qamchuqa Reservoir shown in Fig (4-3), show great separation of Sonic (Primary) Porosity form (N-D) bulk porosity especially in upper part of dolomite unit or in (U1). Porosity of this unit indicates secondary porosity, mainly fractures in all wells.

### 4.8.2: Fractures and Secondary Porosity Identification from Image Log

Borehole image logs have been widely used for detecting fractures and have become the most important tool for imaging sub seismic features (Wu and Pollard, 2002)

Fractures interpreted from electrical image logs are identified by contrasts in conductivity between fractures and the adjacent borehole wall (Davatzes and Hickman, 2005).

Borehole images used to differentiate open fractures from healed fractures, because the mud is conductive, an open fracture appear as dark trace on an electrical borehole image, note that shale filled could also appear as dark traces, such as gamma ray log can help resolve such situation, if fractures filled with cement such as calcite, anhydrite or quartz the fracture might appear as resistive (white) traces on the electrical image (Seiler et al, 1994) and (Asquith and Krygowski, 2004).

Natural and induced fractures can be differentiated in some cases, naturally fractures can occur as on or more fracture set, each with a distinct orientation (Davatzes and Hickman, 2005).

Induced fractures are commonly near vertical, and have well defined strike azimuth, which can cut across beds of different lithology and perpendicular to oval elongation of borehole (Higgins, 2006).

Secondary porosity (vug) which is filled completely or partially with calcite cement appear as light colored objects ringed by darker colored conductive mineral, the open vug appear as features which are darker than the secondary matrix, the ability to image reservoirs with secondary porosity allow analyst to determine the density and conductivity of the vugs (Seiler,1994).

The stylolite appears as dark, irregular features in the electrical image log (Schlumberger, 2002).

In Taq Taq Oil field, TTOPCO conduct image log survey (EMI or XRMI model) to newly drill well which include TT-06, TT-07 and TT-09. In this study it is used as a tool to identify fractures (fractures zone, natural and induced fractures, open and filled fractures, connected and separated or disconnected fractures), and separation of fractures from shale and identification of sedimentary structures if present as well as opening and filled vug pores.

The result of those survey for Upper Qamchuqa reservoir show that in (U1) porosity unit characterized by condense and intensive fractures zone, naturally open fractures with some are filled by secondary mineral i.e. calcite, as well as open and filled vugy pores appear in the some porosity unit, this zone of fractures present in all studied well which causes enhanced reservoir properties and make best reservoir unit in Upper Qamchuqa Reservoir of Taq Taq Oil Field. For TT-06, the intensity of fractures in (U1) porosity unit are more and intensive as compared with other wells especially TT-07 and TT-09, (Fig.4-16) and(4-17 ), while in Tq-1 this zone can be appear in fracture index or sonic-bulk porosity curve separation which indicate present of fracture zone in Tq-1 as well as another wells (TT-06, TT-07 and TT-09 ), occurrence of this fractures supplied by fracture index as shown in Fig(4-3 ).

In (U2) Porosity Unit, the upper part of this unit is characterized by presence of intensive, connected natural, open fractures but distribution or effect of them are less if compared with (U1) is porosity unit as shown in Fig(4-18) and Fig(4-19,A) and lower part of this unit is characterized by non fractured or dense matrix zone in TT-06 .

In (U3) porosity unit, this unit characterized by intensive and high distribution of fractures in lower part of dolomite unit in Upper Qamchuqa reservoir especially in TT-06 and TT-07, Fig(4-19,B) and (4-29,A) which separated (U2) porosity units of dolomite unit from (U4) porosity unit in limestone unit in Tq-1 and TT-09.

Another important point is confusion of fractures with occurency of shale in Upper Qamchuqa Reservoir by using image log, this point solved by using Gamma Ray log as indicater of presence of shale especially presence of Upper Sarmord Formation in TT-09 can by recognized by dark laminated colored in light colored resistive of limestone as shown in fig(4-120,B ),

Another tool to solve this problem is fracture index or Sonic-Bulk porosity separation curve use as tool to separation fractures from laminated shale.

In general Upper Qamchuqa Reservoir characterized by presence of intensive and condenses fractures especially in (U1) and (U3) of dolomite unit and less abundant or effective in (U3) in dolomite unit and (U4) porosity unit of the limestone unit which causes development reservoir character especially permeability and causes fracture flow and fracture flow superimposed by matrix flow in reservoir especially in dolomite unit, so one can consider Upper Qamchuqa reservoir in Taq Taq Oil Field as Fractured Reservoir.

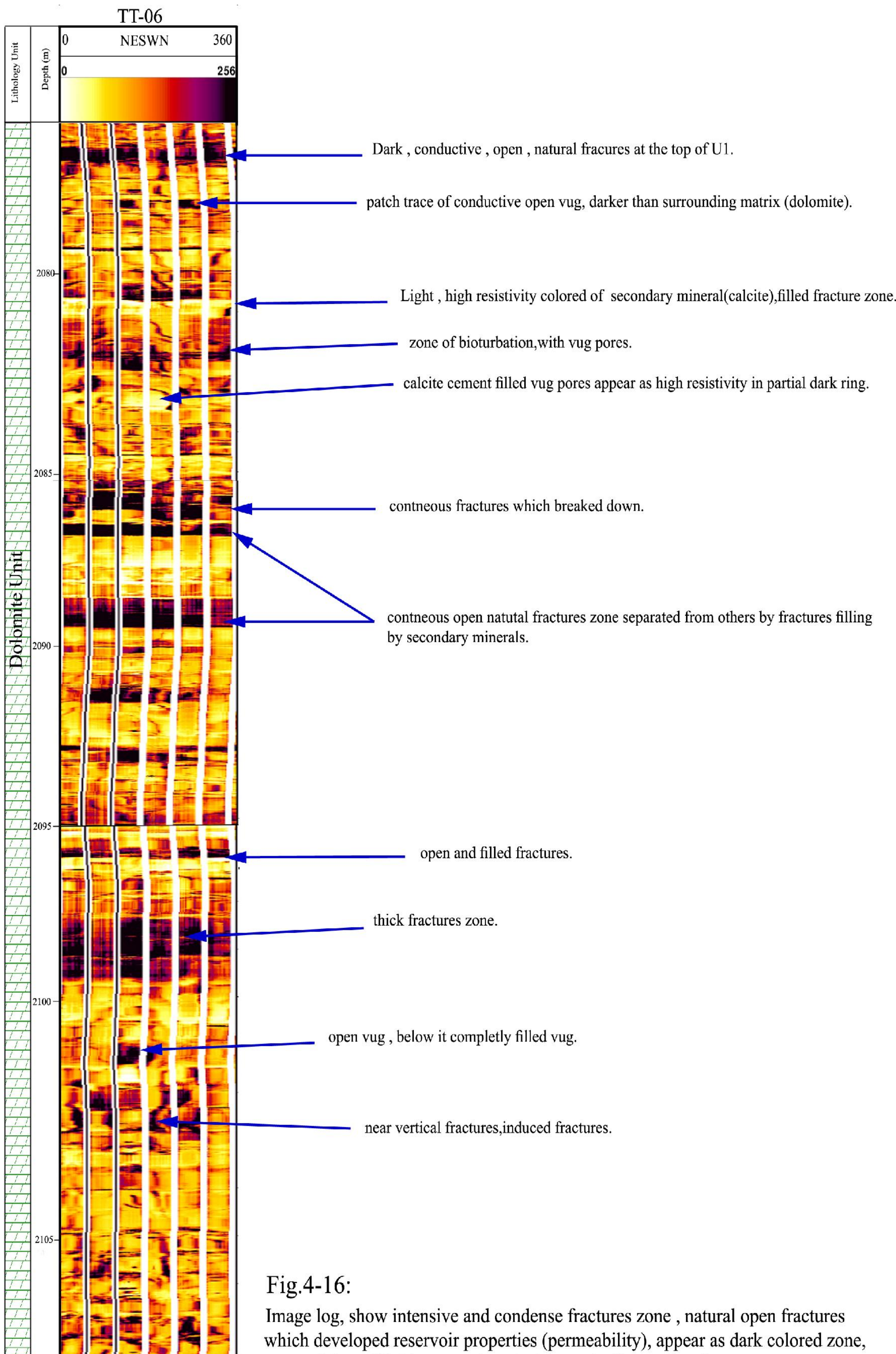



Fig.4-16:

Image log, show intensive and condense fractures zone , natural open fractures which developed reservoir properties (permeability), appear as dark colored zone, same of them filled by secondary calcite ,take light colored.
open and filled vug showen with bioturbation , U1 reservoir unit,TT-06.

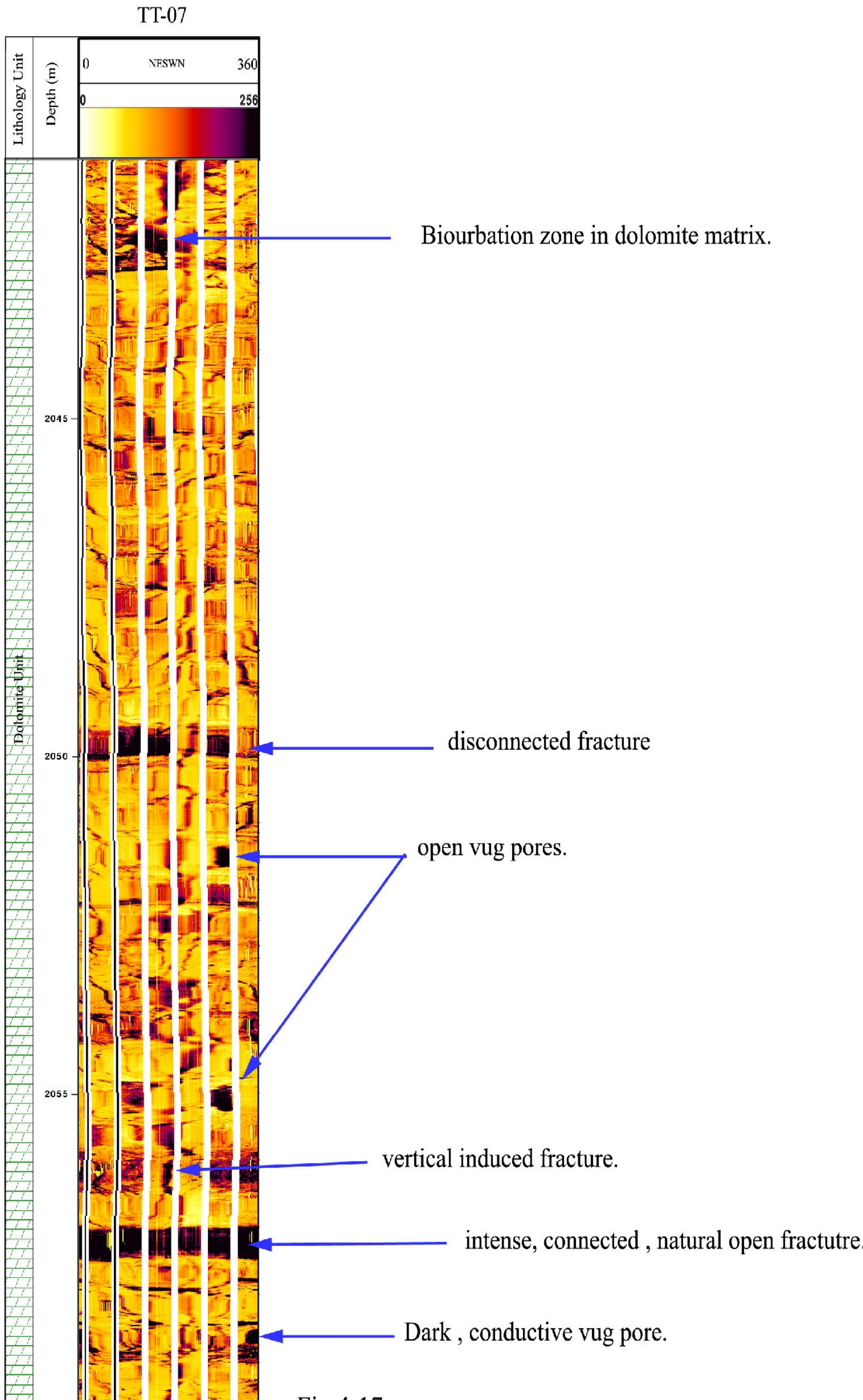



Fig.4-17

Image Log, show open natural fractures and vup pores in (U1) Porosity Unit ,TT-07

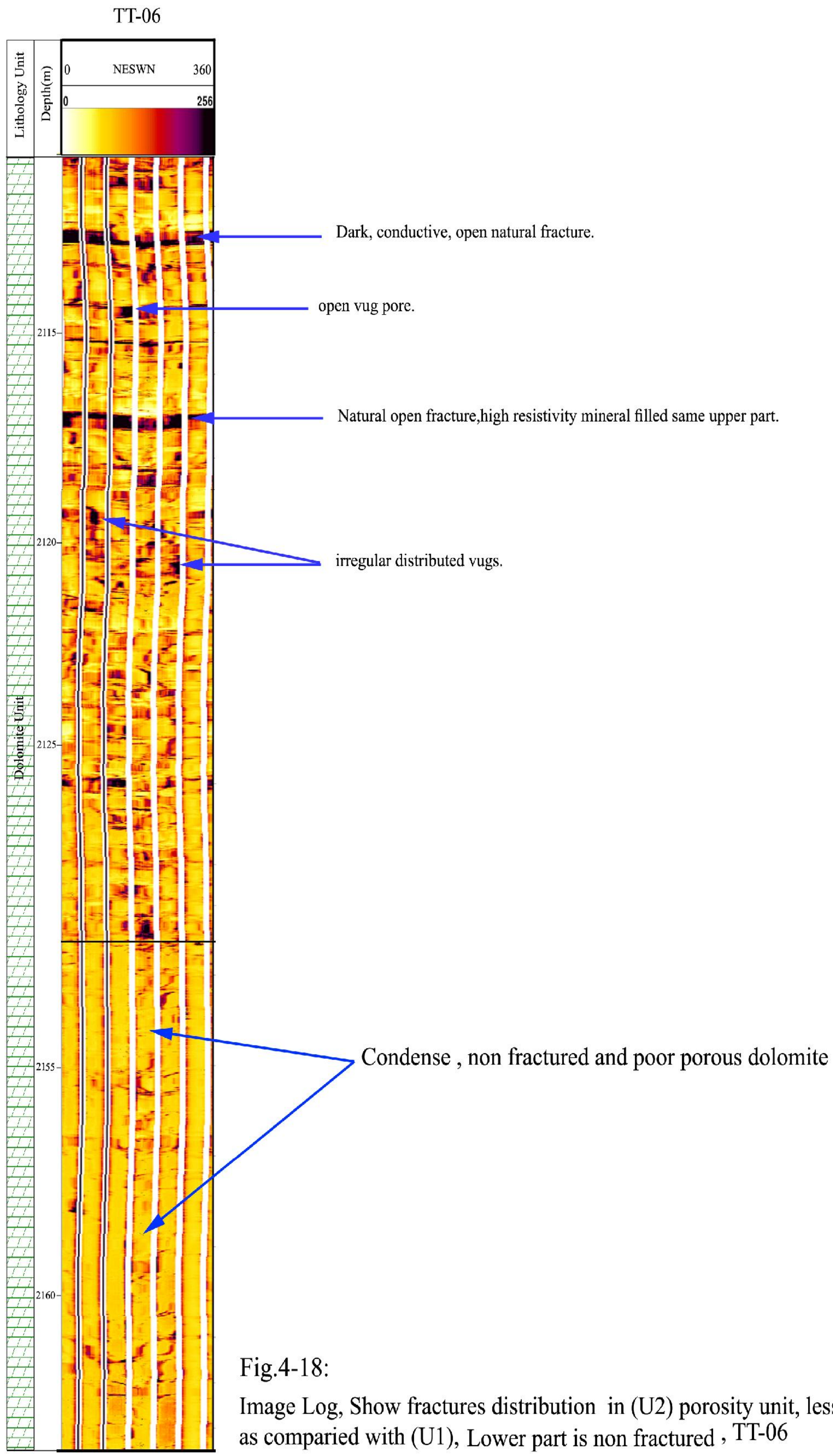



Fig.4-18:

Image Log, Show fractures distribution in (U2) porosity unit, less dense as comparied with (U1), Lower part is non fractured , TT-06

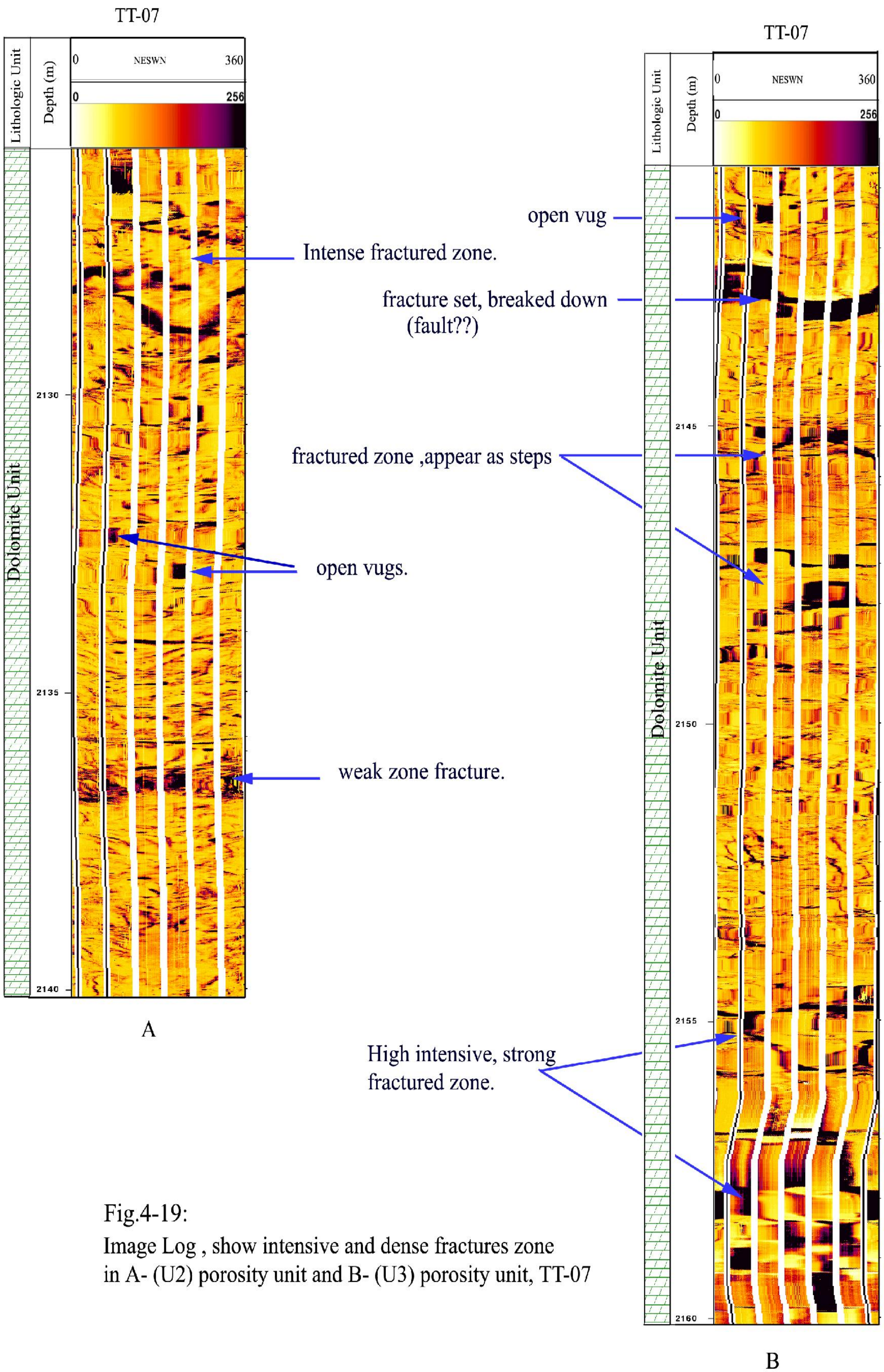



Fig.4-19:
Image Log , show intensive and dense fractures zone
in A- (U2) porosity unit and B- (U3) porosity unit, TT-07

TT-09

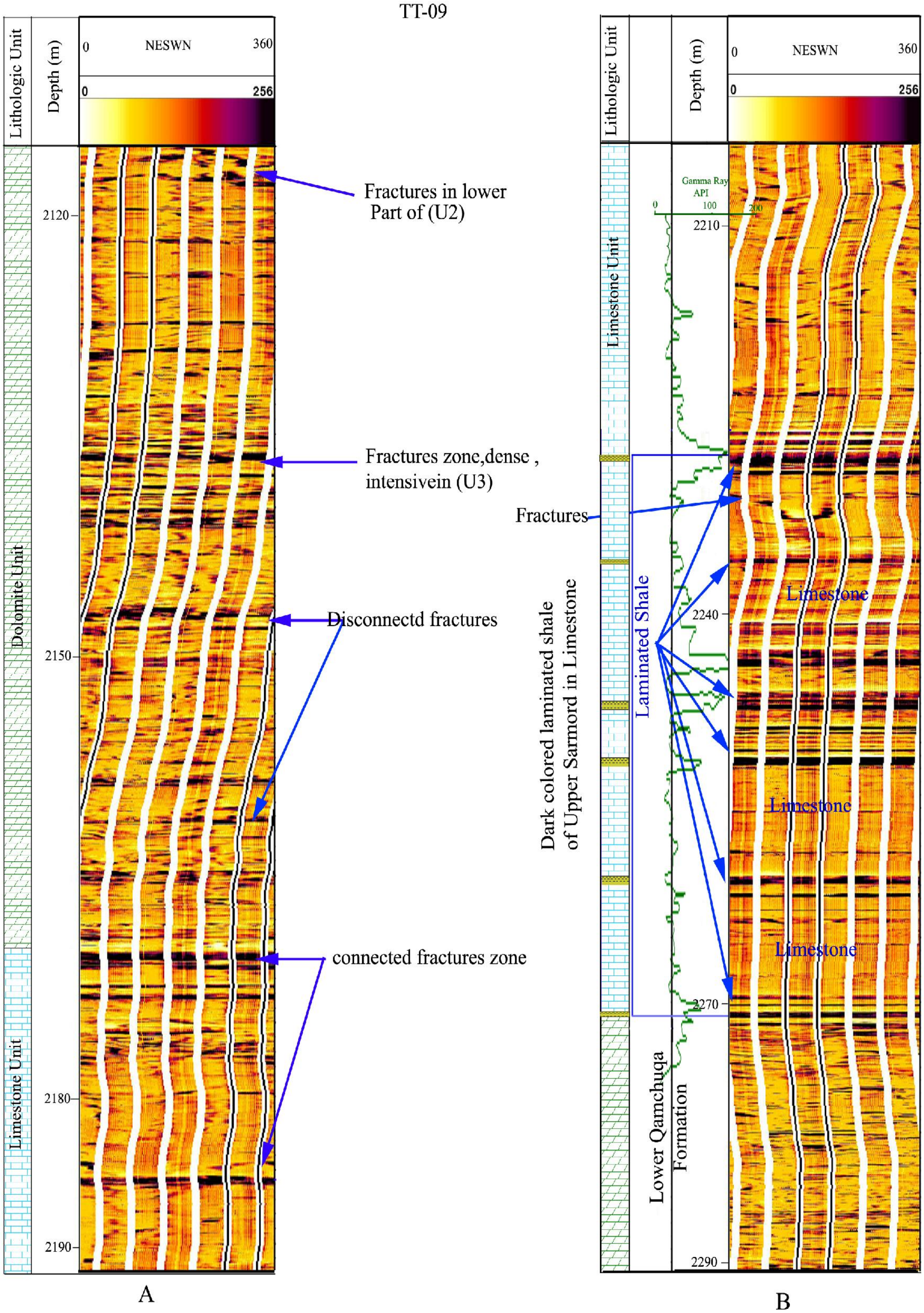



Fig.4-20:

Image Log, A- Show condense and intensive fractures zone in lower part of (U3) causes development reservoir properties,TT-09

B- Show lamniated shale in limestone of Upper Sarmord ,TT-09

## 4.9: Reservoir Units

Based on well log analysis and reservoir evaluation of Upper Qamchuqa reservoir, petrophysical interpretation like porosity, water saturation, hydrocarbon saturation and bulk volume of oil and water with porosity versus water saturation and porosity permeability relations (R35), and with estimation of porosity cut off and water saturation cut off, net pay (productive oil)in each unit is measured .

To indicate water saturation Cut off, drawing the relation between water saturation and porosity(Fig.4-21) Bulk porosity and water saturation Cut off reading show water saturation Cut off in Upper Qamchuqa reservoir equal to 34%(0.34) applied to studied well to estimation of productive oil zone in meters.

Net Pay=Sum. Meters which ∅≥ ∅ Cut off and Sw ≤ Sw Cut off

Net Pay/ Gross ratio = Net pay/ total thickness in meters (in: Hussein, 2008).

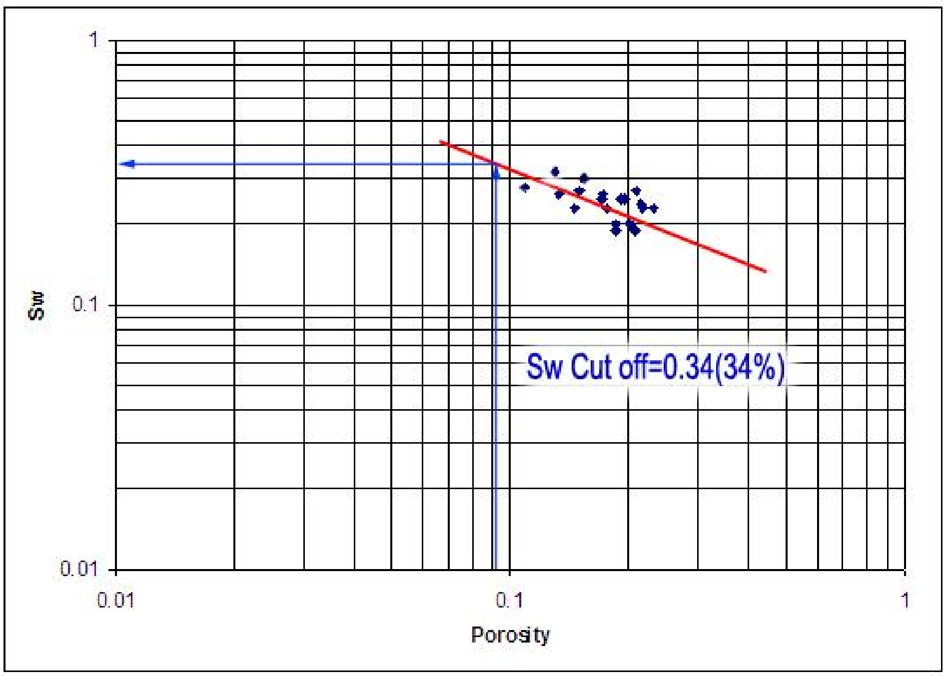



Fig.4-21: porosity-water saturation, show water saturation Cut off.

The Upper Qamchuqa reservoir can be dividing into three reservoir units:

### 4.9.1: Upper Reservoir Unit (RU1)

This unit composed of dolomite (coarse, fine and medium) and dolomite limestone of dolomite unit, its thickness in TT-06 is 31 m (2071-2102 m) , in Tq-1 is 42m (1957-1999m), and in TT-07 is 43.5m (2026 -2069.5) (Fig.4-22). It has average porosity of 0.15 (15%). This unit is saturated with water by 18% and 82% by oil (residual and movable) which average bulk volume of oil is about 0.12 and average bulk volume of water is 0.053. Mostly fractured imposed on matrix flow with some parts of matrix flow which indicate high porosity and permeability relation as well as high porosity and low permeability relation.

Thickness of pay zone in this unit is 25m in TT-06 in the Northwest of the Taq Taq oil field increased to 39.5 m in Tq-1 and become thicker in the Southeast of the field which reached 41m in TT-07. This unit consider best and productive unit in the Upper Qamchuqa reservoir in the Taq Taq oil field.

### 4.9.2: Middle Reservoir Unit (RU2)

This unit mostly composed of coarse crystal of dolomite, medium and fine dolomite also present with dolomitic limestone. Its thickness in TT-06 is 123.5 (2102-2225.5m) only 4m of this interval is represent pay zone. In Tq-1 is 83m (1999-2082m) which 35.5 is productive zone. Its thickness in TT-07 about 85.5m (2069-2154.5m) only 5m of this unit productive. Its average porosity changed from the field, in TT-07 is 0.073 and in TT-06 is 0.055 while in Tq-1 is 0.09, appear that porosity value controlled pay zone distribution in the field, in the Tq-1 42% of this porosity is productive while in TT-07 is 5.8% TT-06 is 3%.The general oil saturation in this unit equal to 70% and 30% of this unit is water saturation with average bulk volume of oil is 0.05 and average bulk volume of water is 0.015.This unit characterized by presence of fractured imposed on matrix flow with some parts of fracture flow type.

### 4.9.3: Lower Reservoir Unit (RU3)

This unit composed of coarse dolomite of the dolomite unit. Its thickness in TT-06 is 24.5m (2225.5-2250m); thickness of pay zone is 1.5m. In Tq-1 is 16m (2082-2098m), which 3m of this interval is pay zone, and in TT-07 is 10.5m (2154.5-2165m), net pay in this unit is 2m. It has average porosity 0.11 (11%) with 20% of this unit is saturated by water and 80% is saturated by oil (residual and movable) with average bulk volume of oil is about 0.06 and average bulk volume of water is 0.028. water is movable in most portion. Mostly fractured which indicate fracture effect on this unit. This unit make weak reservoir unit in lower part of dolomite unit in Upper Qamchuqa Reservoir.

The interval which located below lower reservoir unit (RU3) considered as non reservoir unit (NR) because have poor value of porosity, all porosity value below porosity cut off, mostly cemented pores and dense limestone units, only present in Tq-1, in TT-07 and TT-06 not penetrated.

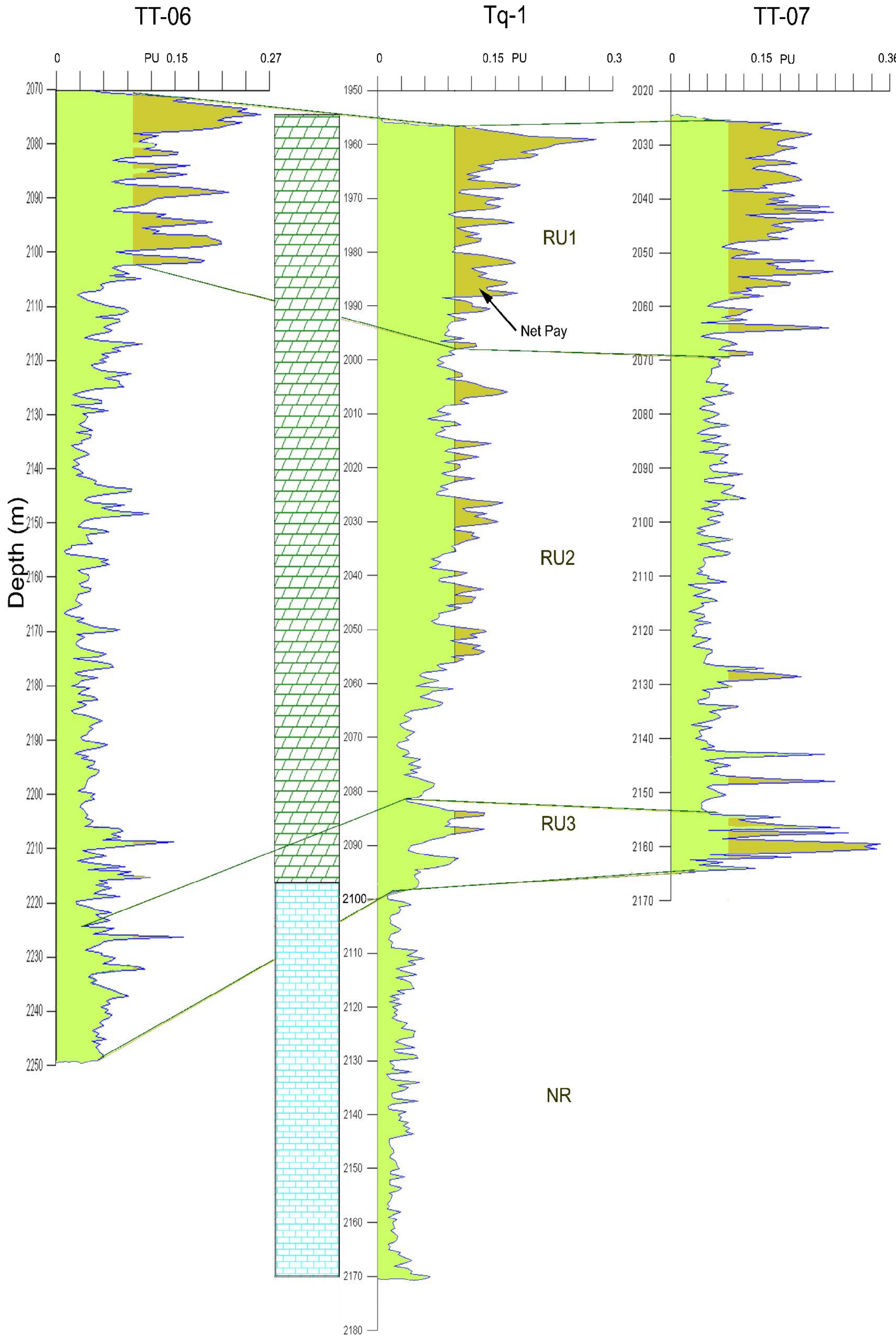



Fig.4-22: Reservoir units in studied wells of Taq Taq Oil Field.

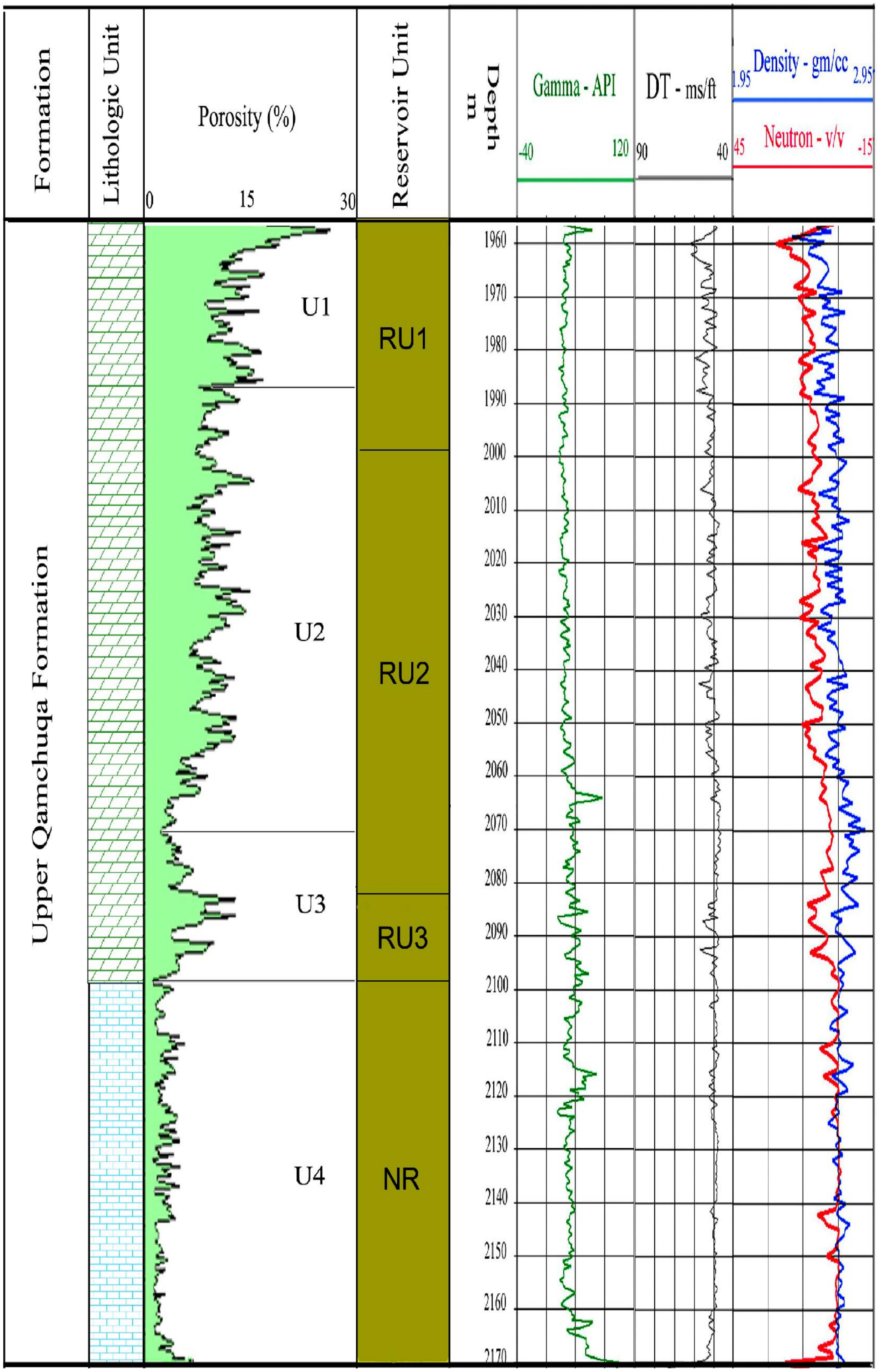



Fig.4-23: Reservoir units and other Petrophysical parameters of well Tq-1.

# Chapter Five

# Conclusion and Recommendations

## 5.1: Conclusion

The study of the Upper Qamchuqa Formation from four studied wells of Taq Taq oil field using core, cutting, and different type of log analysis resulted in several points which could enhance our understanding and evaluation of the reservoir characters of Upper Qamchuqa Formation. These points include:

**1-** The Upper Qamchuqa Formation is divided into two basic lithologic units from top to bottom: Dolomite Unit (D) and Limestone Unit (L) with minor intercalation of Dolomitic Limestone.

**2-** Three groups of microfacies were identified which comprise three limestone microfacies, Five Dolomitic Limestone Microfacies and Three groups of Dolomite Microfacies. Milliolid-Textularid Wackstone ($L_1$), Orbitulina Bioclastic Wackstone-Packstone ($L_2$) and Rudist Bioclastic Wackstone-Packstone ($L_3$) represent Limestone Microfacies. Milliolid-Textularid DoloWackstone ($DL_1$), Porphyrotopic Foraminiferal Clayey DoloWackstone ($DL_2$), Pelliodal-Bioclastic DoloWackstone-DoloPackstone ($DL_3$), Orbitulina DoloWackstone-DoloPackstone ($DL_4$) and Bioclastic Foraminifera DoloBound stone ($DL_5$) are represent Dolomitic Limestone Microfacies. Coarse crystalline Dolomite ($D_1$), Medium crystalline Dolomite ($D_2$) and Fine crystalline Dolomite ($D_3$) with sub division of them, Fine to Medium dolomite ($D_4$) and polymodal dolomite ($D_5$) are representing Dolomite Microfacies.

**3-** Dolomitization and Dissolution are two dominant types of diagenesis processes which affect the Upper Qamchuqa Formation and developed reservoir porosity, among which intercrystalline, vug and moldic pores, are the most common others digenetic processes which has negative effect on reservoir characters are cementation and compaction.

**4-** Analysis of Sonic, Density and Neutron logs supported by gamma ray log as well as M-N plot show that Upper Qamchuqa reservoir consist of dolomite , limestone and dolomitic limestone lithologies.

**5-** The Upper Qamchuqa reservoir can be divided into four porosity units from top to bottom (U1, U2, U3 and U4), in all studied wells first porosity unit (U1) represent best porous and potential unit with differences in thickness.

**6-** Average porosity values in most these units range between 5 - 15%, and average effective porosity range between 11 -20% which indicate good reservoir quality.

**7-** Oil Movability of these units especially in first porosity unit (U1) produced oil with movable water except in TT-09 which produces water with out oil.

**8-** Based on measured value of permeability (K) from log data used with porosity in R35 relation indicated that type of flow is dominantly of fractures flow and fracture flow superimposed on matrix flow and pore size of the potential units range from Mega to Macro to Meso pore size.

**9-** Depending on the relation between primary-bulk porosity relation (fracture index) and study of image log with macro description of cores, it appears that Upper Qamchuqa reservoir is greatly affected by fractures especially (U1) and (U3) porosity units , so this reservoir consider as fractured reservoir.

10- Depending on the porosity cut off, water saturation cut off , hydrocarbon saturation, water saturation, bulk volume of water and oil with value of average porosity, the Upper Qamchuqa Reservoir in Taq Taq Oil Field divided into three units, from top to bottom Upper ($RU_1$) , Middle ($RU_2$) and Lower($RU_3$) units.

11- The Upper reservoir unit (RU1) represent potential reservoir unit in Taq Taq oil field and thickness of pay zone increased from Northwest toward Southeast of the field.

## 5.2: Recommendations

1- Detailed examination of the upper boundary of Upper Qamchuqa reservoir and its identification based on different types of logs (sonic, natural gamma ray, image) as well as thin section "Petrographical' study to support other strartigraphic evidence.

2-Geochemical analysis of formation water especially in the Upper Qamchuqa Reservoir in the newly drilled wells to determine formation water salinity and to enhance formation evaluation.

3- Detailed study of the fractures system that effect the Upper Qamchuqa Reservoir, including fracture modeling and analysis and its relation the stress-strain relation of field general structural geology.

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مابين البلورات و التجاويف المجهرية و الاذابة في تطوير المسامات القالبية بالإضافة إلى التشققات و التي لها تأثير كبير على المكمن.

ان التفسيروالتحليل الأجمالي للأنواع المختلفة و المتوفرة للمجسات البئرية مثل مجسات( اشعة كاما الصوتية, الكثافة, النيوترون, المقاومة الكهربائية , وصوري ) ساعد في أستنباط و دعم استنتاج العديد من المعاملات البتروفيزيائية مثل المسامية الأجمالية, المسامية الفعالة , النفاذية , حجم الماء الكلي , حجم النفط و الماء الكلي , اضافة مقدار النفط التي قابل للأنتاج و الماءالقابل للسحب .

تمكنت الدراسة من تميز اربعة وحدات مسامية تتراوح قيمة المسامية فيها بين 3% الى اكثر من 16.6% و قيمة المسامية الفعالة فيها بين 11% الى اكثر من 20%, هذه الوحدات من الاعلى الى الاسفل هي U4,U3,U2,U1 و بالاستنادا الى المسامية الأجمالية, المسامية الفعالة, المسامية المنتجة و السمك الصافي المنتج ضمن الوحدات المسامية المدروسة تشكل الوحدة ( U1 ) في كل الابار أفضل وحدة منتجة في حقل نفط طق طق.

تفسيرالمعاملات البيتروفيزيائية الاخرى مع أستخدام معامل (R35) و علاقة المسامية و تشبع المائي, المسامية و النفاذية , اظهر ان نوع الجريان في المكمن قمجوقة الاعلى يتصف بجريان التشقق و التشقق المتداخل مع جريان الحشوة الصخرية.

اعتمادا على دليل التشقق, نوعية الجريان و تفسير المجسات الصورية اتظح بأن مكمن قمجوغة العلوي مكمن عالي التشقق و استنادا على تشبع الهيدروكاربون، اشباع الماء، الحجم الكلي للنفط و الحجم الكلي الماء ومعدل المسامية في مكمن قمجوقة الاعلى فقد تم تقسيم مكمن إلى وحدتيين مكمنتين رئيستين, الاعلى($RU_1$) ,المتوسط($RU_2$) السفلى($RU_3$)

## المستخلص

لقد تم اختياراربعة أبارTT-07,TT-06,Tq-1 وTT-09 في حقل طق طق ضمن أقليم كوردستان في شمال شرق العراق لدراسة الخصائص البتروغرافية و المؤشرات المجسية البئرية و أستخداماتها في تحديد الخواص المكمنية لتكوين قمجوقة العلوي النفطي الكاربوناتي.

ان وصف النماذج اللبابية والفتاتية و استخدام المجسات البئرية ساعد في تحديد وحدتين صخريتين رئيسيتين للتكوين قمجوقة الأعلوي هي من الأعلى بأتجاه الاسفل : وحدةالحجر الدولومايت( D ),و وحدة الحجر الجيري( L ) و تتداخل مع هاتين الوحدتين سحنات لأحجار جيرية متدلمتة (DL) .

تضم سحنات الاحجار الجيرية ثلاث سحنات دقيقة هي : سحنة الحجر الجيري الواكي حامل للميليوليد-تيكسولاريد($L_1$) و سحن الحجر الجيري الواكي المرصوص حامل للاوربيتولينا و الفتات الاحيائي($L_2$) و سحن الحجر الجيري الواكي المرصوص حامل للفتات الاحيائي و الرودست($L_3$). اما سحنات الاحجار الجيرية المتدلمتة فقد تم عين خمس سحنات دقيقة رئيسية فيها هي:

حجر جيري واكي متدلمتة حامل للفتات الاحيائي($DL_1$), حجر جيري صلصالي متدلمت حامل للفورامنفرا($DL_2$), حجر جيري واكي مرصوص متدلمت حامل للبيلويدات و الفتات الاحيائي($DL_3$), حجر جيري واكي مرصوص متدلمت حامل للوربيتولينا($DL_4$) و حجر جيري مترابط حامل للفتات الاحيائي و الفورامنفرا($DL_5$).اما سحنات الدولوماتية فقد تم تقسيمها حسب النسيج الصخري الى خمس سحنات الدقيقة هي سحن الاحجار الدولومايتية الخشن البلور($D_1$) , سحنات الاحجار الدولومايتية المتوسطة البلور($D_2$) , سحنة الاحجار الدولومايتية الناعمة البلور($D_3$), سحنة الاحجار الدولومايتية الناعمة الى المتوسطة البلور($D_4$) و سحنة الاحجار الدولومايتية متعددة البلور($D_5$).

تعرضت المكمن لعمليات تحويرية بشكل مركز و التي من اهمها عملية الدلمتة وعملية الاذابة,اضافة الى عمليات السمنتة و التضاغط, و تشكل عملية الدلمتة دورا أساسيا في تطوير المسامية الثانوية للتكوين و بشكل خاص فراغات.

# الخواص المكمنية لتكوين قمجوغة الأعلى( الطباشيري )
# في حقل النفط طق طق, أقليم كوردستان , شمال شرق العراق.

**رسالة**
**مقدمة الى كلية العلوم – جامعة السليمانية كجزء**
**من متطلبات نيل درجة الماجستير**
**في علم الأرض**

**من قبل**
**فريدون نجم رشيد شابان**
**بكالوريوس** / 2004

**بأشراف**
**د. باسم القيم**
**استاذ**

**ذى الحجة** 1428 **كانون الأول** 2008

شیتەڵ کردنی پارەمیتەرەکانی تری پیترۆفیزیاییی وەکو R35, پەیوەندی کونیلە-تێربوونی نەوتی , کونیلە-دەلأندن ئەوە نیشان ئەدەن کەجۆری لێشاولە کۆگەی نەوتی قەمچوقەی سەروو لە کێڵگەی نەوتی تەق تەق بریتی یە لە لێشاوی شکانگە و لێشاوی شکانگە لەگەڵ لێشاوی تێکەڵە.

لەسەر بنەمای رابەری شکانگە, جۆری لێشاو و شیتەڵ کردنی لۆگی وێنەیی دەردەکەوێت کە کۆگەی نەوتی قەمچوقەی سەروو بە کۆگەیەکی شکانگە دا ئەنرێت لە کێڵگەی نەوتی تەق تەق.

بە پشت بەستن بە تێربوونی نەوتی, تێربوونی ئاو, قەبارەی نەوت و ئاو لە گەڵ تێکرای نرخی کونیلە بە شێوەیەکی گشتی کۆگەی نەوتی قەمچوقەی سەروو لە کێڵگەی نەوتی تەق تەق دابەش ئەکرێت بۆ سێ یەکەی کۆگەی نەوتی سەروو $(RU_1)$ , ناوەند . $(RU_2)$خواروو$(RU_3)$.

# پوختە


چوار بیرە نەوتی(TT-09, TT-07, TT-06, Tq-1) لە کێڵگەی نەوتی تەق تەق لە هەرێمی کوردستان, باکوری رۆژهەلاتی عێراق وەرگیراون بۆ دیاریکردنی رەوشتی پیترۆگرافی و شیکار و شیتەڵ کردنی لۆگی بیرەکان بە مەبەستی دیاری کردنی رەوشتی کۆگەی نەوتی و خەملاندنی کۆگەی نەوتی پێکهاتووی قەمچوقەی سەروو لە کێڵگەی نەوتی تەق تەق.

لێکۆڵینەوەی نمونەکانی کرۆك و ووردبوو لە گەڵ شیتەڵکردنی لۆگەکان ئەوەنیشان ئەدەن کە پێکهاتووی قەمچوقەی سەروو ئەتوانرێ دابەشبکرێ بۆ دوو یەکەی لیسۆلۆجی یەوە لە سەرەوە بۆ خوارەوە :

یەکەی دۆلۆمایت(D) , یەکەی لایمستۆن(L) لەگەڵ ناویەکچوونی دۆلۆمیتیك لایمستۆن(DL) لە هەر یەکێکیاندا.

لە رووی پێترۆگرافی یەوە سێ گروپ شێوازی وورد ناسراونەتەوە, گروپی یەکەم پێکهاتوون لە سێ شێوازی ووردی لایمستۆنی :میلیۆلید-تێکستیولارید واکستۆن($L_1$), ئۆربیتیۆلینا بایۆکلاستیك واکستۆن- پاکستۆن($L_2$) و روودست بایۆکلاستیك واکستۆن- پاکستۆن($L_3$). گروپی دووەم پێکهاتوون لە پێنج شێوازی ووردی دۆلومیتیك لایمستۆنی :میلیۆلید-تێکستیولارید دۆلۆ واکستۆن($DL_1$), پۆرفیرۆتۆپیك فۆرامینیفیرال کلەیی دۆلۆ واکستۆن($DL_2$), پیلۆیدال بایۆکلاستیك دۆلۆ واکستۆن-دۆلۆ پاکستۆن($DL_3$), ئۆربیتۆلینا دۆلۆ واکستۆن-دۆلۆ پاکستۆن($DL_4$) و بایۆکلاستیك فۆرامینیفیرال دۆلۆباوندستۆن($DL_5$). پێنح گروپی شێوازی ووردی دۆلۆمایتی کە دابەشکراون بەچەند گروپێکی ترەوە.

کۆگەی نەوتی قەمچوقەی سەروو لە کێڵگەی نەوتی تەق تەق گۆرانەکردارەکان بە شێوەیەکی بە هێز و توونـد کاری تێ کردووە بە تایبەتی بوون بە دۆلۆمایت و توانەوە, جۆرەکانی تری گۆڕانەکردارەکان بەگوێرەی پلەی کاریگەرییان بریتین لە لکاندن و پەستاوتن کە کاریان کردۆتە سەر کەڤری قەمچوقەی سەروو.

کرداری بوون بە دۆلۆمایت رۆڵێکی گرنگی هەیە لە گەشە پێدان و پەرە پێدان و دروستکردنی کوونیلە دووەمیەکان وەکو کونیلەی نێوان کریستاڵەکان و کونیلەی گەورە"ڤەگ", کرداری توانەوە بووەتە هۆی دروستکردنی کونیلەی مۆلدی, سەرەڕای کرداری شکانگدن کە کاریگەری گەورەی هەیە لەسەر کۆگەی نەوتی قەمچوقەی سەروو.

شیتەڵکردن و شیکارکردنی ئەو لۆگانەی لەم لێکۆڵینەوەیەدا بەکارهاتوون بریتین لە جۆرەکانی لوگی (تیشکدەری گاما سۆنیك, چڕی, نیوترۆن, بەرگری و وێنەیی ) بەکارهاتوون بۆ دۆزینەوەی و ئەژمارکردنی پارامیتەرەکانی پیترۆفیزیایی وەکو کوونیلە , کۆکراوەی کونیلە , دەلاّندن , قەبارەی ئاو و نەوت , نەوتی جولاّو ونە جولاّو , ئاوی جولاّو و نەجولاّو لە کۆگە نەوتی قەمچوقەی سەروو.

چوار یەکەی کونیلە دەست نیشان کراوە بە تێکڕای کونیلە لە نێوان 3% بۆ گەورەتر لە % 16.6 لە گەڵ تێکڕای کونیلەی کاریگەر بە بڕی 11% بۆ گەورەتر لە 20% , ئەم یەکانە لە سەرەوە بۆ خوارەوە بریتین لە U4,U3,U2,U1 لە هەر یەکەیەکی کونیلەدا تێکڕای کونیلە, تێکڕای کونیلەی کایگەر, تێکڕای کونیلەیکاریگەری بەرهەم هێنەر, ئەستوری و ریژەی پەی لە هەمویاندا دیاریکراوە کە یەکەی یەکەم( U1 ) لە هەموبیرەکاندا باشترین یەکەی بەرهەم هێنەری نەوتە لە کێڵگەی نەوتی تەق تەق.

# تاييه تمەندیەكانی كۆگەی نەوتی پێكهاتووی قەمچوغەی سەروو( كریتاسی ) لە كێڵگەی نەوتی تەق تەق ,هەرێمی كوردستان , باكوری رۆژهەلآتی عێراق.

نامەیەكە

پێشكەش كراوە بە كۆلێجی زانست , زانكۆی سلێمانی وەك بەشێكی تەواوكەر بۆ
بە دەست هێنانی پلەی ماستەر
لە جیۆلۆجی دا

لە لایەن
فەرەیدون نجم رشید شابان
بەكالۆریۆس-2004

بە سەرپەرشتی
د. باسم القیم
پرۆفیسۆر

بەفرانبار 2708 كانوونی یەكەم 2008