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Petrographical and Petrophysical Porosity Evaluation for Subsurface Cretaceous Nubia Sandstone at South-Ghara Oil Field, Gulf of Suez, Egypt

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ABSTRACT

Due to information scarcity of the study area, so this work is an attempt to uncover important subsurface Nubia sandstone oil reservoir characteristics mainly in terms of porosity using petrographic description in addition to porosity measurements for the core samples got from two wells (GH404-A2A and GH404-A3B) at South-Ghara oil field, Gulf of Suez region. The studied Nubia sandstones are mainly classified as quartz arenite. The recorded quartz varieties indicate that the studied Nubia sandstone in the two wells have been derived from plutonic and high rank metamorphic rocks. The general scarcity of feldspar could be attributed to its decomposition due to the low topography associated with warm and humid climate.

The total porosity of the (15) selected sandstone samples representing the Nubia sandstone is measured by a Helium porosimeter. The average measured value for the studied samples of the Nubia sandstone is 15.24% and 12.22% for the two wells GH404-A3B and GH404-A2A respectively. The values indicate a fair porosity. Based on the petrographic investigation, the recorded porosity is of type interparticle. The precipitated cement in the form of iron oxides, calcite, evaporate and silica (as quartz overgrowth or chalcedony) is the most effective factor in reducing the primary porosity of the studied rocks. Also, authigenic clay minerals and feldspar have reduced the primary porosity.

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تقييم المسامية البتروفيزيائية والبتروغرافية للحجر الرملي النوبي تحت السطحي الكريتاسي فى حقل نفط جنوب الغارة، خليج السويس، مصر

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الملخص

بسبب ندرة المعلومات في منطقة الدراسة ، يحاول هذا العمل الكشف عن خصائص مكامن زيت الحجر الرملي النوبى الجوفى الهامة بشكل رئيسي من حيث المسامية باستخدام الوصف الصخري بالإضافة إلى قياسات المسامية للعينات الأساسية التي تم رفعها من بئرين GH404-A2A) و GH404-A3B) في حقل نفط جنوب الغارة ، منطقة خليج السويس. تصنف أحجار النوبة الرملية المدروسة بشكل أساسي على أنها كوارتز أرينيت. تشير أنواع الكوارتز المسجلة إلى أن الحجر الرملي النوبي المدروس في البئرين قد نشأ من الصخور المتحولة ذات الرتب العالية. يمكن أن تكون الندرة العامة للفلسبار مرتبطة بتحللها بسبب التضاريس المنخفضة المرتبطة بالمناخ الدافئ والرطب.

تم قياس المسامية الكلية لعدد (15) عينة مختارة من الحجر الرملي تمثل حجر النوبة الرملي بمقياس الهيليوم. متوسط القيمة المقاسة للعينات المدروسة من الحجر الرملي النوبة هو 15.24٪ و 12.22٪ للبئرين GH404-A3B) و GH404-A2A)على التوالي. تشير القيمة إلى مسامية عادلة. نوع المسامية المسجلة هى التى بين الحبيبات، بناءً على التحقيق الصخري. تعتبر المواد اللاحمة المترسبة على شكل أكاسيد الحديد والكالسيت والمتبخرات والسيليكا، مثل فرط نمو الكوارتز، أكثر العوامل فاعلية في تقليل المسامية الأولية للصخور المدروسة. أيضا، أثرت المعادن الطينية والفلسبار في المسامية الأولية عن طريق الاختزال .

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Introduction

The area of the present study lies in the southern part of Gulf of Suez, Egypt, where many oil fields of commercial importance are located such as Shoab Ali, Zeit Bay, Bahr North East, Geisum, Esh Mellaha, Tawila, Gazwarina and the studied South Ghara. The studied wells within the South Ghara Oil Field are displayed in Figure (1). The stratigraphic sequence of the studied area ranges in age from Precambrian to (Fig. 2).

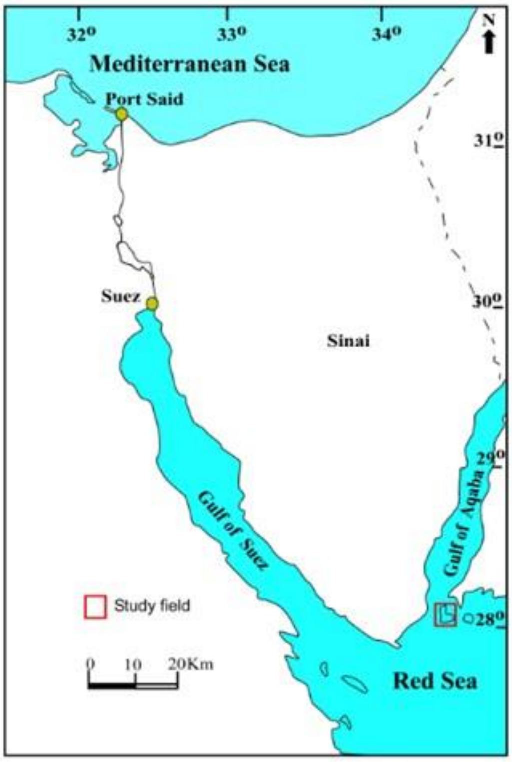

Fig. 1. Location map of the study area

Intensive exploration in the studied area started in 1964 by an aeromagnetic survey over the whole Gulf of Suez. The most detailed and comprehensive survey was carried out by EGPC in 1984. Many marine seismic surveys were carried out in the Gulf of Suez, and the studied area to evaluate their oil potentialities. The first discovery in the southern area of the Gulf of Suez was Gemsa oil field 1908. The geology and hydrocarbon potentiality of the Gulf of Suez were subjects of numerous investigations. The stratigraphy, structure, geologic history and hydrocarbon potential of the area have been investigated by many authors such as Said (1962 and 1990), Egyptian General Petroleum Corporation (E.G.P.C.) Strat. Comm. (1964), Robson (1971), Meshref (1976 and 1990), El Ayouti (1980), Sultan and Schultz (1984), Salah (1989), Robertson Research Center (1986), Bosworth et al. (1998), Sharp et al. (2000), Shazly et al. (2013), El Diasty (2014), El Nady and Mohamed (2016), El Nady et al. (2016), Rohais et al. (2016), Van Dijk et al. (2018), Mohamed and El Nady (2019), Radwan (2020) and Elmaadawy et al. (2021).

The lithostratigraphic units of the southern sector are classified into the main following sequences:

A-Pre-Rift lithostratigraphic units (older), where this megasequence includes sediments deposited under varied environments prior to the Oligocene. The Pre-rift Megasequence consists of the following:

1-Eocene sediments (younger).

2-Paleocene sequences.

3-Upper Cretaceous carbonate sequences.

4-Upper Cretaceous clastic deposited.

5-Nubia sandstone sequence (older).

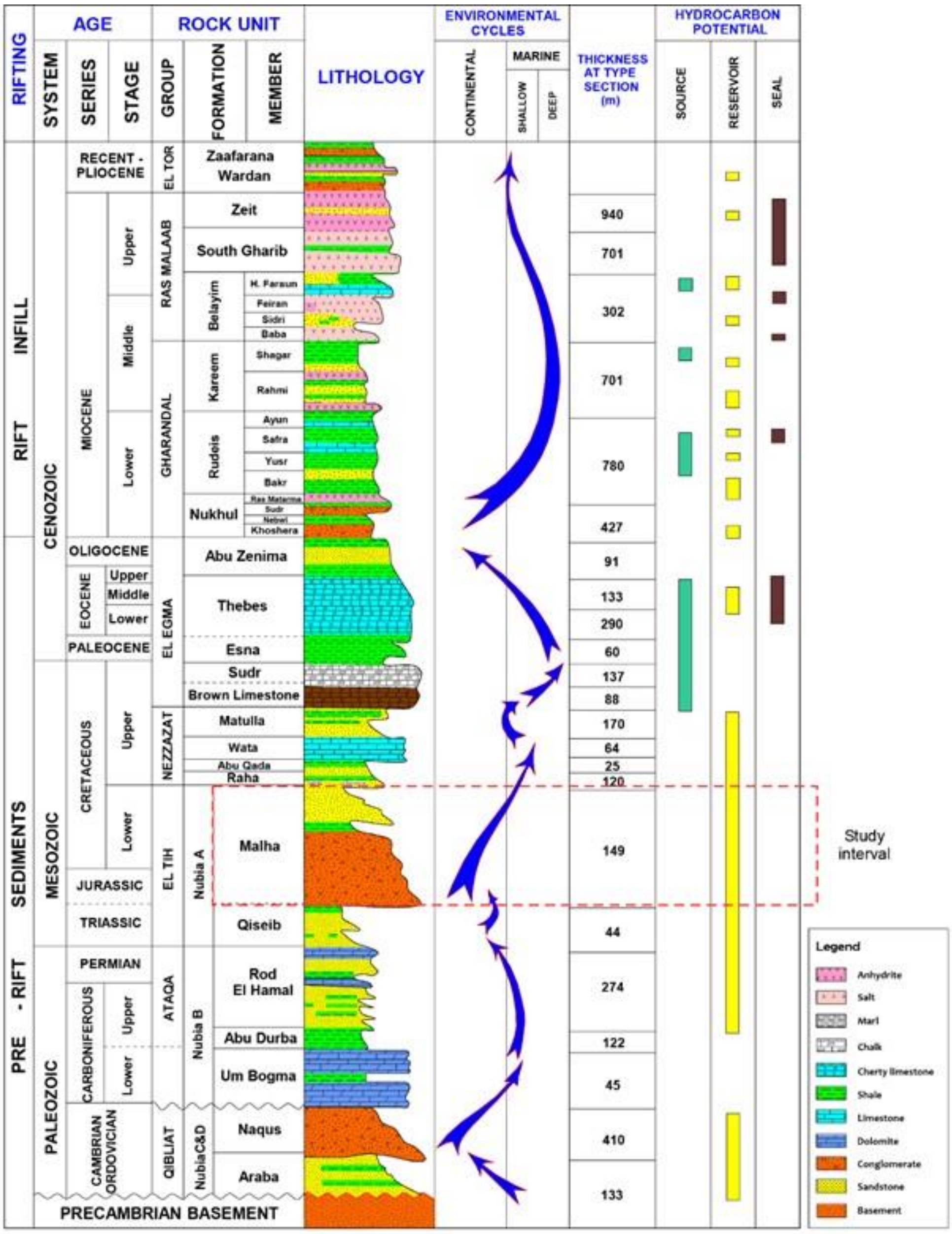

Fig. 2. **Summarized stratigraphy of the central Gulf of Suez (modified after Alsharhan and Salah 1995; Farouk et al., 2022).**

B-Syn-Rift lithostratigraphic units (younger), where this megasequence includes those sediments that were deposited during the Oligocene, Miocene and Post-Miocene times. It consists of several lithostratigraphic units deposited under different environments. Generally, the Syn-Rif Megasequence consists of the following:

1-Miocene sediments (younger).

2-Oligocene sediments (older).

Concerning Nubia, the term Nubia sandstone was first introduced by Russegger (1937) to include the clastic section which lies immediately above the basement complex. The Nubia sandstone studied by many authors (e.g. Said, 1980; Robertson Research, 1986; Masoud et al., 2013; Temraz and Elnaggar, 2016; and Sarhan and Basal 2019). Said (1962) refers the “true”

Nubia sandstone to the Upper Cretaceous age, but the term is loosely used to cover all the Paleozoic and Mesozoic sandstones of Nubia facies.

Using electric logs supported by core and ditch samples got from deep exploratory wells, petroleum companies subdivided this unit into four members (A, B, C and D) (Schlumberger, 1984). The distribution of the units in the southern part of the Gulf of Sues varies widely, they may be missed due to erosion and/or non-deposition in some parts. It is commonly noticed that Nubia (A, C and D) are predominantly sandstone of continental to shallow marine environment, whereas Nubia (B) is interbedded with dark colored shale and represents a shallow marine environment. Available data show that units (C and D) unconformably overlie the Precambrian basement complex, and Nubia (B) conformably overlies Nubia (C and D), while Nubia (A) unconformably overlies Nubia (B) (Robertson, 1986).

Aim of work

The study area nearly has no published researches about it, so this study tries to uncover the subsurface Nubia sandstone reservoir characteristics mainly in terms of porosity using petrographic description in addition to porosity measurements of the core samples from two wells (GH404-A2A and GH404-A3B) at South-Ghara oil field, Gulf of Suez region. This work is considered an additional value for the study area that suffers from the lack of data required for petroleum exploration activities.

Materials and Methods

Fifteen thin sections representing the subsurface Nubia sandstone rocks are prepared and petrographically examined for mineralogical and textural features. The nature and the effect of matrix and cement on the porosity of the studied samples are emphasized. The thin sections are photomicrographed using Leica DM microscope. The porosity and pore connectivity is marked with blue color using exposure contrast interface in Leica LAS software suite. In the present work, the classification of sandstones is based on Okada (1971). In addition, the total porosity of (15) selected sandstone samples representing the studied formation (5 samples for GH404-A3B well and 10 samples for GH404-A2A well) are measured by Helium porosimeter (Model No. 3020-062).

Results and Discussion

Porosity results

The total porosity of (15) selected sandstone samples representing the studied formation (5 samples for GH404-A3B well and 10 samples for GH404-A2A well) are measured by Helium porosimeter. The average measured value for the studied samples of Nubia Formation is 15.24% and 12.22% for the two wells GH404-A3B and GH404-A2A respectively. The values indicate a fair porosity according to Levorsen (1967). The nomenclature of porosity in the present study is that proposed by Choquette and Pray (1970).

The recorded porosity types are interparticle. The porosity values of the measured samples are displayed in Table (1), whereas the average and types of porosity and the plate identification of the studied formations at the studied wells are displayed in Table (2).

Table 1: The measured porosity values of the studied samples from the studied wells.

Formation / Well	Sample	Depth, ft	Plate #	Porosity, %
Nubia Fm. Well: GH404-A3B	4-Nb-1	10613		12.6
	7-Nb-1	10633		21.0
	2-Nb-2	10647	1 (A)	11.6
	6-Nb-2	10669		10.5
	9-Nb-2	10682		20.5
Nubia Fm. Well: GH404-A2A	4-Nb-A	10711	5 (A and B)	10.9
	11-Nb-A	10751		20.4
	13-Nb-A	10763	4 (C and D)	15.9
	4-Nb-B	10787		2.5
	6-Nb-B	10797	3 (C and D)	14.6
	12-Nb-B	10820		12.5
	2-Nb-C	10841		19.3
	6-Nb-C	10860	4 (E and F)	7.2
	11-Nb-C	10882		8.7
	13-Nb-C	10892		10.2

Table 2: The porosity (types and average measured values) and the plate identification of the studied wells.

Fm.	Well	Type of porosity (microscopic)	Plate #	Average measured porosity, %
Nubia	GH404-A3B	Interparticle	1A, 3A, 5C, 6(AandC)	15.24
	GH404-A2A	Interparticle	1(C and E), 2A, 3(C and E), 4 (A, C and E), 5A	12.22

Petrography of the studied samples

The microscopic examination of the Nubia sandstone samples from the two wells (GH404-A2A and A3B) reveals that they are essentially composed of quartz grains, feldspars and rock fragments in a decreasing order of abundance. Quartz, the major component, ranges from 60% to 90% in the two studied wells. Feldspars, mainly as microcline, in fresh and altered grains, are recorded in a proportion reaching up to 10% in sandstones of GH404-A3B well only, while they are very rare in sandstones of well GH404-A2A. Chert, authigenic clays, organic matter and opaque minerals mainly iron oxides and pyrite are abundant in both wells. Also, anhydrite, a few glauconite grains and fossils fragments are recorded especially at GH404-A3B well.

1. Sandstone classification

In reference to Okada (1971) classification, sandstones of the present work are classified as arenites and wackes. The Nubia sandstones in the two studied wells are predominantly arenites, represented by quartz arenites (Fig. 3). The mineral composition and petrography of the Nubia sediments from the studied wells are discussed as follows:

Quartz

Quartz grains are colorless to cloudy, in a few cases they are stained or coated by a thin layer of iron-oxides. The quartz grains range in size from fine to coarse (Plate-1, A and B), occasionally very coarse, and they are poorly to moderately sorted. It is noticed that the grains become finer upwards in the section, a feature well observed in GH404-A2A well, in which the medium grains increase towards the upper part of the formation on the expense of coarser grains. On the other hand, quartz grains of well GH404-A3B sometimes exhibit gradation from very fine to medium (Plate-1A).

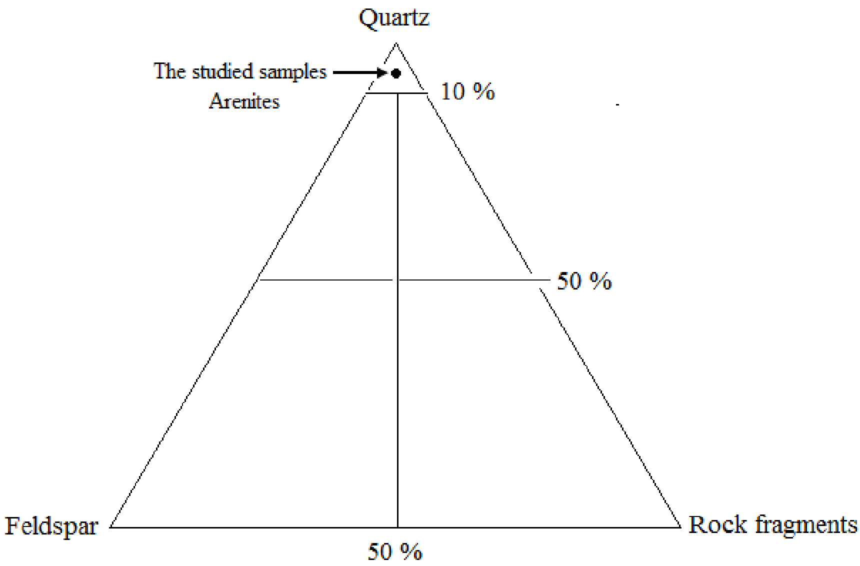

Fig. 3. Classification of Nubia sandstones according to Okada, (1971).

The quartz grains are generally subangular to subrounded, but in a few cases they are rounded. The quartz grains are commonly subequant to slightly elongate, randomly oriented and have variable degrees of packing. They show different types of contacts which are long, tangential point, concavo-convex and sutured contacts in decreasing order of abundance.

The quartz grains are predominantly monocrystalline (more than 90%), while polycrystalline grains are second in abundance (about 10%) especially in GH404-A2A well for minor samples. The majority of monocrystalline grains exhibits straight extinction, with a smaller percentage showing undulose extinction. On the other hand, medium and coarse-grains show a relatively higher percentage of polycrystalline and undulatory grains, in agreement with Blatt (1962), Graham (1994) and Rajak et al. (2022) that undulatory quartz is more common in the coarser fraction of naturally disintegrated primary source rocks.

Conolly (1965), Füchtbauer (1974), Basu et al. (1975), Cherian et al. (2004) and Oliveira et al. (2017) concluded that regional or local faulting, and/or tight folding can produce strain in detrital quartz grains after deposition.

Polycrystalline grains may be used to determine the degree of maturity. According to Blatt and Christie (1963), polycrystalline grains are more abundant in immature than in mature sandstones. The studied Nubia sandstones are classified as mature, where polycrystalline quartz grains reach about 10% with a few percentages of matrix, feldspars and clay minerals.

Monocrystalline quartz in the Nubia Formation shows straight extinction (Plate-1 C, D and E, F) with rare inclusions. Folk (1974) related this type of quartz to a plutonic origin. It may also be produced from other sources like gneisses or schists (Blatt, 1967; Folk, 1968). Undulatory monocrystalline quartz is also common, sometimes extinction takes place as independent gradational bands across the crystal (Plate-2, A and B), a feature called deformation bands and ascribed by Young (1976) to progressive strain.

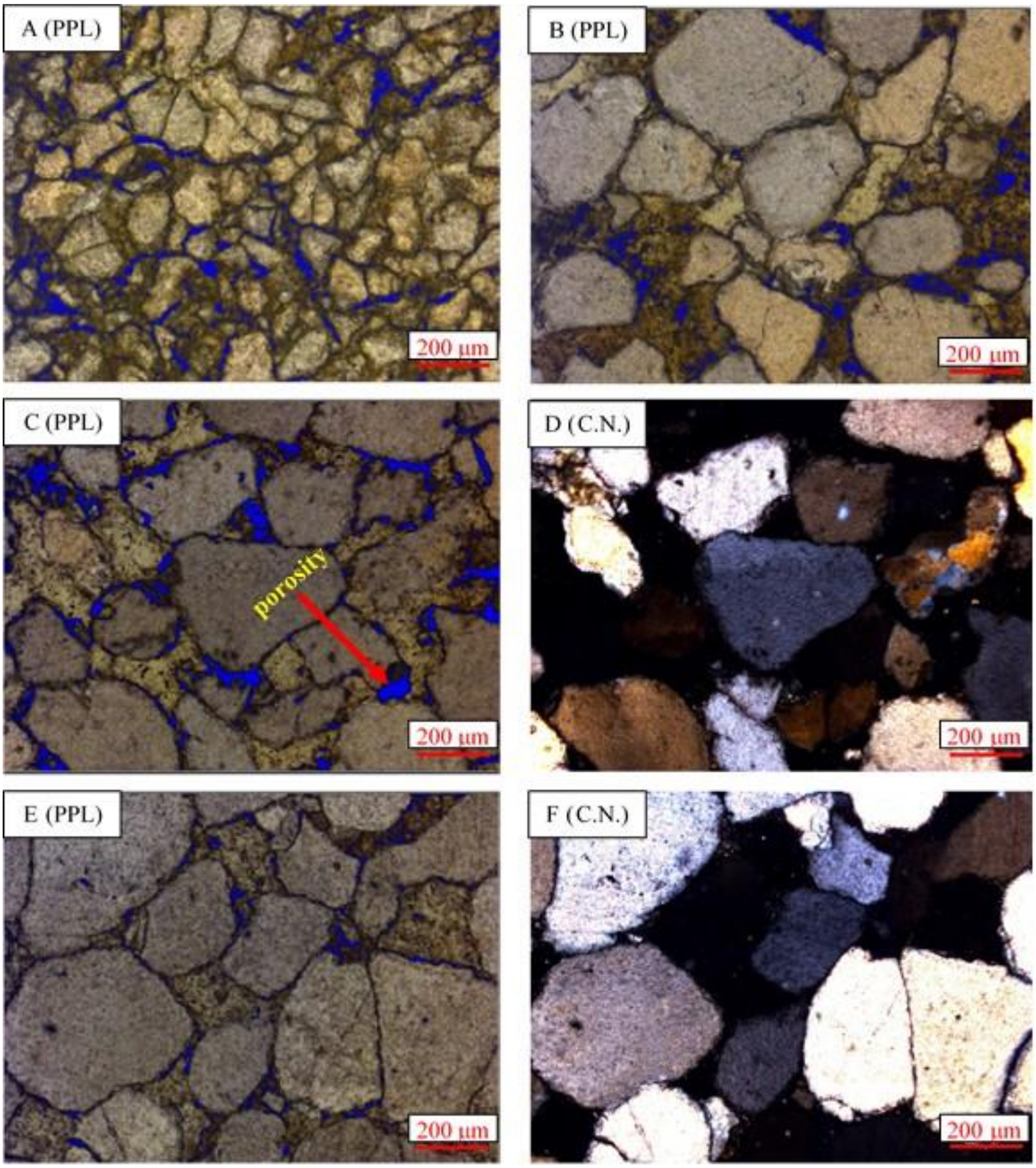

Plate-1: (A) Quartz arenite, silty to fine sand sized quartz grains, rich in iron oxides, well GH404-A3B, depth 10647 ft, S# 2-Nb-2. (B) Argillaceous sandstone, matrix support fabric, quartz grains are loosely packed and appear to be "Floating" in iron rich clayey matrix, well GH404-A2A, depth 10740 ft, S# 8-Nb-A. (C and D): Quartz arenite, monocrystalline grains mostly with straight extinction, rounded, moderately sorted, some grains show straight and concavo-convex-grain contacts, well GH404-A2A, depth 10710 ft, S# 1/Nb/A. (E and F): Quartz arenite, monocrystalline, medium grained, rounded to subrounded displaying straight extinction with sutured and straight grain contact, well GH404-A2A, depth 10749 Ft. S# 10/Nb/A.

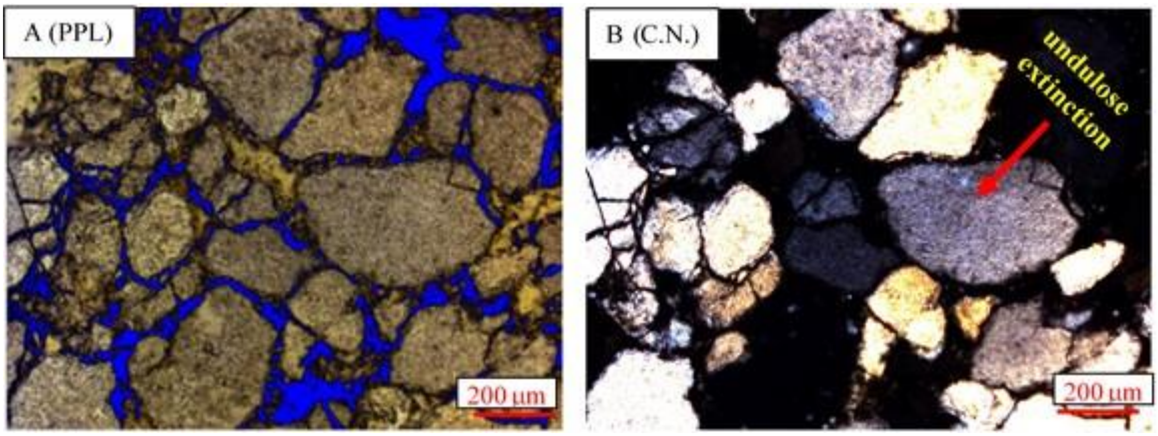

Plate-2: (A and B): Quartz arenite, monocrystalline, fine to coarse quartz grains, subrounded to rounded, poorly sorted, quartz grains mostly with undulose extinction, slightly argillaceous, well GH404- A2A, depth 10881. S# 10/Nb/C.

Quartz grains characterized by worn and rounded overgrowths are sometimes present (Plate-3 A and B, C and D). The presence of overgrowth suggests derivation from an older sandstone (Folk, 1974). Elongated monocrystalline quartz grains (Plate-3 C and D, E and F) have also been recorded at well GH404-A2A denoting a schistose source rock.

Polycrystalline quartz grains of course and very coarse size are common. Following Sholle (1979) and Blatt et al. (1980), different types of polycrystalline quartz grains are identified in the studied Nubia sandstone samples which are:

A. Polycrystalline grains showing crenulated and/or sutured crystal-crystal boundaries and undulosity, which are a result of progressive polygonization and deformation (Plate-4 A and B) reflecting gross discrepancies in strain energy on either side of boundary formed as a response to the local buildup of high densities of dislocations (Young, 1976).

B. Polycrystalline quartz of gneissic origin (Plate-4 C and D) displaying different stages of primary recrystallization to new crystals is recorded in sample No.13/Nb/A (Plate-4 C and D), (well GH404-A2A). Polycrystalline quartz grains of gneissic origin are more finely crystalline than those of massive igneous rocks (Blatt, 1967) and Ahfaf et al., 2021).

C. Polycrystalline quartz grains with polyhedral crystal units, straight crystal-crystal boundaries are recorded in sample 6/Nb/C at well GH404-A2A (Plate-4 E and F). A granitic origin is suggested for this type (Young, 1976) and Pandey et al., 2023). These crystals were formed under a steady state of temperature-pressure conditions reflected by the polyhedral outlines of individual crystals, lack of undulose extinction, smooth crystal-crystal boundaries and high interfacial angles (Kretz, 1966; Malvoisin and Baumgartner, 2021).

D. Polycrystalline quartz grains with silt size individual crystals (Plate-5 A and B) are recorded in sample No. 4/Nb/A (well GH404-A2A) that may have been derived from schist (Folk, 1968) and Blatt et al., 1980).

E. Polycrystalline quartz with two to five intercrystalline units (Plate-5 C and D) has been recorded in sample No. 6/Nb/1 (well GH404-A3B). A granitic origin is suggested for this type (Folk, 1968; Blatt et al., 1980).

Feldspars

Feldspar content is low especially at well GH404-A2A, although at well GH404-A2A ell it shows relatively higher value up to 10% (Plate 6 A and B). Feldspars are microcline with less plagioclase. The majority are altered.

Microcline is more common in the studied samples of well GH404-A3B, while plagioclase is recorded only in a few samples of the same well.

Altered feldspars show dissolution textures and many grains may have been completely removed (Plate-6 A and B).

The relative abundance of microcline at well GH404-A3B may suggest nearness to a granitic or pegmatitic source rocks (Folk, 1974); Pettijohn, 1975; and Al-Salmani and Tamar-Agha (2018) and occasionally high-grade metamorphism, Folk (1974) and Füchtbauer, 1974). Moreover, this suggestion is consistent with the previously mentioned evidences and rock source identification of the studied Nubia sandstone. On the other hand, Folk (1974), pointed out that feldspars reworked from older sediments are very rare and almost all feldspars are derived from primary igneous and metamorphic rocks.

Rock fragments and other constituents

Rock fragments are rarely recorded in the studied Nubia sandstones. However, identification of rock fragments in older rocks is usually difficult due to confusion with diagentically formed clay matrix. The recorded rock fragments are mainly represented by chert and a few metamorphic rock fragments. Chert (Plate-6 C and D) in medium sized grains is recorded in a few samples of the two studied wells, especially at well GH404 A3B.

Generally, the extensive diagenetic processes acting on the Nubia sandstone may have caused the alteration and sericitization of much feldspar grains and lithic fragments.

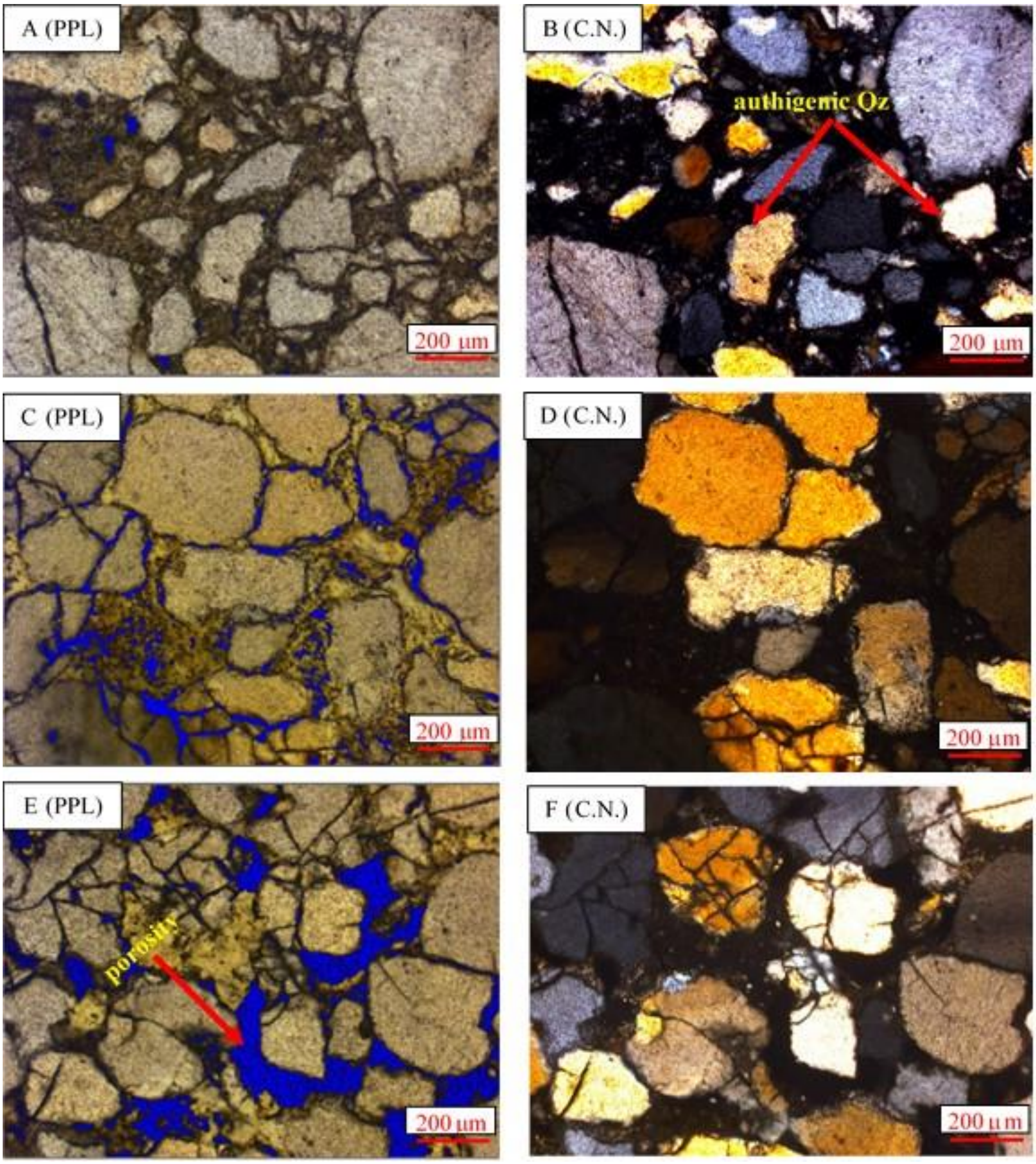

Plate-3: (A and B): Quartz wacke, authigenic quartz around quartz grain replaced by clay minerals, well GH404-A3B, depth 10644 Ft, S# 1/Nb/2. (C and D): Quartz arenite, showing silica overgrowths, also an elongated quartz grains most probably of schistose origin, well GH404-A2A, depth 10787 Ft. S# 6/Nb/B. (E and F): Quartz arenite, showing authigenic clay minerals and silica with iron-oxides filling pore spaces, well GH404-A2A, depth 10728 Ft. S# 5/Nb/A.

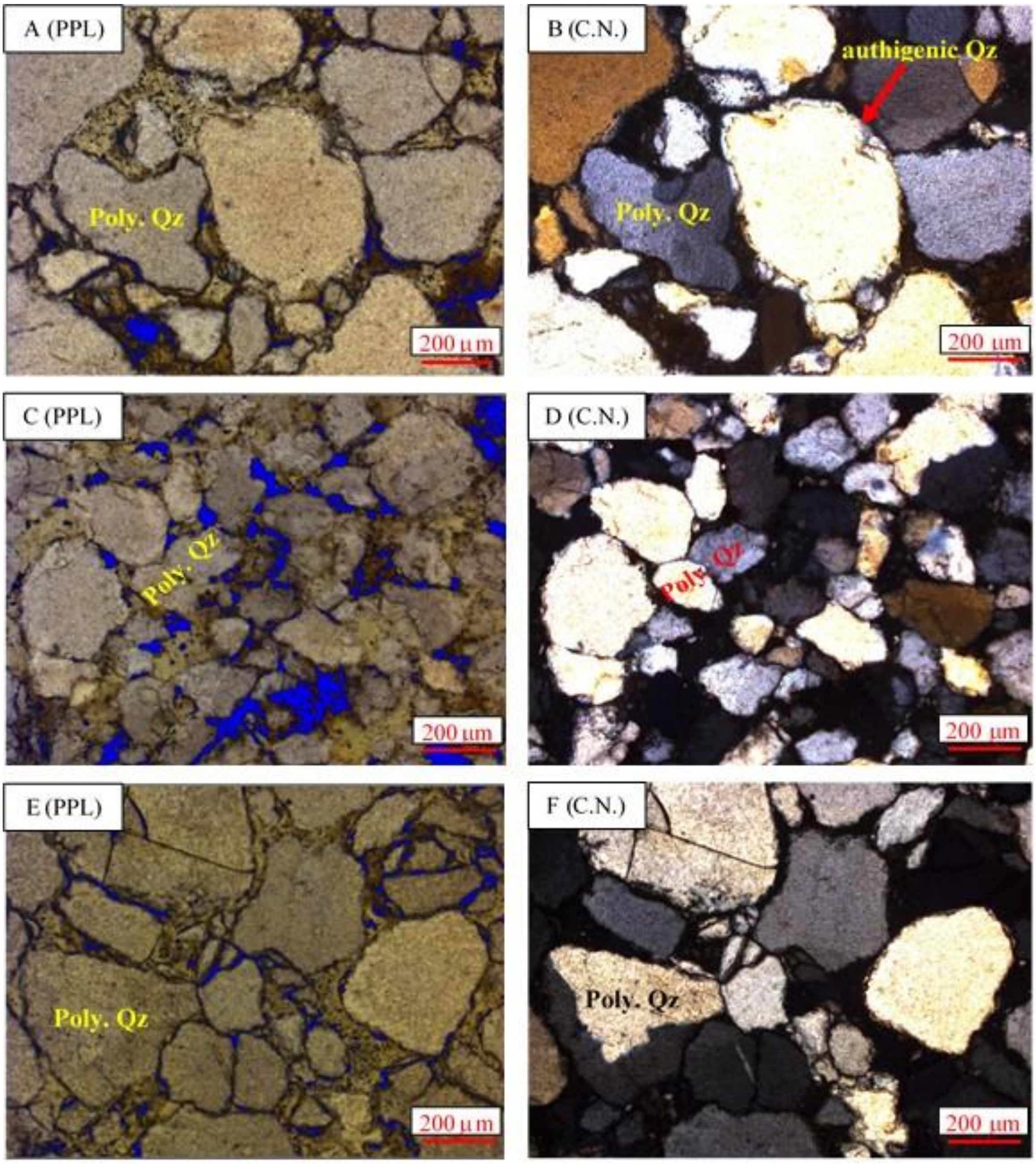

Plate-4: (A and B): Quartz arenite, showing polycrystalline quartz with unequant interlocking mosaic of crystals, pores filled with clays and iron-oxides, well GH404-A2A, depth 10716 Ft. S# 2/Nb/A. (C and D): Quartz arenite, showing stretched polycrystalline quartz grain with elongated individual crystals, crenulated and sutured crystal boundaries, well GH404-A2A, depth 10763 Ft. S# 13/ Nb/A. (E and F): Quartz arenite, showing polycrystalline quartz grains with polyhedral outlines, smoothed and straight crystal boundaries. authigenic clay minerals are present, well GH404-A2A, depth 10860 Ft. S# 6/Nb/C.

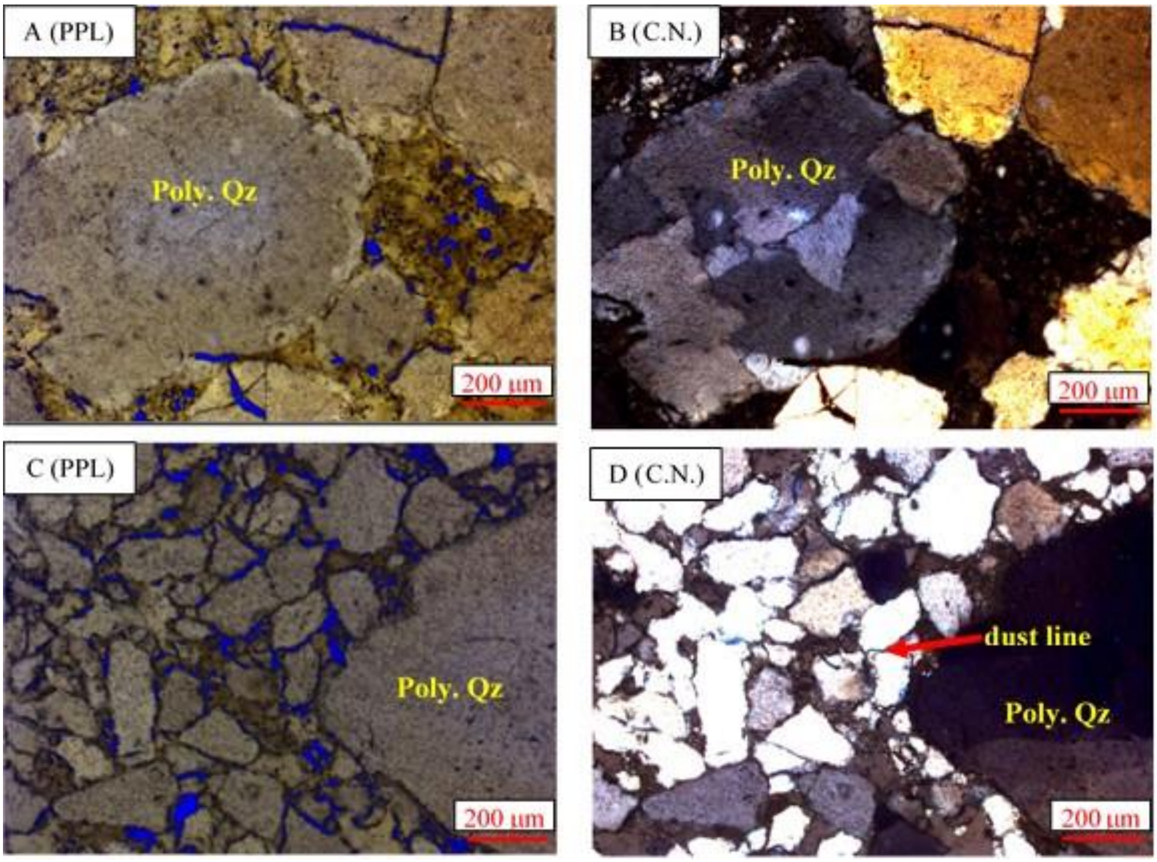

Plate-5: (A and B): Quartz arenite, showing polycrystalline quartz grain, with silt size individual crystals, some of which have sutured contacts, well GH404-A2A, depth 10725 Ft. S# 4/Nb/A. (C and D): Quartz arenite, grain supported fabric, poorly sorted, polycrystalline quartz grains with a fewer crystals of equant shape showing concavo-convex and straight contact, well GH404-A3B, depth 10617 Ft. S# 3/Nb/1.

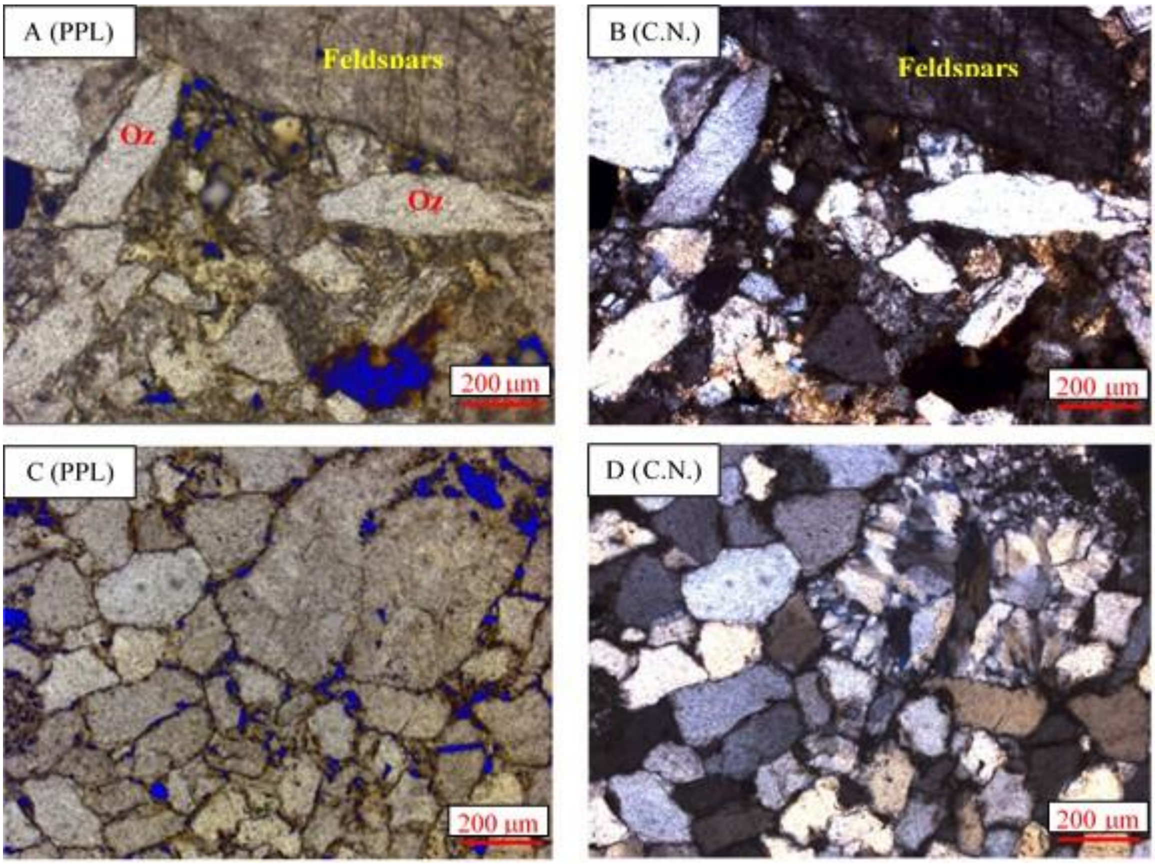

Plate-6: (A and B): Feldspathic quartz wacke, fine to coarse quartz grains, sometimes with undulose extinction, feldspar mostly altered, well GH404-A3B, depth 10689 Ft. S# 11/Nb/2. (C and D): Quartz arenite, monocrystalline, grain supported fabric, fine to medium quartz grains, moderately sorted, most grains showing point contacts. Fibrous spheriolites of chalcedony, well GH404-A3B, depth 10653 Ft. S# 3/Nb/2.

Porosity Evaluation

Petroleum geologists paid their attention to porosity because of its important role in oil accumulation, reservoir potentialities and diagenesis of sediments. One of the purposes of the present study is to identify the porosity types based on petrographic examination of the studied thin sections. The recorded porosity type is interparticle based on the petrographic investigation. In addition, the total porosity of (15) selected sandstone samples representing the studied formation (5 samples for GH404-A3B well and 10 samples for GH404-A2A well) are measured by Helium porosimeter (Model No. 3020-062).

The average measured values of the studied samples of the Nubia Formation are 15.24% and 12.22% for the two wells GH404-A3B and GH404-A2A respectively. The values indicate a fair porosity rank according to Levorsen (1967). The two studied wells have the same ranks of porosity (fair, good, very good) according to Levorsen (1967), except GH404-A2A well that has poor and negligible ranks for some samples (less than 10% and less than 5%), this reflects intensive effect of diagenetic processes.

The low porosity of some samples is due to the precipitated cements in the form of iron oxides, calcite, evaporite and silica as quartz overgrowth or chalcedony maybe considered the most effective factors in reducing the primary porosity of the studied rocks. Also, authigenic feldspar and clay minerals influenced the primary porosity causing its reduction. Bjorlykke (1980) mentioned that calcite and evaporate cements are the most effective factors in reducing primary porosity.

The low porosity of some samples is mainly due to cementation by authigenic minerals (silica, carbonate, clay minerals, evaporite and iron oxides) as indicated by the petrographic study confirmed by petrophysical measurement (Plate-4 (E and F).

Conclusions

Due to information scarcity of the study area, this work tries to uncover an important subsurface Nubia sandstone oil reservoir characteristic mainly in terms of porosity using petrographic description in addition to porosity measurements for the core samples got from two wells (GH404-A2A and GH404-A3B) at South-Ghara oil field, Gulf of Suez region.

The studied Nubia Sandstones are mainly classified as quartz arenite. Polycrystalline quartz with well-defined dust lines and polycrystalline grains with polyhedral crystal units suggest metamorphic origin and sheared rock. Polycrystalline quartz having silt size, individual crystals may have originated from schist. The above recorded quartz types indicate that the studied Nubia Sandstone in the two wells has originated from plutonic and high rank metamorphic rocks.

The general scarcity of feldspar especially at well GH404-A2A could be related to its decomposition due to the low topography associated with warm and humid climate. The presence of microcline may suggest granite, granodiorite and occasionally metamorphic origin.

On the other hand, the abundance of long and tangential contacts and the scarcity of concavo-convex contacts as well as the floating grain fabric in a few samples may lead to conclude that the Nubia sediments of the two studied wells were not affected by strong pressure or deep burial. This may suggest early cementation and/or an intermediate depth of burial.

The average measured values for the studied samples of the Nubia Formation indicates a fair porosity rank. Poor and negligible ranks for some samples of less than 10% and less than 5% reflect intensive effect of diagenetic processes.

The low porosity of some samples is due to the precipitated cements in the form of iron oxides, calcite, evaporite and silica as quartz overgrowth or chalcedony maybe considered the most effective factors in reducing the primary porosity of the studied rocks. Also, authigenic feldspar and clay minerals influenced primary porosity causing its reduction.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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