CHAPTER SEVEN

DISCUSSION AND CONCLUSIONS

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The mineral and petrographic characteristics, the diagenetic history, as well as the hydrocarbon reservoir quality of the Naqus Formation (Upper Cambrian) and the uppermost part of Araba Formation (Lower Cambrian) at Gebel Naqus, southwestern Sinai, together with some subsurface core samples are the main subjects treated in this work. A sedimentary section at Gebel Naqus to the north of El Tor was selected for this study. The section is about 370 m thick and is made up of the entire Naqus Formation underlain by the uppermost part of the underlying Araba Formation. One hundred and fourteen rock samples representing all the possible varieties were collected. Lithological variations and color changes of strata were taken into consideration during sampling. Observations were also focused on sedimentary textures, structures and facies changes.

Subsurface data from Ras Budran oil field were provided by Suez Oil Company. The field is located in the northern offshore area, 4 km west of the eastern coast of the Gulf of Suez. It has three main blocks A, B and C separated by two main faults. Six key wells were selected for this study: two wells from block A (RB-A1 and RB-A5); three wells from block B (RB-B3, RB-B4 and RB-B7) and one well from block C (RB-C2). Data provided included representative Paleozoic core samples (60 samples), core photographs, core analysis data and electric logs.

One hundred and fifty rock samples were selected to represent the studied sandstones. Petrographic and mineral examinations were considered using the conventional polarizing microscope, X-ray diffraction (XRD) analysis, heavy mineral analysis, scanning electron microscopy (SEM) supplemented by X-ray energy dispersive analysis (EDAX). Some important petrophysical parameters were also measured.

Different types of sedimentary structures are recognized in the studied sandstones. They include: erosional surfaces, channel-fill structures, massive bedding, graded bedding, flat bedding and planar lamination, cross-bedding (tabular and trough) and cross-lamination, deformed structures (convolute bedding and recumbent foresets), chemical structures (differential coloration, liesegang bands, mottling, calcite and gypsum veinlets, and silica-filled fractures), mechanical structures (differential weathering, joints, open fractures) and biogenic structures (burrowing organisms, mainly *Skolithos* tubes). Deformed structures are widely recorded in Naqus Formation and its subsurface equivalents, whereas biogenic structures characterize Araba Formation and its subsurface equivalents.

Textural analysis indicates that the studied sandstones are very fine to medium-grained, occasionally coarse-grained, and poorly sorted to moderately well sorted, but the majority are moderately sorted. Grain shape varies from angular to well rounded, but the majority of the sand-size grains are subangular to subrounded.

Microscopic investigation of the studied sandstone samples showed that they are composed mainly of three architectural components; framework grains (F), cement (C) and porosity (P). Detrital matrix is very rare and constitutes a negligible proportion of the sandstone composition. Although infiltrated clay minerals are present in some samples, they are mostly of diagenetic origin. In this concern, Naqus Sandstone ranges in composition of the three components from $F_{57.50}C_{2.50}P_{0.0}$ to $F_{79.25}C_{42.50}P_{27.75}$ with an average of $F_{69.49}C_{12.94}P_{17.57}$. Sandstone of Araba

Formation ranges in composition of the three components from $F_{51.25}C_{19.25}P_{0.0}$ to $F_{75.75}C_{48.75}P_{11.50}$ with an average of $F_{62.29}C_{34.27}P_{3.45}$. On the other hand, the three components in the subsurface sandstone range from $F_{75.25}C_{2.00}P_{0.0}$ to $F_{88.25}C_{24.75}P_{14.75}$ with an average of $F_{82.03}C_{13.12}P_{4.86}$. Differences observed among the studied units, and in samples from the same unit, are primarily due to variations in diagenetic processes.

Because clay matrix is nearly absent, and quartz comprises the only framework mineral, the studied sandstones are considered as quartz arenites. Concerning mineral composition, they are mature to supermature. Texturally speaking, they are submature to mature as evidenced by the abundance of subrounded and rounded grains, and the moderate-to-high degree sorting. The scarcity of detrital clay minerals, rock fragments and feldspars may, however, be a compositional maturity obtained by dissolution during diagenesis (diagenetic maturation), thus, the studied sandstones may be described as diagenetic quartz arenites.

Quartz is the most abundant detrital component in the studied sandstones. The average values for quartz in the Naqus, Araba and subsurface rocks are 99.58, 99.42 and 99.60 %, respectively. Some of the studied samples have polymodal grain size distributions. Coarse sand grains are mixed together with very fine sand grains with some fragments in the intermediate size ranges. Such a texture may result from mixing of sediment from two different environments, storm mixing of material in a high-energy environment, multiple sources of sand supply or, in some cases, may be produced by burrowing or other *in situ* mixing processes. Banding on the scale of a thin section is locally observed.

Quartz grains are either monocrystalline or polycrystalline; the former are the most abundant; averaging 88.13, 97.02 and 96.34 % of the total quartz in the Naqus, Araba and subsurface sandstones, respectively.

Monocrystalline quartz with straight extinction (nonundulose) is the most common (averages 91.23, 96.58 and 95.31 %; respectively). The average values of undulose quartz are 8.77, 3.42 and 4.69 % in the Naqus, Araba and subsurface sandstones, respectively. The average ratios of the undulose to nonundulose types are 0.10, 0.04 and 0.05.

The average values of polycrystalline quartz in total quartz are 11.87, 2.98 and 3.66 % in the Naqus, Araba and subsurface sandstones; respectively. The average ratios of polycrystalline to monocrystalline types are 0.14, 0.03 and 0.04.

The complete spectrum of quartz types present in the studied sandstones is: common, volcanic, recrystallized metamorphic, stretched metamorphic and quartz vein. Petrographic observations indicate that common quartz, typical of plutonic and some metamorphic rocks, is by far the most abundant.

The predominance of quartz in the studied sandstones may indicate that parts of the source region had low relief and underwent deep weathering and the sediment is at least partly multi-cyclic or that transport distances were long. Furthermore, the assemblage of ultrastable heavy minerals indicates high degree of reworking during a multi-cyclic origin of these sands. Moreover, the presence of rounded detrital quartz grains, rounded sedimentary lithic fragments, and rounded grains of zircon and tourmaline suggest that a major component of the provenance is older (pre-existing) sedimentary rocks.

Feldspar minerals are essentially absent in the studied sandstones, except a few extensively altered to completely dissolved grains on the scale of a thin section. The scarcity of feldspar may have resulted from one or more of the following: 1) deposition in a high-energy regime which selectively destroyed feldspar grains; 2) poverty of source rock-bearing feldspars; 3) low topography of the source area associated with the predominance of a warm, humid climate; and 4) extensive diagenetic modification due to intrastratal solution. In the present study, it is believed that the original feldspar minerals were lost due to grain dissolution by ground water in an active hydrologic regime and/or due to excessive alteration during burial diagenesis. Many feldspar grains were completely dissolved leaving behind skeletal remnants or showing no evidence of their former presence. In the later case, the dissolved grains left only oversized pores that indicate their original presence. The proportions of feldspars lost by the effect of these processes were determined assuming that 80 % of the oversized pores and of grains pseudomorphed by kaolinite were originally feldspars. The volume of feldspars lost averages 6.69, 4.64 and 0.77 % in the Naqus, Araba and subsurface sandstones, respectively.

Rock fragments are a minor constituent in the studied sandstones. Their average values in the Naqus, Araba and subsurface rocks are 0.22, 0.18 and 0.14 %; respectively. The recorded rock fragments are sedimentary and, much less commonly, metamorphic and volcanic.

Sedimentary rock fragments consist mainly of chert, fine-grained siliceous and ferruginous sandstones, siltstones and mudstones. Chert fragments are mostly made up of subrounded to well-rounded microcrystalline quartz suggestive of a polycyclic origin. They were generally mechanically and chemically stable during diagenesis. However, some chert fragments have undergone partial dissolution that resulted in microporosity development. Some chert fragments are embayed by quartz grains indicating a higher stability of quartz relative to chert. Silica-cemented siltstone and sandstone clasts are present locally. Hematite-cemented sandstone fragments are occasionally observed.

Metamorphic rock fragments are mainly represented by quartz mica schist and quartz gneiss. Different ductile grains, represented mainly by mica flakes are also recorded. These grains are relatively stable chemically, but they are easily deformed during compaction. Muscovite flakes are by far more common than biotite flakes, due to their abundance in source rocks and greater resistance to chemical weathering. Gypsum flakes are also recorded.

The petrographic data indicate that the source terrane or terranes for the studied sandstones include volcanic, plutonic, metamorphic, and sedimentary rocks. The quartz-rich character of the sandstones, together with the general scarcity of volcanic rock fragments, appears to rule out quartz-poor volcanic rocks as major source rocks. Neither plutonic nor metamorphic source rocks were major sediment contributors to most of the studied sandstones. Further, because much evidence of recycling was observed, quartz-rich sedimentary rocks are supposed to be the major source rocks. Analysis of quartz types further indicates that plutonic rocks were more important than metamorphic rocks as sources for the studied sandstones. However, scant evidences, based on relative rock-fragment abundance and polycrystalline quartz grains characteristics, suggest that metamorphic rocks may have been more important sediment sources than plutonic rocks. Volcanic rocks are the least.

Detrital clays are essentially absent in the studied sandstones except as a few claystone clasts. The average values of detrital clays in the Naqus, Araba and subsurface sandstones are 0.05, 0.4 and 0.23 %, respectively.

Heavy minerals may reach up to 1.45 % (average of 0.15 %) of the framework composition of Naqus Formation, whereas, they constitute a minor proportion of those of Araba Sandstone. On the other hand, heavy minerals in the subsurface sandstone may comprise up to 0.33 % with an average of 0.03 % of the framework composition.

Opaque minerals averages 54.18 and 52.49 % of the total heavies of Naqus and Araba sandstones, respectively. Opaques seem to be size-dependent, constituting the great proportion of the total heavy minerals (averaging 63.24 %) of the very fine sand fraction. This may be attributed to selective sorting during transport and deposition. In the studied sandstones, opaques are mainly represented by hematite, goethite, hydrogoethite and Fe-Ti oxides.

Non-opaque minerals averages 45.82 and 47.51 % of the total heavies of Naqus and Araba sandstones, respectively. Non-opaques also seem to be size-dependent showing percentages which are minimum (average 36.76 %) in the very fine sand fraction and maximum (average 49.01 %) in both the fine and medium sand fraction. Ten non-opaque, ultrastable (zircon, tourmaline and rutile) and metastable (garnet, sphene, epidote, staurolite, sillimanite, monazite and hornblende) heavy minerals were identified. Micas were excluded from the heavy mineral assemblage because of their extremely platy shape, which results in anomalous behavior during transport. The ultrastable minerals are the most abundant nonopaques in the studied sandstones. They were recorded in all the examined samples with a relatively high frequencies. These minerals can survive prolonged transport and were mostly recycled from older sedimentary rocks. The lack of other heavies may be attributed to their rarity in the source rocks and/or their relatively low stability during transport and burial.

Ternary diagrams of quartz, feldspars and rock fragments (QFR) illustrate average present-day composition of $Q_{99.78}F_{0.0}R_{0.22}$ for Naqus Sandstone, $Q_{99.82}F_{0.0}R_{0.18}$ for Araba Sandstone and $Q_{99.86}F_{0.0}R_{0.14}$ for the subsurface sandstone. The present composition of the studied sandstones is different- of course- from their composition at the time of deposition, because these sandstones were progressively subjected to diagenetic processes and weathering. The restored average original composition is $Q_{89.54}F_{8.22}R_{2.24}$ for Naqus Sandstone, $Q_{91.21}F_{6.9}R_{1.89}$ for Araba Sandstone and $Q_{98.70}F_{0.93}R_{0.37}$ for the subsurface sandstone.

Cements and replacement minerals in the studied sandstones vary in abundance. They average 12.94, 34.27 and 13.12 % of the whole rock volume in the Naqus, Araba and subsurface sandstones, respectively. Authigenic cements include quartz, K-feldspars, clay minerals (mainly kaolinite), iron minerals (mostly hematite), calcite, gypsum and halite. Allogenic cement was also recorded and is represented mainly by infiltrated clays.

Quartz cement averages 1.33, 0.53 and 0.78 % of the whole rock volume in the Naqus, Araba and subsurface sandstones, respectively. It is represented mainly by syntaxial overgrowths. Microcrystalline quartz is another type that was recognized in few samples. It occurs as either mosaic cement or isopachous drusy coatings.

Authigenic K-feldspars constitute a negligible amount in the studied sandstones. Commonly they are found as coarse crystals cementing quartz grains. These crystals are not connected to detrital feldspar cores, but occur as isolated crystals partially filling pore spaces. Such feature is known to develop when the pore water becomes supersaturated with respect to K, Al and Si. Dissolution and alteration of authigenic K-feldspars in the studied sandstones have been locally recorded.

Allogenic clay minerals are present in minor proportions. They average 1.21, 1.80 and 4.42 % of the whole rock volume in the Naqus Araba and subsurface sandstones, respectively.

Authigenic clays in the studied sandstones are represented by kaolinite together with traces to minor proportions of illite, smectite, illite-smectite mixed layer and chlorite as indicated by XRD and SEM examinations. They occur as pore-filling and pore-lining cements, and as pseudomorphous replacements. Kaolinite averages 7.73, 14.20 and 1.29 % of the whole rock volume in the Naqus, Araba and subsurface sandstones, respectively.

Iron minerals (mainly hematite) are abundant and ubiquitous cement in the studied sandstones. They vary largely in abundance among the studied sandstone units, and in samples from the same unit. They may comprise up to 6.50 % of the whole rock volume of Naqus Sandstone and up to 32.25 % of those of Araba Sandstone. The average values of iron minerals cement in the two formations are 1.55 and 17.22 %, respectively. On the other hand, iron minerals cement in the subsurface sandstone may reach 13.50 % with an average of 4.04 % of the whole rock volume. Some subsurface sandstone samples may have up to 70 % by volume of iron minerals cement (mainly hematite); these samples were not included in the point counting.

Calcite is the main carbonate mineral present as a cement in the studied sandstones. It averages 0.12, 0.10 and 0.17 % of the whole rock volume in the Naqus, Araba and subsurface rocks respectively.

The average values of halite in the Naqus, Araba and subsurface sandstones are 1.01, 0.52 and 2.3 %, respectively. However, halite is presently undergoing dissolution, and hence, its original extent is unknown.

Gypsum forms scattered patches of cement in few samples. Most patches are at the millimeter scale, but locally, they may be at the centimeter scale.

The detailed and comprehensive petrographic studies conducted on more than 150 thin sections and 100 samples examined by scanning electron microscope showed that the studied sandstones exhibit a variety of diagenetic features that include: 1) mechanical infiltration of clay minerals, 2) dissolution of unstable detrital silicate grains (such as feldspars and ferromagnesian minerals) and the consequent development of secondary porosity, 3) development of an authigenic mineral suite that includes quartz, calcite, iron minerals (mostly hematite) and clays (mainly kaolinite), 4) compaction features such as closer packing, mechanical fracturing, deformation and bending of ductile and cleavable grains, 5) dissolution of early-formed carbonate cement followed by fracturing and secondary porosity initialization and 6) development of late stage cements made up of quartz, K-feldspars, kaolinite, iron minerals, calcite, gypsum and halite.

The paragenetic sequence of the diagenetic processes began shortly after deposition of the sediment by a limited infiltration of clays. A phase of precipitation of quartz cement occurred soon after deposition at shallow depths before the commence of real burial compaction. Cementation with iron minerals occurred early in the burial history and continued for a long time. However, recent studies revealed that iron minerals in sandstones may be introduced at any stage, viz, burial compaction, cementation or at any stage in diagenetic events, therefore the existence of iron minerals is valueless for any diagenetic sequence interpretation. The major part of cementation by calcite preceded significant mechanical compaction and followed quartz cementation. Dissolutions of feldspars and rock fragments probably occurred after the main episode of calcite cementation. Kaolinite, K-feldspars and late stage iron minerals cement were deposited following the dissolution process at late mesodiagenesis. Kaolinite commonly breaches secondary pore spaces and is mainly interpreted as a late diagenetic cement. Based on their textural relationships with other cements and their fresh surfaces, halite and gypsum are interpreted to be formed very late in the paragenetic sequence.

In spite of their age and the large volumes of ground water that probably passed through them, the studied sandstones retain, with a few exceptions, sufficient porosity and permeability to possess a good reservoir quality. In the present study, porosity was measured petrophysically by using a helium porosimeter and in thin sections by point counting. Naqus Sandstone has helium porosity that averages 23.1 %. About 84 % of Naqus samples have porosity greater than 20 %. Sandstone of this porosity magnitude makes it as an excellent reservoir rock. In Araba Sandstone, helium porosity averages 17.8 %. This sandstone has a high kaolinite content and its porosity is usually intercrystalline. On the other hand, helium porosity in the subsurface sandstone averages 10.4 %.

Thin section porosity in Naqus Sandstone has a mean value of 17.7 %, while in Araba Sandstone it averages 3.6 %. On the other hand, thin section porosity in the subsurface sandstone averages 4.9 %. Of the total present thin section porosity, primary porosity averages 75.06, 54.75 and 95.70 %, and secondary porosity averages 24.94, 45.25 and 4.3 % in the Naqus, Araba and subsurface sandstones, respectively.

In Naqus Sandstone, permeability ranges from 1 md to 19526 md with an average of 2818 md. About 46 % of Naqus samples have permeability greater than 1000 md. Sandstone having this permeability magnitude makes an excellent reservoir characters. On the other hand, in Araba Sandstone, permeability ranges from 3 md to 162 md with an average of 50 md. 50 % of Araba samples have permeability values between 10 and 50 md, indicating a moderate reservoir quality. The subsurface sandstone has a horizontal permeability ranging from 0.0 md to 1270 md and averaging 92 md. On the other hand, its vertical permeability varies from 0.0 md to 1340 md with an average of 100 md. This slight difference in permeability magnitude is attributed to the presence of small-scale open vertical fractures, which enhance vertical permeability. These fractures are sometimes only detectable in thin sections (hairline fractures). Sandstone having this permeability magnitude makes a good reservoir characters.

The reservoir quality of the studied sandstones was controlled mainly by compaction and secondarily by the degree of cementation (except in Araba Sandstone where cementation was more effective than compaction in reducing porosity). From an estimated initial porosity of 45 %, thin section porosity in Naqus, Araba and subsurface sandstones is reduced to the present value of 17.7, 3.6 and 4.9 %, respectively. The average Naqus, Araba and subsurface sandstones lost 31.69, 19.03 and 33.66 % porosity, respectively, by compaction and 5.45, 24.16 and 8.33 % porosity, respectively, by cementation.

Development of secondary porosity (about 4.39, 1.54 and 0.21 % total rock volume in Naqus, Araba and subsurface sandstones, respectively) locally enhanced the reservoir quality of the studied sandstones. This porosity resulted mainly from the dissolution of feldspars, rock fragments and calcite cement. Minor proportion of secondary porosity was also created by fracturing due to tectonic stresses or overpressure (hydrofracturing).

The sandstones of Naqus Formation are believed to have a non-marine mode of deposition. The numerous quartz pebbles that are either randomly distributed in Naqus Sandstone or preferentially oriented along cross-bedding planes may suggest a high-energy shallow agent of transportation, probably a meandering fluvial system. The streams were probably very erratic and intermittent with coarse load at the bottom followed by the finer sediments with the diminishing of the flood. The proposed fluvial origin for Naqus Sandstone is strengthened by the presence of convolute bedding and recumbent foresets.

The presence of cross-bedding, fossil tracks of *Cruziana* and *Skolithos,* as well as traces of burrowing organisms in Araba Formation may support a shallow marine depositional environment. The *Skolithos* ichnofacies clearly indicates clean, well-sorted near-shore sands with high levels of wave and current energy (intertidal zone). The varicoloration of the sandstone beds could be the result of oxidation processes due to the wind activation of oxygen dissolved in the seawater or the alteration of iron bearing minerals such as mica and feldspars. Biotite and hornblende may have been altered by weathering to hematite and goethite, which give the red coloration. The dominant sedimentary structure in the varicolored sandstones is conventional horizontal bedding, which also suggests a quite water agent. The observed small-scale cross-beds with horizontal planes in between could be due to an abrupt decrease in the current velocity and increase of the water depth.

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APPENDIX

Abbreviations used in the Tables 4.1-4.4

Na	Samples from Naqus Formation
Ar	Samples from Araba Formation
Q	Quartz
MCQ	Monocrystalline quartz
MCQU	Undulose monocrystalline quartz
MCQN	Nonundulose monocrystalline quartz
MCQT	Total monocrystalline quartz
PCQ	Polycrystalline quartz
PCQ 2-3	Polycrystalline quartz of two to three crystals
PCQ 3-5	Polycrystalline quartz of four to five crystals
PCQ >5	Polycrystalline quartz of more than five crystals
U/N Ratio	Undulose/Nonundulose ratio
P/M Ratio	Polycrystalline/Monocrystalline ratio
Feld.	Feldspar
R.F.	Rock fragments
H.M.	Heavy Minerals
Det. Clay	Detrital clay
Qtz. Over.	Quartz overgrowth
Mic. Qtz.	Microcrystalline quartz
Kao. P.F.	Pore-filling kaolinite
Kao. Rep.	Replacement kaolinite
Kao. Total	Total kaolinite
Gyp.	Gypsum
Inter	Intergranular porosity
Intra	Intragranular porosity
OVSP	Oversized pores
Frac.	Fracture porosity
1st Por.	Primary porosity
2nd Por.	Secondary porosity
PCP	Pre-cement porosity
PLOSS-Comp	Porosity loss due to compaction
PLOSS-Cement	Porosity loss due to cementation
Comp Index	Compaction Index

ARABIC SUMMARY

دراسات ترسيبية وعمليات ما بعد الترسيب وكفاءة الخزان لبعض القطاعات السطحية وتحت السطحية من منطقة بلاعيم والمناطق المجاورة لها ، جنوب غرب سيناء ، مصر.

رسالة مقدمة من

وائل سعيد على مطر

ماجستيرفى العلوم فى الجيولوجيا – جامعة الملك فهد للبترول والمعادن- المملكة العربية السعودية

١٩٩٦

باحث مساعد بمعهد بحوث البترول

للحصول على

درجة دكتوراه الفلسفة فى العلوم فى الجيولوجيا

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قسم الجيولوجيا - كلية العلوم

جامعة عين شمس

٢٠٠٧

بسم الله الرحمن الرحيم

In The Name Of Allah
The Most Merciful
The Most Gracious

صفحة العنوان

اسم الطالب : وائل سعيد على مطر

الدرجة العلمية : دكتوراه الفلسفة فى العلوم فى الجيولوجيا

اسم الكلية : العلوم

الجامعة : عين شمس

سنة التخرج : ١٩٨٩

سنة المنح : ٢٠٠٧

رسالة دكتوراه فلسفة فى العلوم فى الجيولوجيا

عنوان الرسالة : دراسات ترسيبية وعمليات ما بعد الترسيب وكفاءة الخزان لبعض القطاعات السطحية وتحت السطحية من منطقة بلاعيم والمناطق المجاورة لها ، جنوب غرب سيناء ، مصر.

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الدراسات العليا

ختم الإجازة **أجيزت الرسالة بتاريخ / /٢٠٠٧**

موافقة مجلس الكلية : / /٢٠٠٧ **موافقة مجلس الجامعة : / /٢٠٠٧**

شكر

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٣- معمل التحاليل الصخرية (إبرى كورلاب) - معهد بحوث البترول.

٤- شركة السويس للزيت (سوكو).

دراسات ترسيبية وعمليات ما بعد الترسيب وكفاءة الخزان لبعض القطاعات السطحية وتحت السطحية من منطقة بلاعيم والمناطق المجاورة لها ، جنوب غرب سيناء ، مصر.

رسالة مقدمة من
وائل سعيد على مطر

للحصول على
درجة دكتوراه الفلسفة فى العلوم فى الجيولوجيا

ملخص الرسالة باللغة العربية

تتضمن هذه الرسالة دراسات معدنية وبتروجرافية والعمليات المابعدية للصخور الرملية لبعض القطاعات السطحية وتحت السطحية فى منطقة بلاعيم (جنوب غرب سيناء). كذلك تضم الدراسة تقييما لكفاءة الخزان ومدى ملاءمته كمكمن للبترول.
اعتمد الباحث فى إجراء دراسته عن القطاعات تحت السطحية على بيانات موثقة للخرائط وبعض السجلات والدراسات وأيضا عدد (٦٠ عينة لبية core samples) من شركة السويس للزيت (سوكو).
وقد اختيرت مئة وخمسين عينة تمثل كل الأنماط الممكنة للحجر الرملى، درست بالتفصيل فيها البنيات والأنسجة الصخرية التى تميز هذه القطاعات بتروجرافيا ومعدنيا باستخدام الميكروسكوب المستقطب والميكروسكوب الإلكترونى الماسح وحيود الأشعة السينية. و قام الباحث أيضا بتحديد المعاملات البتروفيزيقية للصخور المدروسة، إضافة إلى التحليل الحجمى ودراسة مدى تأثير توزيع الحجوم ومعاملاتها على طبيعة هذه الصخور.
وتضم الدراسة السطحية للصخور الرملية دراسة جيولوجية لمتكونين هما: متكون ناقوس (الكمبرى العلوى) ومتكون عربة (الكمبرى السفلى). وسجلت الدراسة الحقلية المستفيضة للبنيات والتراكيب وجود أسطح السحنات ورواسب ملء القنوات والتطبق الكتلى والتطبق المتدرج والسطائح النضدية والتطبق المتقاطع والتطبق الملفوف والمتحرف كذلك تمت دراسة التمايز اللونى فى الصخور المدروسة وعروق الجبس والكالسيت التى تتداخل مع الحجر الرملى. وتم مناقشة ظروف تكوين البنيات والتراكيب على أساس علمى منهجى وتمت أيضا دراسة البنيات التى تكونت ميكانيكيا، وكذلك مدى تأثر الصخور المدروسة بأنواع التجوية المختلفة.
وكذلك تمت دراسة البنيات الأحيائية التى سجل وجودها بمناطق البحث. وتدل الدراسات التى أجريت على هذه الصخور أنها أحجار رملية لها حجوم تتردد بين

دقيقة التحبب جدا إلى متوسطة التحبب. لكنها فى بعض الأحيان تكون غليظة التحبب. كذلك فهى رديئة الفرز عموما، و تميل إلى أن تكون لها درجة فرز متوسطة، أو جيدة فى بعض الأحيان. وفى مجملها فهذه الصخور لها درجة فرز متوسطة. أما حبيبات الرمل فهى متباينة فى أشكالها بين الزاوى إلى الدائرى، أيضا هى شبه زاوية إلى شبه دائرية بصفة عامة.

وتدل الدراسة البتروجرافية التفصيلية أن أحجار الرمل المدروسة يتكون بنيانها من الحبيبات والملاط والمسامية والوسط الفتاتى الذى يكون نسبة بسيطة للغاية يمكن إهمالها عند تقسيم هذه الصخور الرملية. وبالرغم من وجود معادن الصلصال المتغلغلة فى بعض العينات، إلا أن أصلها فى الغالب يعد ثانويا (ما بعديا). وعلى أساس نسب المكونات المعدنية والصخرية المكونة، فإن الصخور المدروسة تصنف على أنها كوارتز أرينيت، وتتميز بصحبة معدنية ناضجة تتدرج إلى معادن فوق ناضجة. ونظرا لتأثر هذه الصخور بالعمليات المابعدية إلى حد كبير، فيمكن تسميتها " كوارتز أرينيت ما بعدى".

وقد دلت الدراسة المعدنية والبتروجرافية أن حبيبات الكوارتز قد توجد على هيئة بلورات مفردة التبلور أو عديدة التبلور وقد تكون ذات انطفاء متموج أو غير متموج. لكن أكثر أنواع الكوارتز شيوعا هو المتميز بالانطفاء المتوازى غير المتموج.

ولوحظ ندرة معادن الفلسبار أو غيابها تماما، وقد يكون ذلك راجعا إلى ذوبانها بفعل المياه الأرضية فى الدورة الهدرولوجية النشيطة أو من خلال عمليات الدفن فى المراحل المابعدية التى أثرت فى صخور الحجر الرملى المدروسة. ومن الأدلة المهمة لتأكيد ندرة وجود معادن الفلسبار وجود الفجوات المتنامية الحجم سواء أكانت مملوءة بالملاط أم خالية منه. ومن أهم أنواع الملاط التى تملأ الفراغات بين حبيبات الحجر الرملى معادن الكوارتز و الكالسيدونى والأوبال والصلصال والهيماتايت والجوثيت والهاليت والجبس، وكذلك معدن الكالسيت الذى يوجد فى الفجوات و الذى قد يكون من أصل فتاتى أو ملاطا مكانى النشأة. كذلك توجد معادن الفلسبار البوتاسى ولكن بكمية ضئيلة للغاية. ويمثل الفتات الصخرى مكونا قليل الشيوع بنسبة لا تتعدى ٠,٢٢% لمتكون ناقوس ، ٠,١٨% لمتكون عربة ، بينما فى القطاعات تحت السطحية تصل النسبة إلى ٠,١٤%. والفتات الصخرى فى مجمله قد يكون من أصل رسوبى أو نارى أو من أصل متحول .

وتعد معادن الصلصال ذات الأصل الفتاتى شبه نادرة الوجود فى الصخور الرملية المدروسة حيث إنها تكون١,٠٦ % من العماد الهيكلى لصخور متكون ناقوس بينما فى متكون عربة فهى تكون ٢,٨٦%. أما فى القطاعات تحت السطحية، فتوجد معادن الصلصال ذات الأصل الفتاتى بنسبة معدلها ٠,٢٣%.

وتكون المعادن الثقيلة صحبة معدنية تتمثل فى معادن الزركون والتورمالين والروتيل والجارنت وسفين وإيبيدوت وستوروليت وسيلمانيت ومونازيت وهورنبلند.
وتدل الدراسات التى أجريت لدراسة معادن الصلصال سواء باستخدام الميكروسكوب الإلكترونى الماسح وحيود الأشعة السينية أن الصحبة المعدنية لمعادن الصلصال تتكون من معدن كاولينيت (بصفة أساسية) مع وجود كميات قليلة من معادن إلليت وسمكتيت وإلليت- سمكتيت؛ طبقة صلصالية مختلطة وبعضا من معدن كلوريت.
وبالنسبة إلى دراسة مسامية الصخور الرملية المدروسة فقد قدرت على أساس حسابات ومعادلات رياضية طبقت على القطاعات الرقيقة ، ووجد أن معدل مسامية الصخور فى متكونى ناقوس و عربة ١٧,٥٧% ، ٣,٤٥% على الترتيب، بينما بلغت النسبة ٤,٨٩% لقطاعات تحت السطح. ودلت الدراسات التى أجريت باستخدام جهاز تعيين المسامية أن معدل مسامية الصخور فى متكونى ناقوس وعربة ٢٣,١، ١٧,٨% على الترتيب، بينما سجلت ١٠,٤% لقطاعات تحت السطح. وبينت الدراسات التى أجريت باستخدام جهاز تعيين النفاذية أن معدل نفاذية الصخور فى متكونى ناقوس وعربة ٢٨١٨ ملى دارسى ، ٥٠ ملى دارسى على الترتيب، بينما سجلت الدراسة ٩٢ ملى دارسى (نفاذية أفقية) و ١٠٠ ملى دارسى (نفاذية رأسية) لقطاعات تحت السطح.
وتدل الدراسات التفصيلية على وجود تغيرات ما بعدية كثيرة أثرت فى الصخور المدروسة إلى حد كبير و تشمل هذه العمليات : الرشح الميكانيكى لمعادن الصلصال وذوبان المعادن غير الثابتة التى أدت إلى زيادة مسامية الصخر وكذلك تكوين معادن مكانية النشأة. وأيضا تضاغط الصخر وتماسكه و ذوبان معادن الكربونات التى تكونت فى مراحل سابقة ثم يلى كل هذه المراحل جميعا تكوين الأنواع اللاحقة للملاط بأنواعه، مما أعطى صخور الحجر الرملى فى مناطق الدراسة صورتها الحالية التى نطلق عليها
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