Palacký University Olomouc

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Comparison of outcrop and subsurface carbonate porosity and permeability of upper Cretaceous Qamchuqa Formation, Northern Iraq

Bachelor thesis

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I declare that I have prepared the bachelor's thesis myself and that I have stated all the used information resources in the thesis.

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Název práce: Porovnání výchozové a podpovrchové uhličitanové pórovitosti a propustnosti svrchní křídové formace Qamchuqa, severní Irák

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Abstrakt: Souvrství Qamchuqa bylo definováno v severovýchodním Iráku. Hlavním cílem projektu je provést korelaci mezi povrchovými a podpovrchovými výskyty karbonátových hornin souvrství Qamchuqa (svrchní křída) prostřednictvím údajů o porozitě a permeabilitě, které byly získány v obou oblastech. Pro kvantifikaci porozity jsou důležité dva hlavní zdroje dat. Jedná se o vzorky hornin (vzorky z vrtných jader a z výchozů) a geofyzikální karotážní data (vrtná karotáž). Vzorky hornin mohou být odebrány z vrtných míst nebo z horninových ekvivalentů vystavených na povrchu. Tato metoda je analytická, protože bod vzorku je jasně a přesně definován a v ideálním případě lze odebrat nebo napodobit vzorek jakékoli požadované velikosti bez potřeby podpovrchového vzorkování. Vrtná karotážní data jsou nepřímým a méně přesným, avšak mnohem lépe proveditelným proxy parametrem pro měření porozity. Měření porozity analogů rezervoárových hornin z výchozů může být použito k modelování podpovrchových rezervoárů a usnadnění korelace mezi vrty. V této případové studii z svrchnokřídového souvrství Qamchuqa jsou demonstrovány variace porozity mezi povrchem a podpovrchem a vysvětleny účinky hluboké diageneze (diageneze pohřbením) na tyto variace. Souvrství Qamchuqa je odkryto v oblasti Zewe, region Kurdistán, Irák, kde představuje analogii hornin z ložiska v ropném poli Khabbaz. Porozita byla měřena ve čtyřech vzorcích výchozu a ve 112 podpovrchových vzorcích, kde byla vypočtena z hustotní a neutronové karotáže s ohledem na obsah jílovité složky (shaliness) stanovený z gamakarotážního záznamu. Po přípravě a analýze dat z hloubek mezi 2900 a 3000 m ve vrtu Kz-1 jsme kategorizovali spodní zónu souvrství Qamchuqa do 7 subzón s vysokou rezervoárovou kvalitou. Zóna A obsahuje jemné porézní médium s vysokou permeabilitou. Zóna B obsahuje horniny s nejlepší rezervoárovou kvalitou. V porovnání s výše uvedenými subzónami není zóna C jemnozrnná hornina. Horní zóna souvrství Qamchuqa sahá od 2750 do 2890 m hloubky. Porozita byla určena na základě záznamů dat z nástrojů pro porozitu. Souvrství Qamchuqa je v této hloubce odlišné, proto je region rozdělen do tří hlavních subzón, z nichž každá má jinou vlastnost. D1, D2 a D3 jsou tři hlavní subzóny. D1 má dobrý rozsah poréznosti 5 až 25 %. Subzóna D2 vykazuje průměrnou porozitu 15 %. Subzóna D3 je méně porézní než horní subzóny. Mezi povrchovou a podpovrchovou porozitou souvrství existuje široká variabilita a obecně neexistuje dobrá shoda. Výsledky práce ukazují, že porozita z výchozů není nutně dobrou alternativou pro korelaci mezi vrty a podpovrchové modelování v karbonátových rezervoárech, avšak může se blížit podpovrchové realitě. Tato variabilita je způsobena komplexností karbonátových hornin. Kvalita karbonátových rezervoárů je funkcí diageneze, která je pravděpodobně účinnější pod povrchem než ve výchozech a která může rezervoárovou kvalitu zlepšit nebo zhoršit.

Klíčová slova : formace Qamchuqa , pórovitost , propustnost , data z vrtů , data jádra vzorků hornin.

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Abstract: The Qamchuqa Formation has been defined in northeastern Iraq. The project's main objective is to correlate surface and subsurface carbonate rock occurrences of the Qamchuqa Formation (Upper Cretaceous) through porosity and permeability data obtained in both areas. Two main sources of data are important for porosity quantification. These are rock samples (samples from core samples and outcrops) and geophysical logging data (well logging). Rock samples may be taken from drill sites or rock equivalents exposed at the surface. This method is analytical because the sample point is clearly and precisely defined and ideally any desired size sample can be taken or simulated without the need for subsurface sampling. Borehole log data is an indirect and less accurate, but much more feasible proxy parameter for measuring porosity. Porosity measurements of reservoir rock analogous to outcrops can be used to model subsurface reservoirs and facilitate correlation between wells. In this case study from the Upper Cretaceous Qamchuqa Formation, porosity variations between surface and subsurface are demonstrated and the effects of deep diagenesis (diagenesis by burial) on these variations are explained. The Qamchuqa Formation is exposed in the Zewe area, Kurdistan Region, Iraq, where it is analogous to rocks from the Khabbaz oil field deposit. Porosity was measured in four outcrop samples and in 112 subsurface samples, where it was calculated from density and neutron logging without content of the clay component (shaliness) determined from the gamma log record. After preparing and analyzing data from depths between 2900 and 3000 m in the Kz-1 well, we categorized the lower zone of the Qamchuqa formation into 7 subzones with high reservoir quality. Zone A contains a fine porous medium with high permeability. Zone B contains rocks with the best reservoir quality. Compared to the above subzones, Zone C is not a fine-grained rock. The upper zone of the Qamchuqa formation extends from 2750 to 2890 m depth. Porosity was determined based on data logs from porosity tools. The Qamchuqa Formation is distinct at this, depth; therefore, the region is divided into three main subzones, each with a different characteristic. D1, D2 and D3 are the three main subzones. D1 has a good porosity range of 5 to 25%. Subzone D2 shows an average porosity of 15%. Subzone D3 is less porous than the upper subzones. There is wide variability between the surface and subsurface porosity of formations and there is generally no good agreement. The results of the work show that porosity from outcrops is not necessarily a good alternative for correlation between wells and subsurface modeling in carbonate reservoirs, but it can approximate the subsurface reality. This variability is due to the complexity of carbonate rocks. The quality of carbonate reservoirs is a function of diagenesis, which is probably more effective below the surface than in outcrops, and which can improve or degrade reservoir quality.

Keywords: Qamchuqa Formation, porosity, permeability, well data, rock sample core data.

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List of Abbreviations	Full names
IPC	Iraq petroleum company
BP	British petroleum
MNR	Nuclear Magnetic Reasonable log
mD	millidarcy
CaO	Carbon oxide
MgO	magnesium oxide
XRF	(X-ray fluorescence)
Myr	million years
GR	Gamma ray
SP	Spontaneous potential
W	West
E	East
S	South
N	North
g	gram
Cm	Centimeter
m	meter
Kg	Kilogram
Km	Kilometer
Ja	Jambur oil field
Kz	Khabbaz oil field
CNL	Compensated Neutron Log
FDC	Formation Density Log
In	inches
N-D cross plot	Neutron density cross plot
API	American Petroleum Institute
V shale	Volume of shale
In	Inches
A, B, C	Rock samples porosity and permeability from subsurface Legends

PPL	Parallel polars
XPL	Crossed polars
rho, *ρ*	Greek symbol uses for density
ma	matrix density
b, RHOB	bulk density
IGR	gamma-ray index
D1, D2, D3	Legends of Subzones
Fl	fluid density
N, PHIN, or NPHI	Neutron porosity
%	Percentage

1. Introduction

1.1 preface

The first exploratory geological studies were conducted in Iraq during World War I, culminating in the discovery of petroleum in the 1920s. The contribution of the petroleum industry to the country's early development following independence in 1921 was critical to the advancement of the geologist profession in Iraq. The Iraq Petroleum Company (IPC) and its subsidiaries produced surface geological maps in northern Iraq and underground maps in southern Iraq. In 1959, scientists at IPC published important stratigraphic results. The establishment of the Development Council (Maj1is Al I'mar) in 1954 resulted in an ambitious program for multinational companies such as Site Investigation Company and Parsons to discover metal ores, building materials, and groundwater in Iraq. This program ran from 1956 to 1958. At that time, geological maps of northern and eastern Iraq were created. Six 1:100,000 scale map sheets were created, covering a critical border region with Iran and Turkey. Baghdad University established the Institute of Geology in 1954, which had a tremendous impact on the geological profession in Iraq. mineral exploration continued in 1961, with contracts with the Soviet Union state enterprises mapping NE Iraq for metallic reserves and W Iraq for phosphate, glass sand, and clay (Jassim and Goff, 2007). Iraq is the Middle East's largest producer and exporter of crude oil. According to the British Petroleum (BP) company Statistical Review of World Energy for the Year 2020, Iraq produced 145 billion barrels of proven recoverable oil reserves by the end of 2020, accounting for 8.4 percent of world reserves (British petroleum, 2020). Despite the fact that Iraq possesses considerable crude oil and natural gas reserves, the expansion of this sector looks to be problematic. According to various sources, this country has one of the world's largest reserves; experts argue that by utilizing a participative, democratic, and transparent production system, democratic and real management of the benefits of this sector can provide a high level of welfare and thus human development. However, this money has not been used or distributed in line with these values. This crucial sector of Iraq's economy, surrounded by international and domestic interests, has been gravely harmed by the country's subsequent catastrophic conflicts, as well as decades of state rule (by a military administration and dictatorship).

(Miguel, 2018), Most of the oilfields in Iraq are located in the Zagros Mesopotamian Cretaceous and Tertiary systems. The Khabbaz oilfield is one of Iraq's largest; it has multiple pay zones and produces from Tertiary and Cretaceous reservoirs, with the main reservoir system consisting of the Middle Lower Cretaceous Qamchuqa Group. The Iraqi Petroleum Company conducted the first seismic survey of the Khabbaz oilfield in 1955. The second seismic examination of the Khabbaz region began in 1971, revealing the field's structure. The first oil well was drilled in 1976 based on seismic measurements. (Ghafur and Hasan, 2017). Porosity is a measure of a reservoir's storage capacity. It is defined as the pore volume to bulk volume ratio. Carbonate reservoir porosity can range from less than 1% in firmly cemented carbonate rock to above 40% in unconsolidated sediments. All rocks, in general, lose porosity and permeability as a function of depth owing to compaction. Limestone and dolomitic limestone are more permeable than dolostone at depths less than 2 km. (Mohammed Sajed and Glover, 2020).

1.2 Porosity

Porosity is the fraction of the total volume of the rock that is pore space. Total porosity is made up of primary and secondary porosity (Selley, 1998). Most reservoirs have significant variations in porosity, both laterally and vertically. Effective porosity is the interconnected empty space filled by recoverable oil or gas (North 1985); it is generally 5-10% less than total porosity, and dolomitization increases effective porosity in carbonate rocks because its rhombs give flat grain surfaces and polyhedral holes (Levorsen, 1967). The sonic log, density log, neutron log, and the recently developed Nuclear Magnetic Reasonable log (MNR) may all provide information on rock porosity (Asquith and Krygowski, 2004). The tool response for all of these devices is influenced by the formation porosity, fluid content, and matrix.The tool response can be connected to porosity if the fluid and matrix effects are known or can be determined. The log porosity data must be compared to the laboratory core analysis. Core plug analysis is the best approach for measuring direct porosity; it is generally assessed every thirty centimetres. The porosity of most reservoirs ranges from 5 to 30%, with the most frequent value being between 10% and 20%. Carbonate reservoirs have significantly less porosity than sandstone reservoirs, although their permeability may be greater (North, 1985). A reservoir with less than 5% porosity is typically deemed non-commercial or marginal unless there are compensating elements such as fractures, fissures, Vugs, and caverns that are not visible in the tiny portions of rock cut by the plugs (Levorsen, 1967; North, 1985). Table 1 shows an approximate field evaluation of porosities (in percent) according to (North, 1985).

Table 1 Classification of porosity by (North ,1985).

Quality of porosity	%
Negligible	0-5
Poor	5-10
Fair	10-15
Good	15-20
Very good	20-25

1.3 Permeability

Permeability is the ability of a porous media to transmit fluids; permeability governs how fluid moves through a reservoir. Because it regulates the production rate, permeability is an important metric in reservoir development and management. Permeability often rises with increased porosity, particle size, and better sorting (Selley, 1998; Tagavi, 2005). The major control for permeability in carbonates rocks is the connection between pores. Carbonate reservoirs / heterogeneity due to variations in depositional environment and subsequence diagenetic processes. A reservoir's permeability may be assessed in three ways: The first method is to conduct a drill stem test or a production test from the reservoir, which is dependent on the rate of flow and pressure drop. The second method is to identify permeable zones qualitatively using SP and Caliper records using wireline logs. The third method is to use a laboratory core plug measurement. (Salley, 1998). The best approach for measuring direct permeability is by core plug analysis; it is generally done every thirty centimetres. Coring is also exceedingly expensive and time-consuming when such measurements are limited. The scale is another issue with core plug measurements. Small-scale heterogeneities that may not affect reservoir flow are measured and must be upscaled. The permeability of average reservoir rocks ranges between 5 and 1000 millidarcys, with a millidarcy (mD) equaling 0.001 darcy. Commercial production has been obtained from rocks with permeabilities as low as 0.1 md, but such rocks may have highly permeable fracture systems that are not revealed by standard laboratory analysis (Tagavi, 2005). Permeability, like porosity, varies widely laterally and vertically in the ordinary reservoir rock; a reservoir rock with a permeability of 5 (mD) or less is referred to as tight sand or thick limestone (Levorsen 1967; North, 1985) table 2 shows the Classification of Reservoir Permeability by (North ,1985).

Table 2 Classification of Reservoir Permeability by (North,1985).

Type of permeability	Range of permeability
Poor of fair	< 1.0 -15md
Moderate	15 – 50md
Good	50 – 250md
Very Good	250 1000 md
Excellent	> 1000 md

1.4 Research Objectives:

The aim of this study is to measure and compare the porosity of the Qamchuqa Formation in outcrops and subsurface. Because the determination of the spatial distribution of rock attributes in the subsurface at the inter-well scale is challenging, The characterization of outcrops, particularly the measurement of porosity, is commonly used to provide quantitative descriptions of reservoir architecture (Stalkup and Ebanks, 1986; Fisher et al. 1993; Barton, 1994; Kerans et al., 1994; Willis 1997).The distribution of storage units crucial for the reservoir fluid build-up is shown by quantifying porosity in outcrop reservoir analogs. as shown in below points.

- To determine the major controls on porosity in the Qamchuqa Formation both in outcrop and subsurface,

- To investigate whether burial diagenesis has altered the porosity structure between the outcrop and subsurface of the Qamchuqa Formation,
- To determine the petrophysical properties such as shale volume, porosity, and lithology of the formation, from well-log data,
- To measure, identify, and quantify the porosity and permeability of the outcrop samples,
- To make and study thin sections from the outcrop samples, for determining the type of fossils and rocks, Estimate properties of the components by thin sections samples
- To compare between the outcrop core plug, subsurface core plug, and well-log porosities and permeabilities,

2. Geologic setting

2.1 study area

Iraq is divided into three tectonically different areas: the Stable Shelf, which has surface anticlines but no huge subterranean arches and anti-forms, the Unstable Shelf, which contains surface anticlines, and the Zagros Suture, which contains thrust sheets of radiolarian chert. In the Stable Shelf, tectonic subdivisions tend N-S, while the Unstable Shelf and the Zagros Suture trend NW-SE or E-W. The N-S trend results from Palaeozoic tectonic movements, whereas the E-Wand and NE-SW trends result from Cretaceous-Recent Alpine orogenesis. There are four tectonic zones on the Unstable Shelf. The Foothill Zone is defined by long anticlines with Neogene cores and large synclines with thick Miocene-Quaternary molasse. The High Folded Zone is defined by high-amplitude anticlines with Palaeogene or Mesozoic carbonates exposed in their cores. The zone was elevated during the Cretaceous, Palaeocene, and Oligocene periods, although it also had an Eocene molasse basin. (Jassim and Goff, 2007). The Khabbaz oil field is one of Iraq's largest oil fields. The subsurface represents a minor anticline, whereas the Northeast limb is steeper than the Southwest limb, indicating an asymmetrical anticline. The field is located 23 kilometres to the west and northwest of Kirkuk governorate, between the Jambour and Bai Hassan Oil Fields The initial seismic examination, conducted in 1955, revealed a subterranean structure that fell to the northwest. The second seismic was started in July 1971 and finished on October 22, 1971, proving the presence of the structure. It is tectonically positioned in the Foothill Zone (Hamrin - Makhul Subzone) of the Unstable Shelf's Folded Zone (Buday and Jassim, 1987). The tiny anticline of the Khabbaz field is approximately 20 km long and 4 km wide. In the Khabbaz field, around 30 wells were sunk, with a considerable number of wells targeting the Tertiary reservoir (Al-Qayim and Qadir, 2010). Outcrop data from the Zewe section was also used for this study. The Qamchuga formation is identified at the Zewe location, with a thickness of 175 meters. The section exposes thick to thinly bedded, coordinates for zewe section latitude (35°44156) and longitude is (44°093179), well consolidated, grey, fossiliferous limestone (Figure ,1). The Zewe segment travels along the southern edge of the Pira Magroon anticline; the Tabin section runs along the northwestern edge of the Pira Magroon anticline; and the third piece runs through the Qamchuqa Gorge along the Surdash anticline (Al-Qayim, Hussein and Qader, 2016).

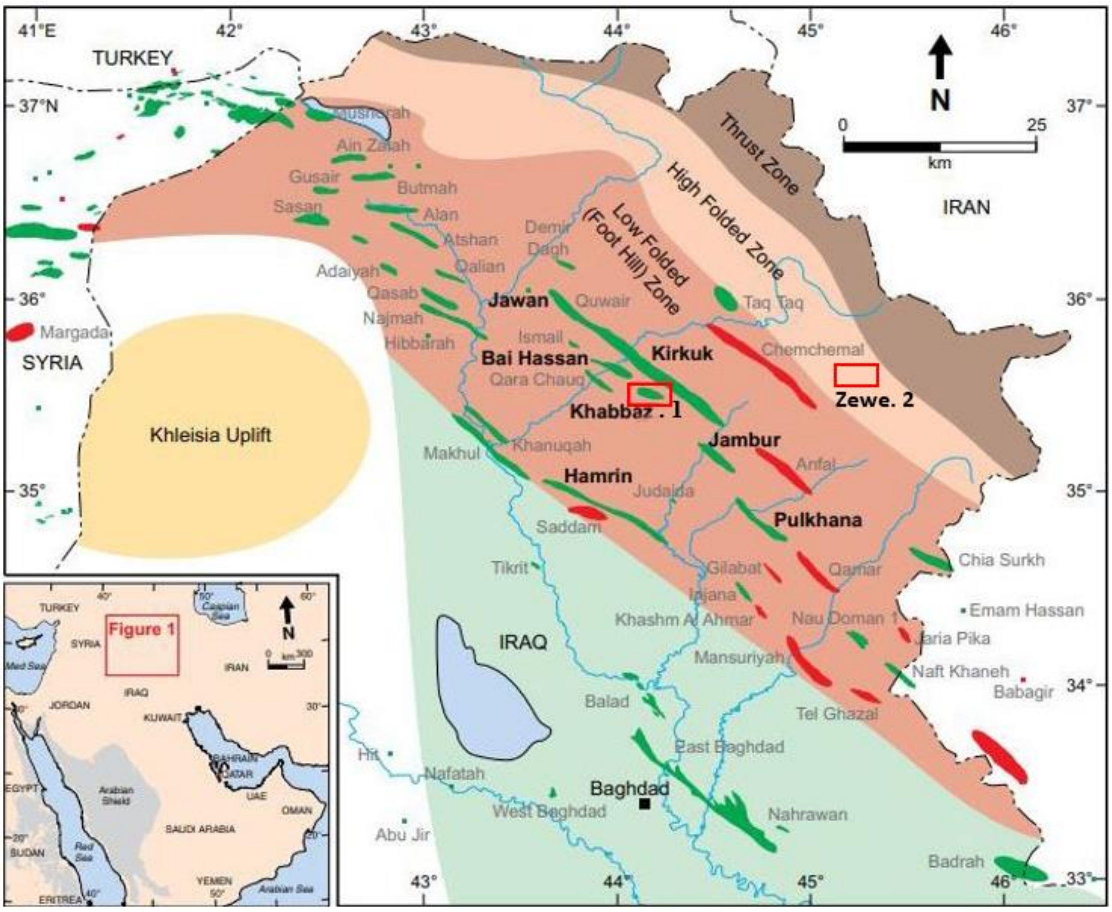

Figure 1 The location and tectonic subdivision of the study areas (1 Khabbaz oil field and 2 Zewe section) adopted from (Al Qayim et al., 2010).

2.2 Qamchuqa Formation

Limestone at Qamchuqa Formation turned into exactly described by (Van Bellen et al.,1959). near the Qamchuqa Canyon in northern Iraq, to the northeast of Sulaimania. The formation is approximately 800 m thick and is distinguished by huge, dolomitized carbonates of early to late Cretaceous (Barremian, Aptian, Albian, Cenomanian) age. At the type locality, the Qamchuqa Formation may be divided into six lithologic units: upper dolomite, upper limestone, middle dolomite, middle limestone, lower dolomite, and lower limestone. The limestone units contain miliolid foraminifers, *Choffatella*, *Cuneolina*, and *Orbitolina*, as well as sponge spicules, echinoids, mollusks, and bioclastic detritus. In its type section, the Qamchuqa Formation rests conformably on grey marlstones of the Sarmord Formation and is unconformably overlain by glauconitic oligosteginal limestones of the Kometan Formation (van Bellen et al., 1959). The dolostone microscopy in Qamchuqa formation is characterized by a highly finely crystalline dolomite mosaic (10 m). It either replaces a lime mud facies or the lime mud that fills the intergranular voids in a bioclastic packstone facies. Bioclasts, miliolids, algae, and uncommon peloids are all found in grains. There are microvugs and fractures. In an early stage of diagenesis, this form of dolomite replaces micritic matrix (Al-Qayim, Qadir and Albeyati., 2010).

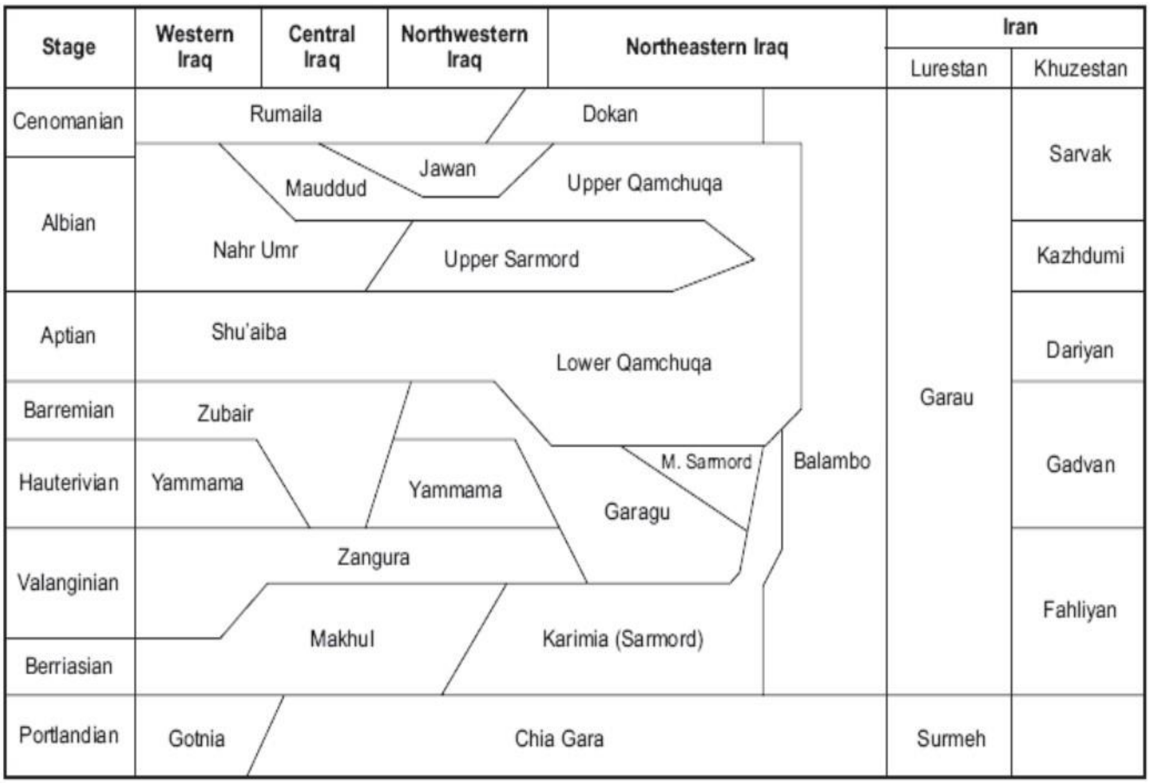

Figure 2 Stratigraphic correlation of Cretaceous units in Iraq and neighbouring locations adopted from (Al Qayim et al., 2010).

Subsurface investigations in the Kirkuk region indicate that the carbonate succession of the Qamchuqa Formation is interrupted by 35 m of grey basinal marlstones of the

Sarmord Formation (Al-Shdidi et al., 1995). The Lower Qamchuqa Formation, Upper Sarmord Formation, and Upper Qamchuqa Formation are integrated into the Qamchuqa Formation (Figure ,2). The comparable units of these three divisions of the Qamchuqa Group in central and southern Iraq are the Shu'aiba Formation (= Lower Qamchuqa), the Batiwah Formation (= Upper Sarmord), and the Mauddud Formation (= Upper Qamchuqa) (Sadooni and Aqrawi, 2000). The Upper Qamchuqa (Mauddud) Formation (Late Albian age) is a vast unit that spans the Arabian Platform (Sadooni and Alsharhan, 2003). Across Iraq, its thickness varies as a result of lateral facies alterations and erosional truncations. The formation's thickness decreases around Mosul and rapidly climbs westward (Sinjar Trough), It reaches 125 meters in Well Butma-1 and 198 meters in Well Tal Hajr-1 (Sahar, 1987). The thickest portion of the formation is found to the southeast of Kirkuk, from 170 m in the Khabbaz Field to 237 m in the Kirkuk107 Well, 250 m in the Chemchemal-1 Well, and up to 350 m in the Kor Mor-3 Well. There is no notable difference in the lithology of the Upper Qamchuqa (Mauddud) Formation in the Kirkuk region. Intercalations of limestone, dolomitic limestone, and dolostone are common, with occasional marl intercalations (Figure ,3). The lower contact of the Upper Qamchuqa (Mauddud) Formation with the Upper Sarmord (Nahr Umr) Formation in the Khabbaz Field is conformable and gradational. An unconformity related to either non-deposition or erosion marks the upper contact with the Dokan Formation. (Al-Qayim et al., 2010). The upper Qamchuqa reservoir of the Khabbaz oil field is 140 to 180 meters thick (with an average of 167.63m). The thickness of the Zewe portion is approximately 175 m.

2.3 literature review

Many researchers have examined the Qamchuqa Formation since the undiscovered pioneer study of (Wetzel, 1950) who proposed the name Qamchuqa Limestone Formation and chose the Qamchuqa Gorge as its type site. Later researchers have given several names to the formation, e.g., the Qamchuqa Limestone (Hudson, 1954), Qamchuqa Dolomite and Qamchuqa Limestone (Anon, 1955); see (Van Bellen et al., 1959) for further references. A following investigation produced a slew of stratigraphic terminology that are incompatible with one another, even within the writings of the same author (s). The existence of the Qamchuqa Formation was first formally defined by (Van Bellen et al., 1959). (Al-Sadooni, 1978) gave the Qamchuqa Formation the status of the lithostratigraphic group (Qamchuqa Group) and subdivided it into three formations, the Garagu, Shu'aiba, and the Mauddud Formation. The Jawan Formation and the Mauddud Formation were identified as lagoonal and neritic deposits by the same author. In the Kirkuk region, the Qamchuqa Group is subdivided into the Lower and Upper Qamchuqa formations separated by the Upper Sarmord Formation (Al-Shdidi et al., 1995). They identified neritic facies in the Qamchuqa Group in the northwest, which progressively grades into an unidentified middle neritic-pelagic zone, which is combined with basinal facies of the Balambo Formation in the southeast (Al-Qayim and Rashid, 2012) investigated the top of the Qamchuqa Formation in the Taq Taq oilfield, claiming that it is positioned above the "Upper Sarmord" and classifying it into two primary lithological units: lower limestone with subordinate dolostone interbeds, and an upper unit dominated by dolomite lithofacies. (Ameen and Gharib, 2014) studied the Cretaceous sequence outcropping in northern Iraq from a biostratigraphic standpoint. They focused on biostratigraphic zonation using benthic and planktonic foraminifera. They noticed that the Sarmord Formation gradually merges with the Qamchuqa Formation and assigned Valanginian to Hauterivian, and Barremian to Early Cenomanian ages to the two formations, respectively. The Qamchuqa Formation is made up of six units with alternating limestone and dolomite lithologies. The bottom limestone and overlying dolomite are Barremian in age, overlain by the Aptian intermediate limestone block, and finally followed by Albian intermediate dolomite and higher limestone. The uppermost upper dolomite unit is Early Cenomanian in age. These authors have also discovered the Qamchuqa-Kometan unconformity, which spanned from 0.5 to 4.5 Myr. (Rashid et al., 2020) carried out a subsurface investigation of the Qamchuqa reservoirs in the Miran West block. They have found that the formation in the examined wells is less dolomitized than in neighboring outcrops. They have chosen a streamlined nomenclature of vertically continuous sections, from bottom to top, of Sarmord, Qamchuqa, Dukan, and the formations of Gulneri and Kometan.also, he found out the comprehensive research reveals that the Qamchuqa Formation is distinguished by a variety of sedimentary and tectonic characteristics.

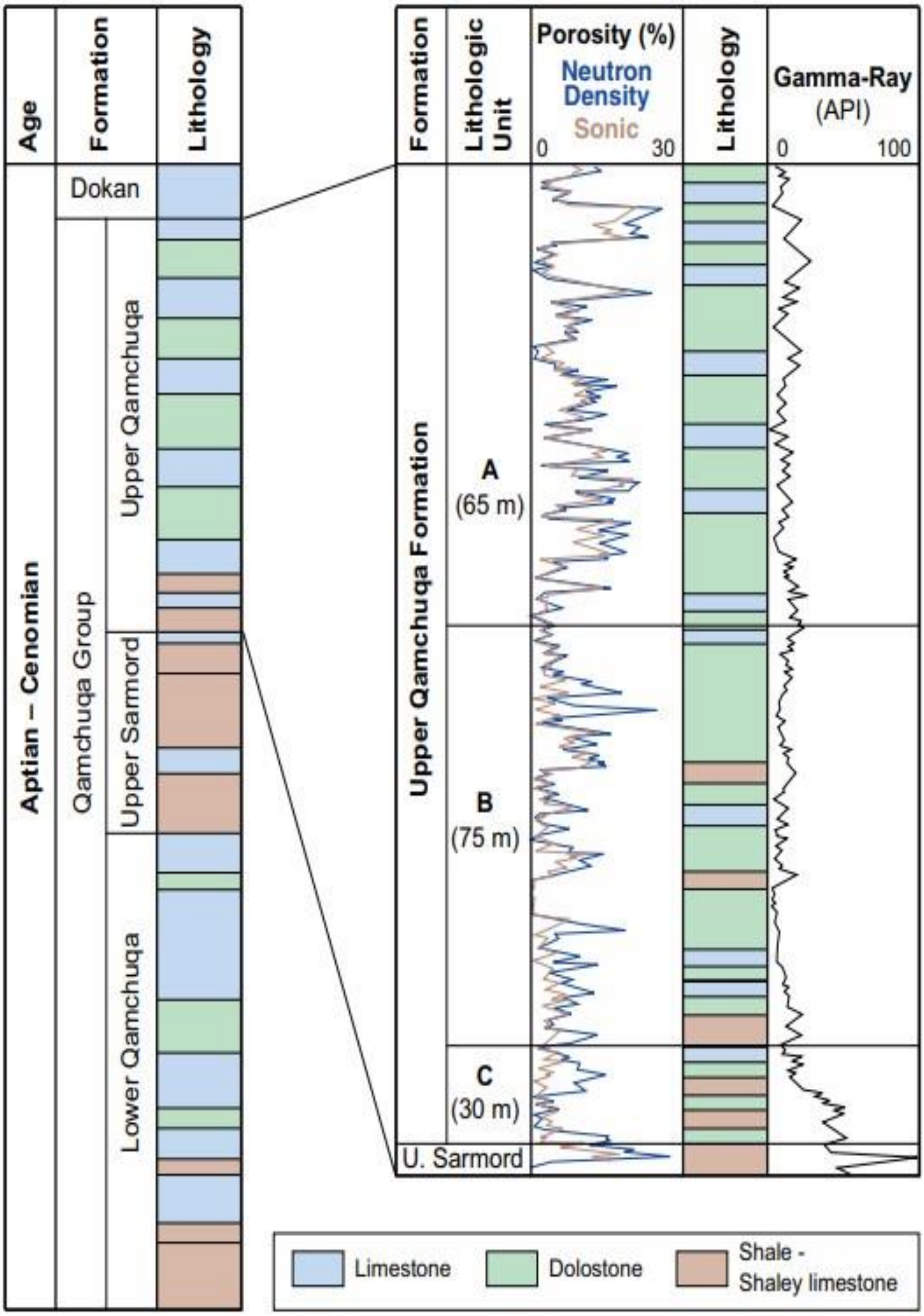

Figure 3 General stratigraphic column of the Qamchuqa Group (left) illustrating the lithologies, log features, and unit names of the Upper Qamchuqa (Mauddud) Formation of the Khabbaz Field (right), (AlQayim et al., 2010).

Burial stylolites, dissolution seams, and certain fractures developed during the early phases of burial and diagenesis are among the sedimentary characteristics (Phase 1).Later tectonic action created open fractures, partially open mineralized fractures, veins, and tectonic stylolites (Phase 2). (Ameen and Karim., 2008) conducted a field and laboratory study at the contact between the Qamchuqa (Early Cretaceous) and Bekhme (Late Cretaceous) formations in four areas, based on the lithology. The investigation found that the boundary seems to be gradational in all four parts; two of the four sections (Zante gorge and Perse Mountain) are devoid of conglomerate, breccia, or erosional surfaces, suggesting a conformable contact. The other two sections (outlet and inlet of Bekhme gorge) feature layers of apparent breccias (or conglomerate-like masses) with angular limestone clasts, which are believed to be diagenetic rather than depositional They interpreted several features at the sections as a secondary ball and pillow structures formed by lithostatic tension during burial. These structures have been found in a pile of breccia (approximately 1.5 m thick) positioned 10 m above the beds in the Bekhme gorge region. (Sissakian et al., 2021) used XRF to detect the concentration of oxides for 10 rock samples According to the XRF data, the ten rock samples are limestone with varying amounts of oxides. The estimated weighted averages of the oxides in the collected samples revealed that the limestone beds along the analyzed area in the upper portion of the Qamchuqa Formations are appropriate for the cement industry. CaO and MgO concentrations average 55.13% and 0.26%, respectively. (Sahib and Al-Dulaimi., 2022) investigated the Qamchuqa Formation in three wells (Ja-15, Ja-20, and Ja-22) inside the Jambur oil field of northern Iraq. Based on a polarizing microscope study of 335 thin sections, they identified 37 species of benthic foraminifers and the following fossils in the Qamchuqa Formation: calcareous algae - *Coptocampylodon fontis*, rudist fragments, pelecypods, gastropods, bivalves, brachiopods, ostracod shells, echinoid fragments, corals, and algae. They assigned the assemblages to the Praeorbitolina cormyi - Palorbitolina lenticularis concurrent Zone (Early Aptian), Mesorbitolina parva Range Zone (Middle Aptian), Mesorbitolina texana Range Zone (Late Aptian - Early Albian), Mesorbitolina subconcava Range Zone (Late Aptian - Early Albian), and Orbitolina sefini Range Zone (Late Aptian). (Ghafur and Hasan., 2017) discovered the key component influencing reservoir quality is shale volume; as the shale volume grows, the reservoir quality declines. All reservoir portions of the Upper Qamchuqa are nearly pristine formations with low shale contents. The computed porosity from the N-D combination of sonic porosity was compared. It ranges from 19% in the Upper Qamchuqa to approximately 14% in the Lower Qamchuqa unit. The average water saturation in both upper and lower units is low while the average hydrocarbon saturation is high, around 90%. (Al-Peryadi, 2002) investigated the effective porosity and sedimentology of the Jwan formation and Upper Qamchuqa Formation in the Bai Hassan oilfields. Based on gamma-ray log data, he classified the Top Qamchuqa Formation into four reservoir units and stated that the Dokan Formation is unconformably detached from the top portion of the Qamchuqa Formation. The formation's boundary with the overlying Upper Sarmord Formation has been also established. (Ameen, 2008) investigated the lithostratigraphy and sedimentology of the Upper Qamchuqa Formation in northern Iraq. Based on the fossil material and lithology of the Top Qamchuqa Formation, he subdivided it into eight units and described the Upper Qamchuqa boundary with the Dukan Formation in the upper portion, and with the Sarmord Formation in its bottom part. (Qadir, 2008) investigated the genesis of the Upper Qamchuqa reservoir in the Khabbaz oil field. Ten wells in the Khabbaz oil field were chosen for this study. He measured permeability, porosity, and resistivity using core plugs and wireline logs, which included porosity, gamma ray logs, and resistivity logs. As a result, he split the Upper Qamchuqa reservoir into three lithological units, A, B, and C, where the impacts of dolomitization on the majority of the reservoir rocks were seen. According to the findings, Unit A has the best reservoir characteristics among the three lithological units. (Rasheed, 2008) examined the Cretaceous Upper Qamchuqa Formation in the Taq Taq Oil Field to examine its reservoir characterizations. He investigated four wells in order to find the best portion of the Upper Qamchuqa Formation. As a consequence, he was able to analyze porosity, permeability, residual oil, moveable oil, movable water, and residual water utilizing plug and core analysis and different well logs such as gamma ray, sonic log, resistivity log, density log, spontaneous potential log (SP), neutron log, and image log (EMI). He also calculated effective porosity, analyzed the fracture influence on reservoir rock development, and evaluated the impact of diagenesis and microfacies on the reservoir development.

3. Material and Methods

3.1 Preface

The materials and methods include analysing two sets of data (well logging data and rock samples data) directly and indirectly measurements achievements for determining and qualifying porosity and permeability at surface and subsurface of the Qamchuqa formation.

3.2 Rock samples

The observe of the Qamchuqa Formation relies upon on fieldwork studies. Eight outcrop samples from Qamchuqa Formation in the Zewe section were collected. Core plugs (Figure ,4 c) samples were drilled from the outcrop rocks in the reservoir engineering laboratory in University Kurdistan Hewler UKH, Iraq. Core plugs were used to measure porosity and permeability by Vinci Helium porosimeter (Figure ,4a) to measure porosity and Permeability was measured by Vinci Nitrogen gas permeameter (Figure ,4b) in University Kurdistan Hewler laboratory. The rock samples have been used to study petrographic and microscopic examination. Thin sections were manufactured at the Palacky University, Olomouc UPOL, and further studied under optical polarizing microscopy (Figure ,4d). Porosity and permeability measurements on cored samples from the Qamchuqa formation, obtained from published data and descriptions, are also reported for 112 data sets at depths ranging from 2900 to 3000 m. (Qadir ,2008). The microscopic examination of all paleontological and sedimentological parameters of carbonate rocks utilizing thin slices, peels, and polished slabs is referred to as microfacies analysis (Flugel, 1982). Microfacies analysis was used for both limestone and dolostone lithologies in this study to:

• Estimate properties of the components (micrite, allochems, and sparite)

• Identify the (fossils)

• Examine the kinds and distribution of microfacies to define rock types.

• Determine the kind and distribution of pore spaces, as well as their relationship to reservoir characteristics.

3.3 Well-log data

Several types of well-log data have been used in this study for analysis, measurements, calculation, and interpretation of reservoir properties. Geophysical and conventional software was used to digitize and plot the log data, including the Getdata and Graph Digitizer Grapher 10 (64-bit) and Microsoft Excel 2010 were used to digitize the logs and preserve the data as raw log data, allowing us to quantify the petrophysical parameters of the Upper Qamchuqa reservoir such as lithology, shale volume, and porosity. The logs used in this study for well Kz-1 included Gamma Ray (GR), Compensated Neutron Log (CNL), Formation Density Log (FDC) and calliper log. The primary seismic research inside the Khabbaz area (Kunarewi Valley) began out in 1995 through the Iraqi Petroleum Company (IPC) and confirmed a NW-plunging structure. The initial finding well Kz-1 was drilled in August 1976, and development began in 1987 for the North Oil Company by France's Technip Geoproduction.well log data obtained from well Kz-1 at depth 2752 to 2923,6 m and the thickness (148m) at the upper Qamchuqa formation.

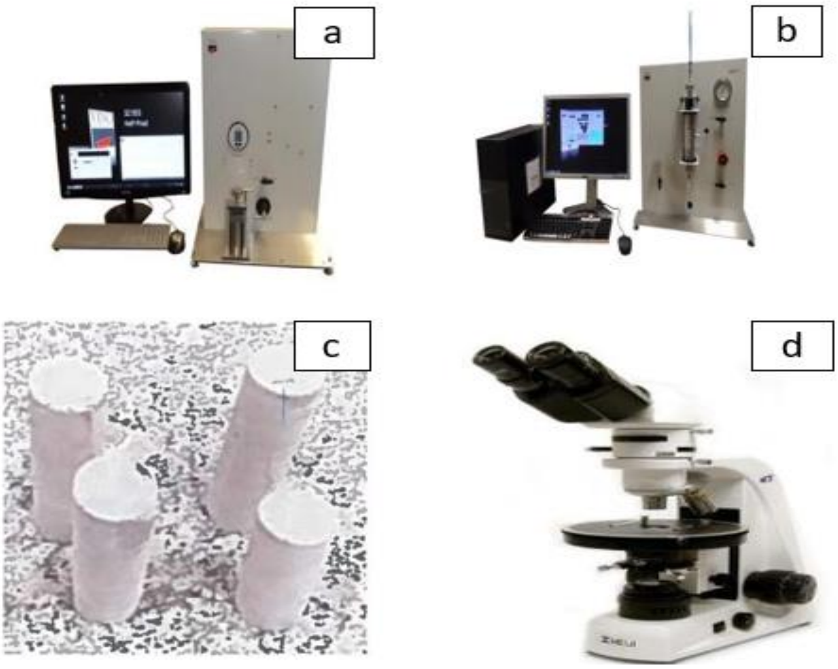

Figure 4 Instruments used for rock samples, a) Vinci Helium porosmiter b) Vinci Nitrogen gas permeameter c) Core plugs d) polarizing microscopy.

4. Results

4.1 Preface

This chapter overview consists of two sets of data collected from the surface and subsurface of the Qamchuqa Formation (wireless log data and rock sample data) due to calculated and estimated porosity and permeability and lithology with thin sections of the surface and subsurface of upper Qamchuqa Formation.

4.2 Basic Description of the outcrop, and rock samples

Rock physics empirical basics are derived from observations of rock samples under certain conditions (pressure and temperature). Physical parameters (for example, pore spaces, electrical, elastic, and thermal properties) of several kinds of rocks are determined in laboratories. Core analysis is a subset of experimental rock assessment. It is based on determining reservoir rock qualities directly on samples. There are two forms of well-core acquisition:

(1) conventional or (rotary) cores.

(2) core of the sidewalls (percussion and rotary sidewall coring).

A full-diameter core measures 1.75-5.25 in (4.5-13.5 cm) in diameter. The core is split into several plugs (approximately 1 inch in diameter and 3 inches long) for normal laboratory measurements. (Schön, 2015). Core plugs (Table 3) displays the size and lithology of the outcrop of Zewe section results analyzed from a laboratory of the University of Kurdistan Hawler. Also picture of core plugs shown in (Figure 4, C).

Table 3 lithology and size of core plugs.

Sample no	Formation type	Dimeter (mm)	Length (mm)
1	Limestone	25,4	50
3	Limestone	25,4	75
4	Limestone	25,4	70
8	Limestone	25,4	68

4.3 Thin section

Eight thin sections have been prepared from core plugs sampled in the top parts of the Qamchuga Formation. All the samples can be classified as wackestones to packstones according to Dunham classification (Figure ,5). The rock is dominated by dark micrite containing about 20 to 30 % of allochems. The allochems include abundant calcispheres (size about 0.06 mm) and planktonic foraminifers (globigerinids and globotruncanids), commonly between 0.1 and 0.25 mm in size. Most of the calcispheres and foraminifers (Figure, 6) are filled with sparite (cement); fewer of them are filled with micrite. Echinoderms are also present, but less abundant. There are a few poorly identifiable objects, probably bivalve fragments (Figure, 7). The rock is penetrated by many veins filled with coarse-grained sparite with many dark inclusions (probably filled with organic matter?), with some intergranular porosity. There is also infrequent fracture porosity in thin fractures (up to 0.1 mm) (certainly less than 1% of porosity).

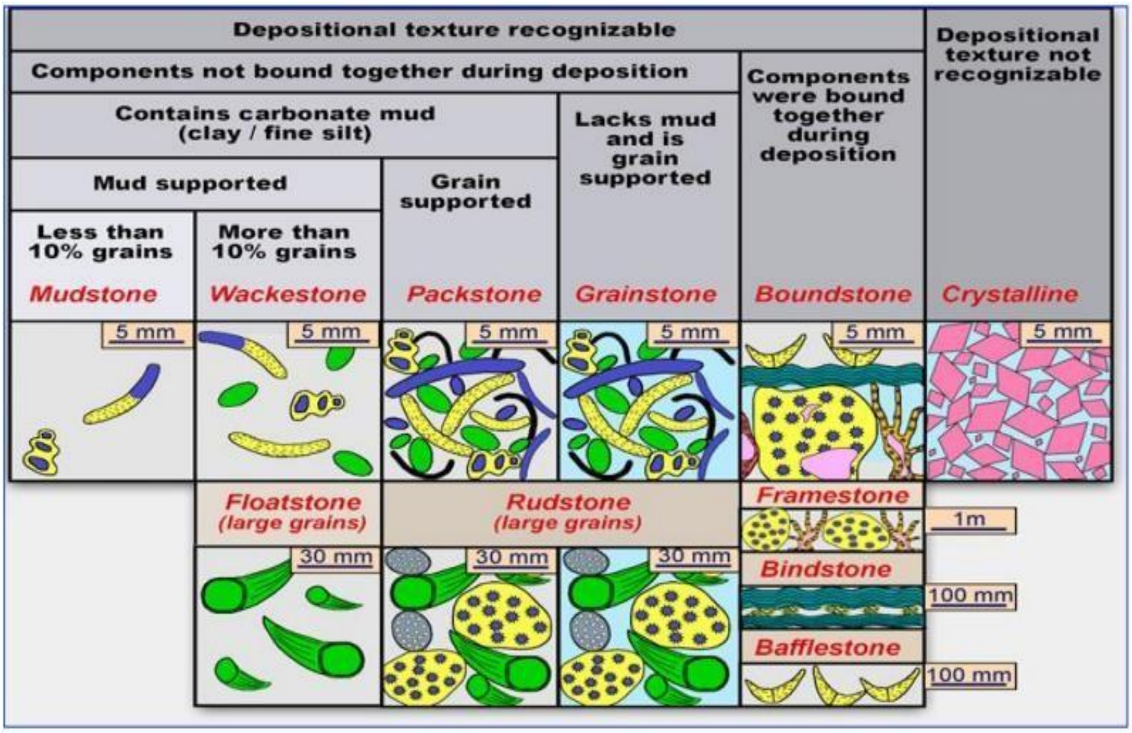

Figure 5 Classification of carbonate rocks according to Dunham (1962) and Embry and Klovan (1970); adopted from (Hussain et al., 2021).

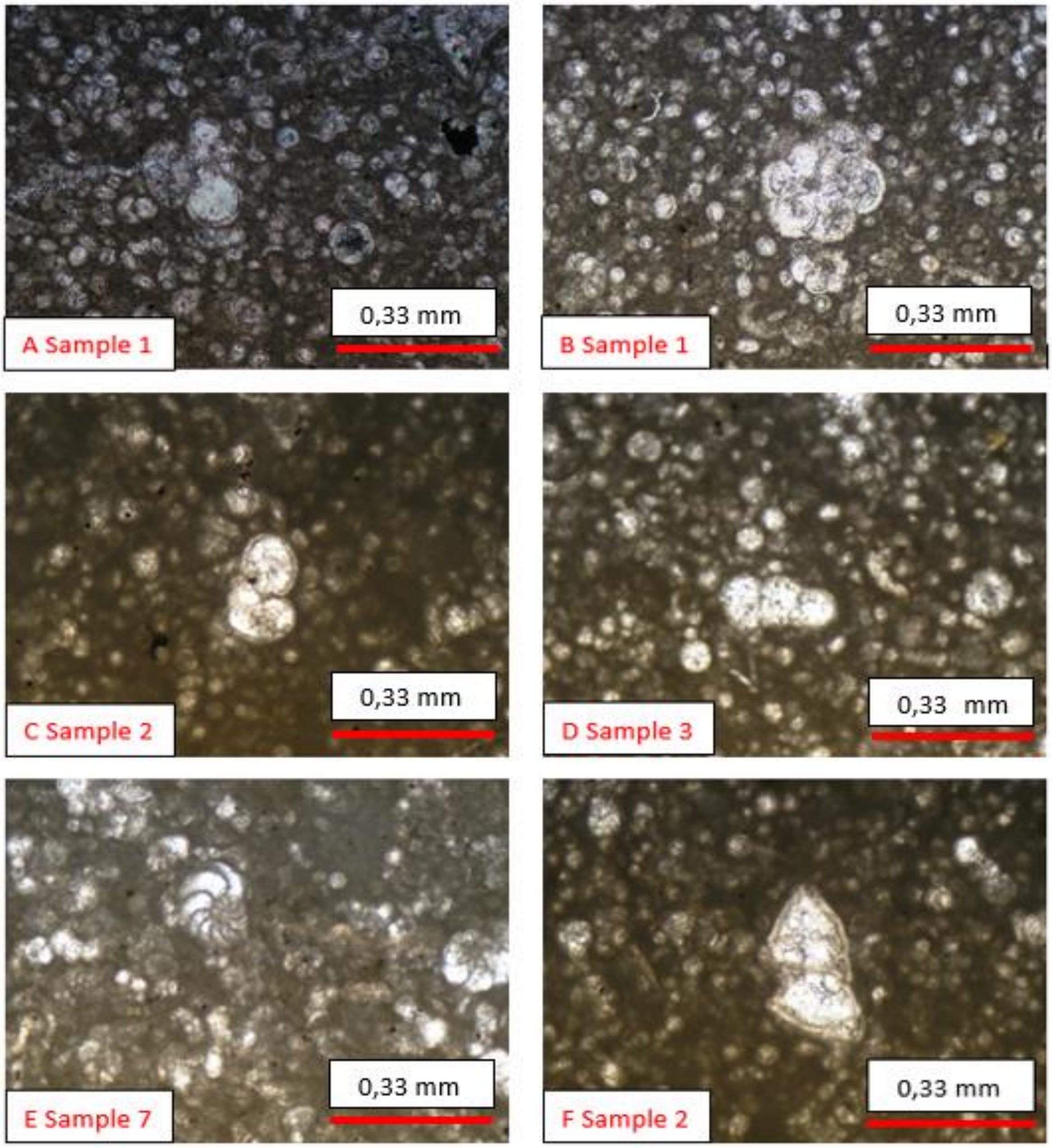

Figure 6 Microphotograph images from thin sections from the top of Zewe section; A and B: Sample 1, packstone with planktonic foraminifers (*Globigerina*) and possible calcispheres, all filled with sparite, A: crossed polars (XPL), B: parallel polars (PPL); C;Sample 2, wacke/Packstone with Planktonic foraminifers and and calcispheres (PPL); D: Sample 3, packstone with *calcispheres* and *globigerinid* foraminifers (PPL); E: Sample 7, packstone with planktonic foraminifers (*Globorotalia*, *Globigerina*) (PPL); F: Sample 2; wackestone with *Globotruncana* foraminifer (PPL).

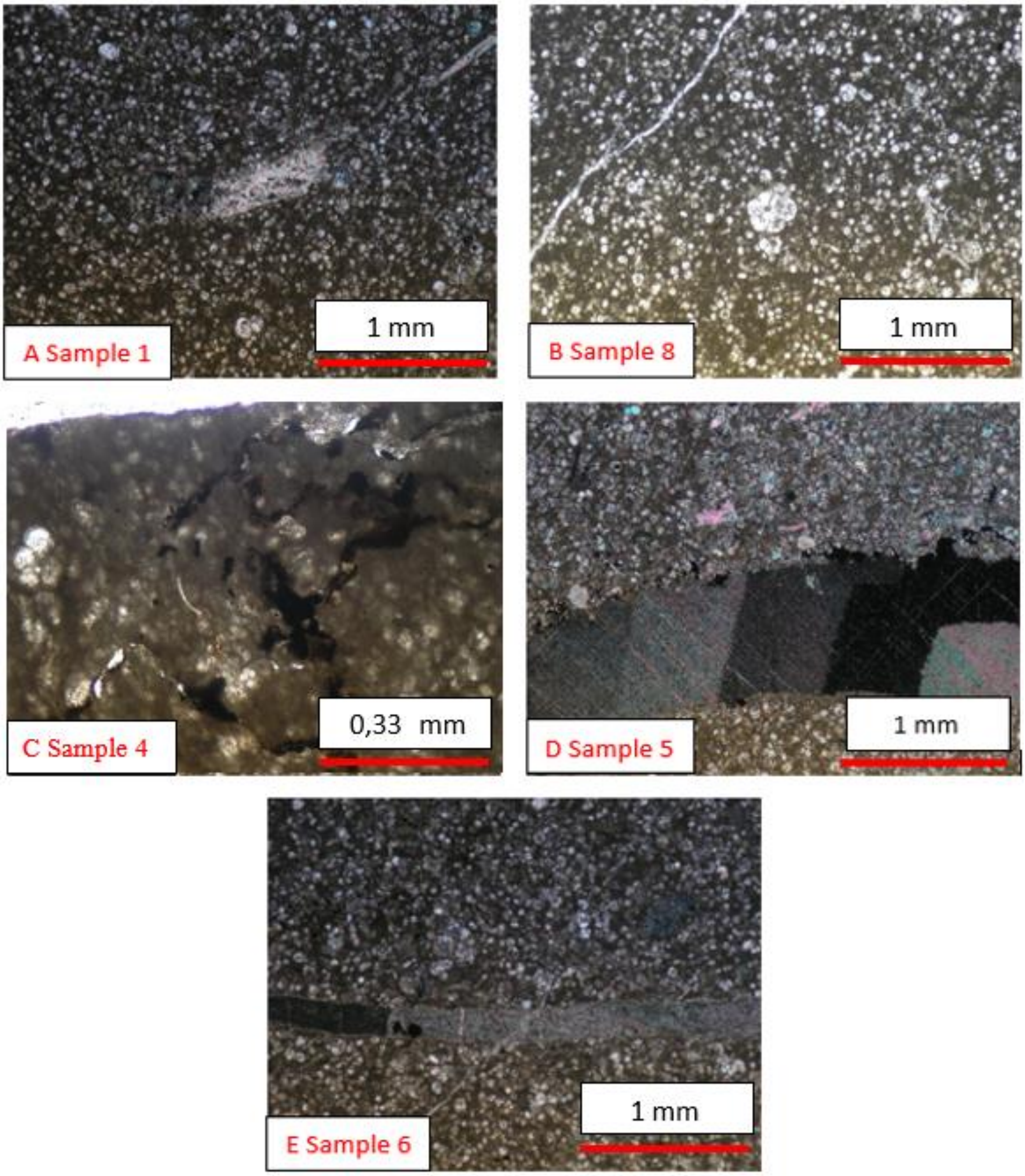

Figure 7 Microphotograph images from thin sections from the top of Zewe section (A, D, E, XPL; B, C, PPL). Packstone with planktonic foraminifers (*Globigerina*) are common fossils in all samples, as shown, e.g., in B (Sample 8). The samples 1, 5, and 6 show this veins filled by calcite; the sample 4 shows a stylolite with possible porosity obscured by organic matter.

4.4 Basic description of the well logs

Wireline for well Kz-1 is used for calculating porosity and lithology via porosity logs (neutron log, density log, sonic log) and gamma-ray log. Get Data software and Microsoft Excel with Grapher were used to analyse and digitize this instrument, and 859 points were selected by Get Data software for each preface logs from well Kz-1 at depth (2752-2923,6) m. The neutron log counts the collisions between neutrons emitted by a tool source and hydrogen atoms within the rock of the borehole wall, and the average neutron porosity (14%) and maximum (35%) for well Kz-1. The density log is a measure of the apparent density of the rock that is calculated from the absorption of gamma rays released by a tool radioactive source by the formation, average density porosity (9%), and maximum (34%). The third method of porosity estimation is based on acoustic sound speed measurements across the formation. The sonic tool has a mechanical source of compressional energy that transmits sound through the borehole wall's rock formation. The acoustic velocity of the rocks is recorded as a trace in the log, which is shown as a continuous function of depth. The log is measured in microseconds in keeping with foot of transit time. Sonic porosity range (0-3%). Typical porosity logs such as neutron, density, and acoustic logs were used to compute the volume of shale. The equation is written in terms of a number of parameters derived from well-log measurements. This equation, which takes matrix, fluid, and shale features into consideration, works well for many shaly formations independent of shaly distribution. Neutron porosity and density porosity are also useful for mapping and identifying lithologies. The neutron-density lithology plot was used in this study to assess the lithology of the Qamchuqa formation.

4.5 Neutron Density Cross Plot

The density-neutron cross plot we used to determine lithology of upper Qamchuqa formations from neutron and density logs data prepared after we inserted with depth on plot via Grapher software, that are pure lithologies like sandstone, limestone, or dolomite. The density–neutron cross plot evaluation may be ambiguous whilst the formation is of blended mineralogies, like a dolomite-cemented sandstone. For the case of fresh mud drilling fluid at The Qamchuqa Formation well Kz-1 appears to be composed mostly limestone, dolomitic limestone, and dolomite. (Figure 8) depicts a neutron-density lithology map from well Kz-1 in Qamchuqa Formation.

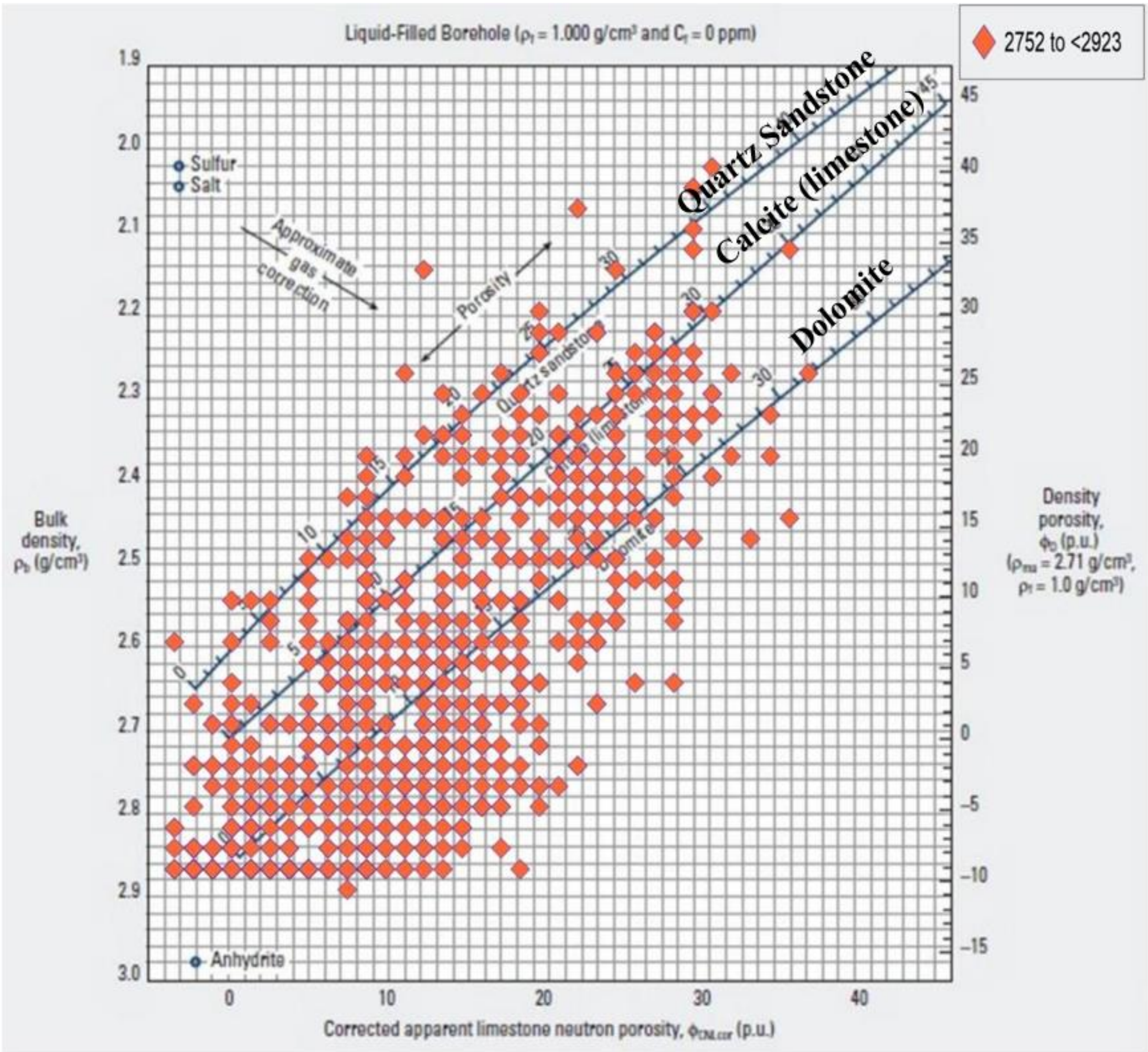

Figure 8 N-D cross plot for lithology identification of the studied formation in the well Kz-1.

4.6 Lithological Column

Based on the lithologies that have been determined by neutron-density cross-plotting, the lithological column has been created as a column of a whole section of the Upper Qamchuqa Formation in an interval of (2752-2923,6) m. The dominant lithologies are dolomitic limestone, dolomite, limestone, shale, and argillaceous limestone, as shown in the following (Figure 9).

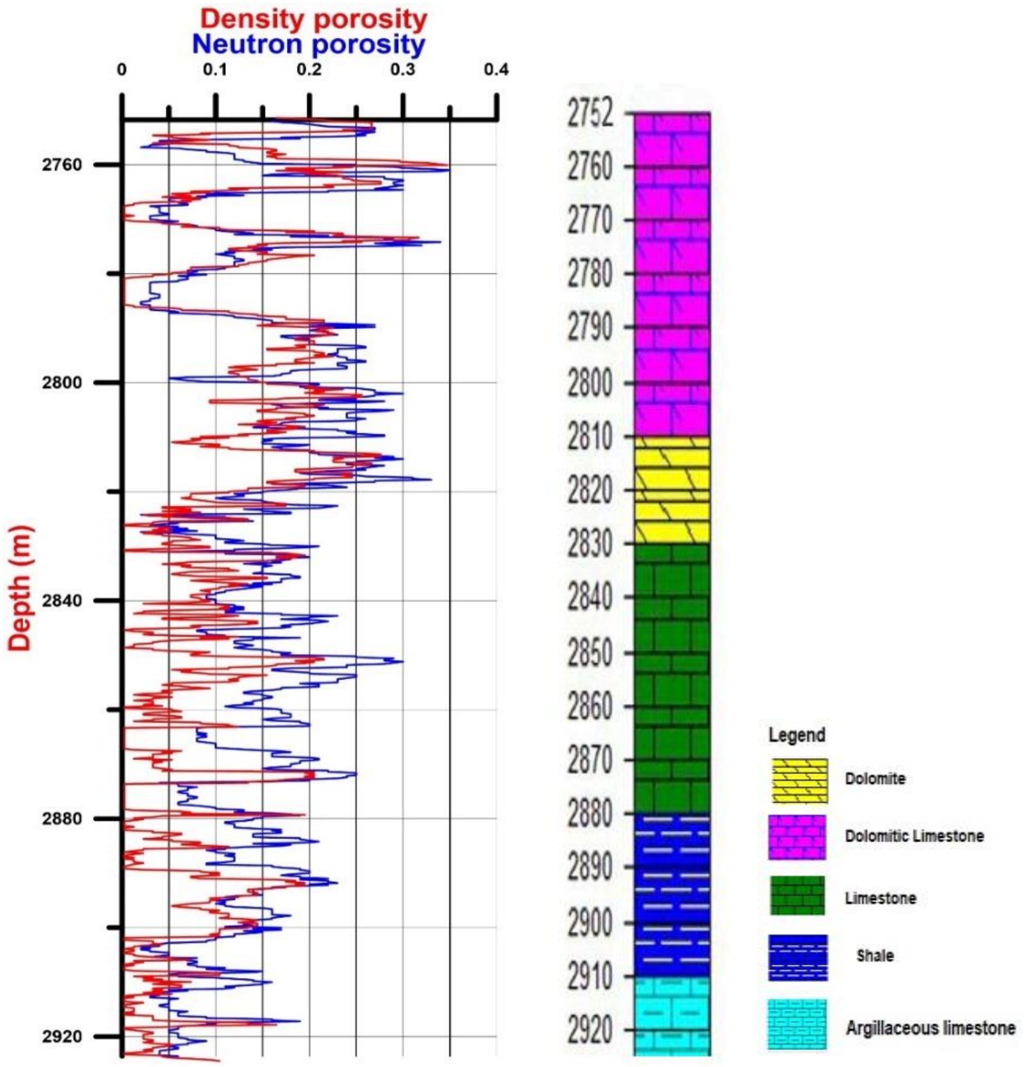

Figure 9 lithology column.

4.7 Gamma-ray log

Gamma-ray (GR) logs are used to describe lithologies and correlate zones by monitoring the natural radioactivity in formations. Shale-free sandstones and carbonates contain predominantly minerals (quartz, calcite, aragonite) with low radioactivity and provide low gamma-ray measurements. Because of the abundance of radioactive elements in shale and Shales frequently include potassium as part of their clay makeup and are known to absorb uranium and thorium, the gamma-ray log response rises as shale content rises. Nonetheless, if the sandstone contains potassium feldspars, micas, glauconite, or uranium-rich fluids, clean sandstone (i.e., with low shale content) may also have a robust gamma-ray reaction. In areas where the geologist knows potassium feldspars, micas, or glauconite are present, gamma-ray logs can be utilized not only for correlation or lithology identification but also for calculation of shale (clay) volumes from non-shale volumes (Asquith and Krygowski, 2004). The gamma-ray log is typically measured near the centre of the borehole. The gamma-ray log is often denoted by the sign GR, and its unit is given in the conventional American Petroleum Institute (API) units. In the Qamchuqa Formation, gamma-rays exhibit a strong deflection in the range (2752-2923,6) m. (Figure 10) depicts the gamma-ray measurement for the Qamchuqa Formation. The average gamma ray log result is approximately (26.92 API), the maximum is approximately (73.76 API), and the minimum value is approximately (5.38 API).

4.8 Shale volume

The shale parameters (concentration of uranium, thorium, and potassium) must be chosen from the shale layers surrounding the reservoirs and corresponding to the same depositional sequence. Shale is frequently more radioactive than sand or carbonate, hence gamma ray logs can be used to quantify shale volume in porous reservoirs. The volume of shale (Vshale) is represented as a decimal fraction or percentage of the total rock volume. The first step in determining the volume of shale from a gamma ray log is to calculate the gamma-ray index, IGR (Asquith and Krygowski, 2004) using the formula (1).

$$GR = \frac{GRlog - GRmin}{GRmax - GRmin} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

I_{GR} = gamma ray index,

GR_{log} = gamma ray reading of formation

GR_{min} = minimum gamma ray (clean sand or carbonate)

GR_{max} = maximum gamma ray (shale)

There are other techniques for estimating (Vshale), however we utilized the Larionov Equation (2) (Larionov, 1969) for determining shale volume based on the depositional period of the Qamchuqa Formation, which dates back to the upper Cretaceous (Turonian-Middle Campanian):

$$V_{shale} = 0.33 * [(2^{2.1GR}) - 1.0] \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

V_{shale} = shale volume

I_{GR} = gamma-ray index

The criterion established by (Ghorab, 2008) for evaluating zones based on their shale content was used (table 4). As shown in Figure 10 (concentration), the zones (Table 5) were identified in the depth intervals of the Qamchuqa Formation in the examined area based on their shale. According to the collected results (shale volume and Gamma ray log), five zones have been obtained; two of them are clean zones, one is shale, and the rest are shaly zones. the maximum result for shale volume is approximately (0.99%). Gamma ray sharp reflected at bottom of log depth (2880-2923 m)**.** The top of the log depth (2752-2760 m) clearly shows clean rocks.

Table 4 shale zonation based on the percentage shale volume (Ghorab, 2008).

V_{shale} (%)	Zones
< 10	Clean zone
10-35	Shaly zone
>35	Shale zone

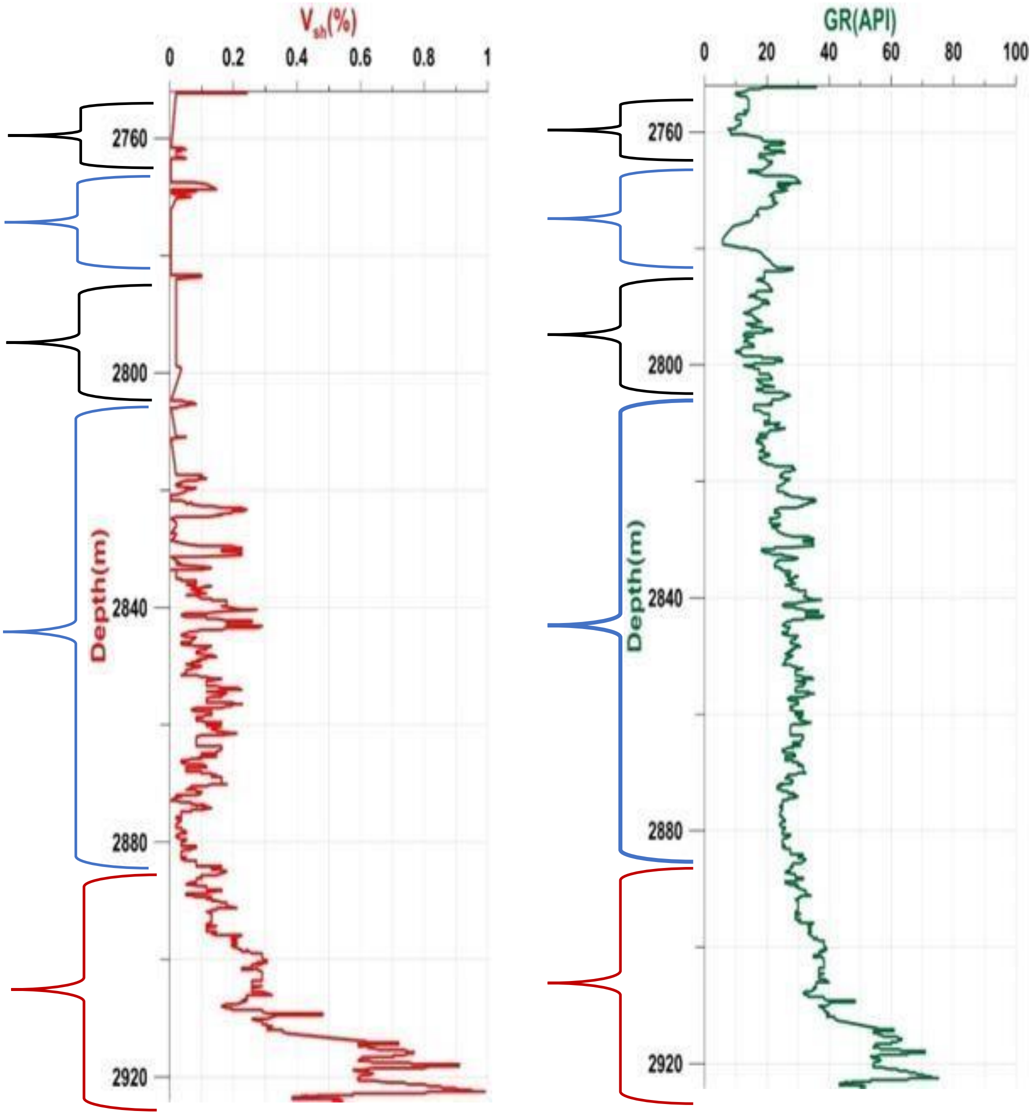

Figure 10 Gamma ray log (right) and shale volume zonation (left) of the Qamchuqa formation in the studied field black arrow show clean zone blue arrow show shaly zone red arrow show shale zone.

Table 5 shale zonation for Qamchuqa Formation shale volume based on table 4.

Formation	Interval	zones
Qamchuqa Formation	2752_2760 m	Clean zone
	2760_2780 m	Shaly zone
	2780_2800 m	Clean zone
	2800_2880 m	Shaly zone
	2880-2923 m	Shale zone

4,9 Porosity and permeability measurements

porosity and permeability measurements from the surface and subsurface of the Qamchuqa formation in northern Iraq Data have been analyzed from rocks in the laboratory and wireline logs on the field. Outcrop samples were taken from the Zewe section, and subsurface data were taken from well Kz-1. Eight rock samples have been prepared from the Zewe section to measure porosity. Four core plugs were broken by the driller at the laboratory; the rest have been used successfully. Also, neutron, density, and acoustic logs and their combinations are utilized to estimate porosity. Porosity logs (density and neutron) are largely determined by porosity; however, the formation matrix, lithology, and kind of fluid present in the pores all have an impact.The degree and amount of shaliness, as well as the type of porosity.

4,10 Rock samples porosity and permeability from outcrops

Porosity was measured for all the core plugs using the Vinci helium porosmeter. Table 6 shows the porosity results from the surface of the Zewe section of the Qamcuqa Formation by core plugs data, which ranges from (0.91 to 3.23 %), which is very low after qualifying with the (North, 1985) classification for four core plugs with negligible porosity.

Table 6 Porosity results.

Sample no	Porosity (%)	Permeability (mD)
1	0.91	0.051
3	1.72	0.06
4	3.66	0.0899
8	3.23	0.082

The carbonate rocks are characterized by extremely low matrix permeability. The measurement of permeability depends on Darcy Law which requires the satisfaction of the Darcy Law assumptions (Steady-State Flow). However, due to the very tight nature of core plugs (low matrix permeability with no fracture and/or vugs) according to (North,

1985) classification (Table 2), the measurements of permeability could not be stabilized. Hence, the average range of the permeability of the samples is (0.05 - 0.082 mD). Permeability values are given in (Table 6).

4,11 Rock samples porosity and permeability from subsurface

Porosity and permeability measurements on cored samples (Figure 11) from the Qamchuqa formation are presented for 112 data sets, taken from published data and descriptions (Qadir ,2008). These data have been taken and analyzed from the subsurface of the Khabbaz oil field in well Kz-1 at a depth of (2912 - 3000) m. This depth interval has been subdivided into three different zones with specified rock properties, which are explained in the following text. The top unit (A) at a depth of 2912 to 2940.85 m is characterized by an average porosity of 0.12% and an average permeability of 9.68 mD. The middle point (B) at a depth of 2940.85 to 2970 m is characterized by an average porosity of 0.15 percent and an average permeability of 16.18 mD. Point (C) in below, at a depth of 2970.85 to 2998.22 m, has an average porosity of 0.09 percent and an average permeability of 8.74 mD. For a more accurate prediction, we can divide A, B, and C into some subzones in which the formation in some thin layers is different from another lower one. For example, zone A is divided into three sub-zones (A1, A2, and A3), which illustrate a good quality of porosity and permeability; after that, zone B includes two fine zones (B1, B2), and zone C as well (C1, C2).

4.12 Porosity logs

The neutron, density, and acoustic pace gadget are examples of logging techniques used to decide the quantity of pore place in a rock. We used an equation to calculate porosity for density and sonic porosity logs; however, the results for neutron logs are the same as those obtained from wireline logs. The acoustic log was used as a foundation, and the other logs were interpreted using acoustics, as shown in next slides.

4,12,1 Density porosity

Porosity logs are mostly utilized with density logs. Other applications include identifying evaporitic minerals, detecting gas-bearing zones, determining hydrocarbon density, evaluating shaly-sand reservoirs, and evaluating complicated lithologies (Schlumberger, 1972). Density is expressed in grams per cubic centimetre, (g/cm^3) (kg/m^3 or Mg/m^3) and is represented by the Greek symbol (rho, ρ). The density log employs two distinct density values: the bulk density (b or RHOB) and the matrix density (ma). The density of the whole formation (solid and fluid portions) as recorded by the logging gear is referred to as the bulk density. The matrix density is the density of the rock's solid structure. To calculate density porosity, the matrix density and kind of fluid in the borehole must be determined. The density porosity formula as follows:

$$ØD = \frac{\rho ma - \rho b}{\rho ma - \rho fl} \quad (3)$$

where φ_D = density derived porosity ρ_{ma} = matrix density (gr/cc) ρ_b = formation bulk density (the log reading, gm/cc) ρ_{fl} = fluid density (1.0gm/cc for freshwater mud)

The proposed matrix densities for different lithologies are presented in table 7 (Asquith and Krygowski, 2004), and the value of ma used to calculate density porosity is mostly decided by the N-D cross plot (chapter three). The fluid density (fl), which changes with fluid type salinity, will also be used to calculate porosity from bulk density. Because the drilling fluid utilized in this study was a freshwater base mud, the flow value employed was 1.0 g/cc.

Table 7 Matrix density values common types of rock by (Asquith and Krygowski, 2004).

Lithology	Density (g/cm^3)
Sandstone	2.65
Limestone	2.71
Dolomite	2.87
Anhydrite	2.98

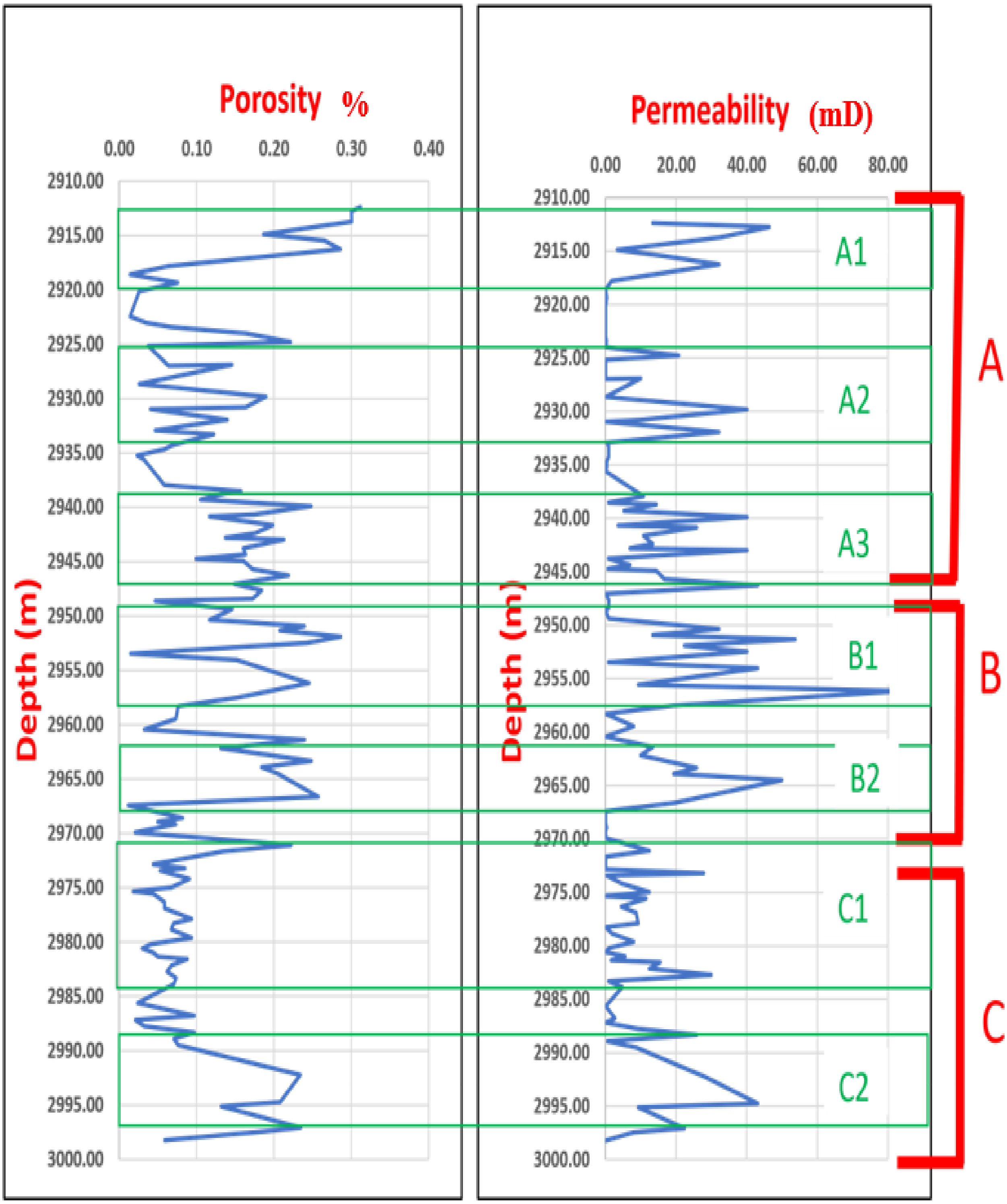

Figure 11 Core samples porosity and permeability of Qamchuqa Formation in Khabbaz oil field data adopted from (Qadir, 2008).

4,12,2 Neutron porosity

Neutron logs are primarily used to delineate porous rocks and determine porosity (N, PHIN, or NPHI). They are mostly affected by the amount of hydrogen in the formation. Thus, the neutron log indicates the amount of liquid-filled porosity in clean rocks with pores filled with water or oil (Schlumberger, 1991). Porosity may be read directly from the neutron log in most circumstances, such as in limestone lithology. To eliminate lithology impacts, it should be applied to the other lithology by taking the average porosity calculated from density and neutron logs (Rider and Kennedy, 2011).

4,12,3 Sonic porosity

porosity log that captures the transit time (At) of a compressional sound wave as it goes through the formation along the borehole's axis is known as a Sonic log. The interval transit time in microseconds per foot, usec/ft (or microseconds per metre, usec/m), is the reciprocal of the velocity of sound. Borehole compensated (BHC) devices and the Wyllie time-average equation (Asquith and Krygowski, 2004) used for estimate porosity from sonic rock.

$$Øs = \frac{\Delta t \log - \Delta\, tma}{\Delta\, tfl - \Delta\, tma} \quad \text{………………………………………………….} \ (4)$$

Where:

ØS = Sonic-derived porosity

Δtma = interval transit time in the matrix (At limestone is used)

ΔT log = interval transit time in the formation (measured by log)

ΔTfl = interval transit time in the fluid in the formation (freshwater mud = 189 μsec /ft; saltwater mud = 185 μsec/ft), this term chosen according of type of used drilling mud in each well.

4.13 Porosity logs evaluation

The next zone of the Qamchuqa formation illustrated in Figure 12, is from 2750 to 2923,6 meters. According to the obtained porosity from the well logging data using the methods mentioned in the text, the density and neutron porosity confirm each other. This zone divided into three parts of very fine rock, with a thickness of 170 meters. Subzones are D1, D2, and D3.

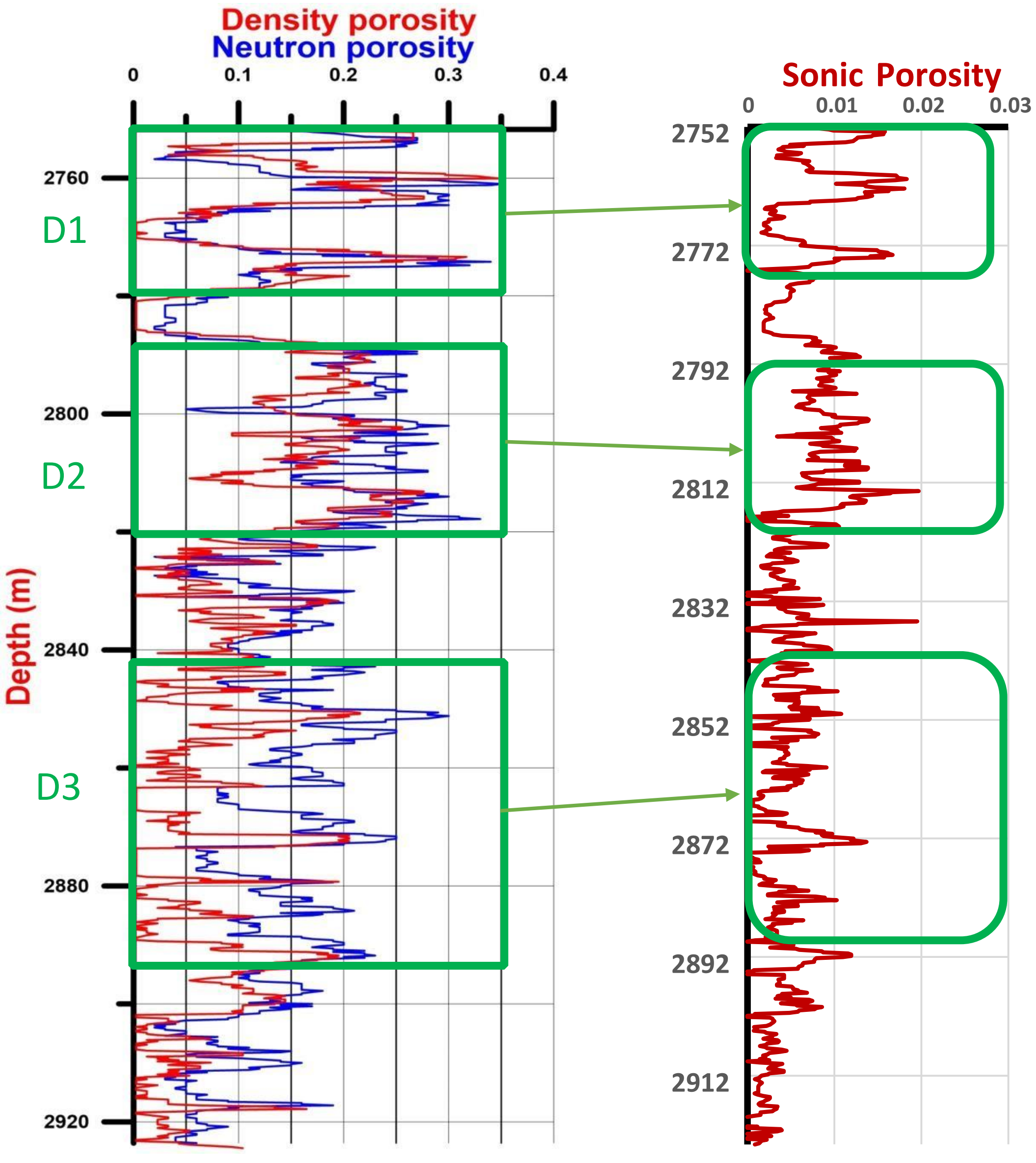

Figure 12 correlation of calculated porosity from well logging data.

Subzone D1:

Porosity increases from 2750 meters to 2760 meters, and when subjected to sonic log porosity, we discovered that the formation contains a high volume of fractures, which is known as secondary porosity or dual porosity. D1 is the best subzone of the whole depth of the formation for bearing fluids. In some way, it has the potential to be a pay zone. The thickness of the D1 is about 10 meters.

Subzone D2:

This part from depth of 2755 to 2790 include 15 meters' thickness. In similarity with the D1, D2 is a fine rock with good porosity which is different from 15 to 20 in average. Sonic log shows the confirmation of a less homogenous rock versus D1. This section ranges in depth from 2755 to 2790 meters. The D2, similar the D1, is a fine rock with good porosity, which ranges from 15 to 20 on average. The sonic log shows the confirmation of a less homogenous rock versus D1.

Subzone D3:

This zone differs from the subzones D1 and D2, which are located above. The thickness of D3 is about 45 meters, which ranges from 2842 to 2887 meters. The porosity is not very different in the whole depth of this area. The porosity average is about 15%. The sharp difference between both porosities from density and neutron log shows that this zone includes more fractures.

For more accuracy and in-depth characteristics of the Qamchuqa formation subject to net pay, which can represent the potential of being a pay zone, we divide into more small subzones. We specified 10 subzones subjected to net pay and fine rock. This depth has five subzones with good-quality rock and another five with less porous rock.as shown in Figure 13.

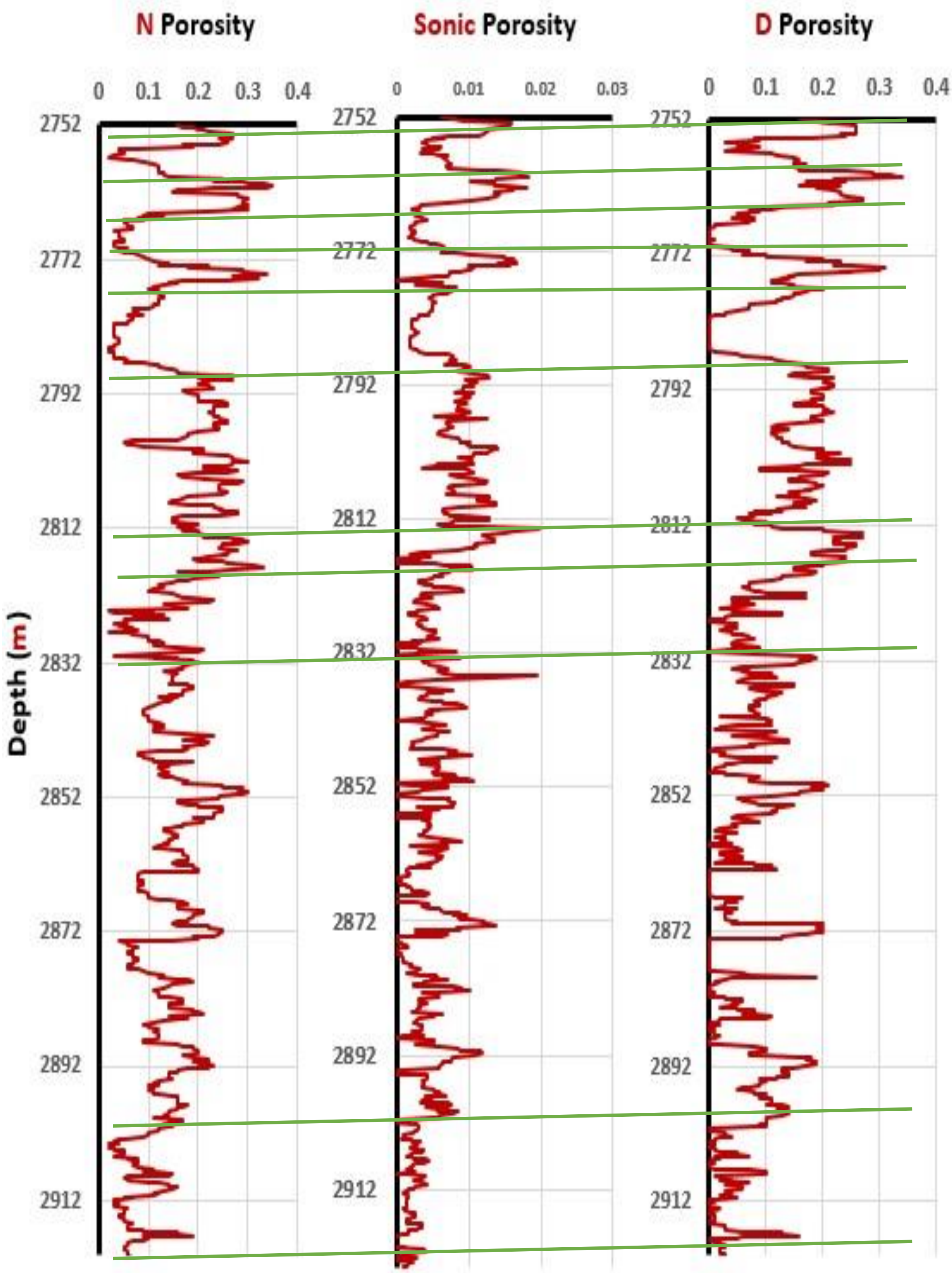

Figure 13 porosity logs correlation.

5. Conclusion and Discussion

5.1 Discussion

The investigated carbonate rock has an incredibly low matrix permeability. Because there were no fractures, the core plugs' permeability measurements could not be stabilized. The samples' average permeability ranges from 0.05 to 0.08 mD as a result. The real permeability of the rock in the well cannot be captured by permeability values. We came to the conclusion that surface-sampled core plugs are free of cracks. According to a case study of the Upper Cretaceous Qamchuqa Formation, burial diagenesis increases porosity fluctuations between the surface and subsurface and emphasizes them.

It has been noted that the upper zone of the Qamchuqa formation extends from 2750 to 2890 m. Well, the porosity for all logs has been determined based on the logging data from the porosity tools. The Qamchuqa formation at this depth is different, as shown by the Figure 12 correlation of density and neutron porosity. As a result, the region is divided into three major subzones, each with a different property. D1, D2, and D3 are the three main subzones. A good average of porosity from 5 to 25% is present in D1. The average porosity in the D2 subzone is 15%. Less porous than the upper subzones is the D3 subzone. Compare this to a gamma ray log taken at the same depth of the well; Kz-1 fine rocks were found at the top of the log, while deeper results detected more shaly and shale rocks .

Bore hole direct core data categorized to the 7 subzones with high quality and good characteristics after preparing and analyzing the measured data from the depth of 2900 to 3000 meters. Zone A has good permeability and fine porous medium. The best rock may be found in Zone B. In contrast to the above subzones, Zone C is not a fine rock. Zone B can be estimate as effective porosity cause of high value of porosity and permeability in same time.

5.2 Conclusion

After analysing and calculations (Borehole log data log data and Rock samples data) at surface and subsurface of Qamchuqa formations to Comparison porosity and permeability.

- Log porosity at depth 2750 to 2923,6 m in well Kz-1 after evaluated the highest quality of porosity occurred at zone (D1).
- Bore hole direct data (cores) for Porosity and permeability at depth 2900 to 3000m best reservoir rock occurred at zone B.
- According to rock sample data from the surface of Qamchuqa Formationthe , porosity and permeability results in the Zewe section are poor; additionally, those limestone rocks are classified as wackestones to packstones by Danhum, and the most common fossils are planktonic foraminifers (*Globigerinids and Globotruncanids*).
- The Upper Qamchuqa reservoir is mostly made up of dolomitic limestone and dolomite, limestone, shale, and argillaceous limestone according to the neutron and density cross plot.
- The highest shale volume quantity was obtained at a depth of 2880-2923 m, according to Gamma-ray log results for well Kz-1 at depths of 2750-2923 m.

In summary, the porosity and permeability quality at the subsurface of the Qamchuqa Formation are better in Kz-1 than at the surface in the Zewe section, according to calculations and evaluations for this project.

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