Middle East Journal of Applied Sciences, 4(4): 1016-1022, 2014
ISSN: 2077-4613

Mineralogical and Mechanical Compaction Characteristics of Nubian Sandstones, Gebel Duwi, Central Eastern Desert, Egypt

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ABSTRACT

The current study aims to evaluate potentiality of the Nubian sandstones of Gebel Dawi west of Qusier, Central Eastern Desert, Egypt. The obtained data refer that these sandstones are almost entirely quartz with trace amounts of fresh or partly altered feldspars and mica. The quartz grains are rounded to well rounded, also sorted to well sorted.

Packing parameters are used to quantify compaction processes as well as to assess burial depth. Both number and types of contacts were dated. Percentages of packing parameters which expressed as; consolidation factor (Cf), contact strength (Cs), packing proximity (Pp), and contact index (Ci). The contact strength (Cs) has positive correlation with (Pp) and (Cf**)** where (Ci) has positive correlation with (Pp), (Cf) and (Cs).

Various types of pores are occurred where the loss of feldspars and unstable grains by digenetic processes produce appreciable amount of secondary porosity as well as the oversize pores reached up to 8.42%. The pre cement porosity values (PCP) ranges from 14.7 to 29.02% with an average 23.5% indicating that total values of porosity was lost with values range from 27.51 to 35.52% with an average 27.41%. This loss refers to the fact that most of both original and secondary porosities were partially destroyed by mechanical compaction and cementation processes. The mean absolute porosity percent has been detected by (GEOPECNOMETER 1360). The results range from 14.24 to 32.65% with an average 26.21%. Little percentages of detrital and authigenic kaolinit and illite showed by SEM images.

The results indicate that these sandstones are quartz arenite, texturally mature compared to the other sandstones of known burial depth (1.5 to 2.5) km. So the high quality reservoir characteristic data refer that these sandstones have medium to high reservoir potential. Then we consider that the subsurface rock unit belongs to the same formation promise for oil reservoir or even water aquifer.

Key words: Burial Depth, Compaction, Porosity, Packing Parameters.

Introduction

The term Nubian Sandstone is well established in the stratigraphic column of Egypt and is used to describe the extensive sandy formations (clastic series) either overlying the Precambrian basement rocks or conformably underlying the marine sequence of Upper Cretaceous variegated shale (Fig.1).

The fact that it covers vast areas in Egypt with a broad age window ranging from Early Palaeozoic to Late Cretaceous due to lack of any credible record of index body fossils has always caused a problem of where to consider it in the Egyptian geochronological sequence. The age dating of the Nubia section in the Northern Red Sea (Quseir area, Gebel Duwi) is believed to be Early- Late Cretaceous as it lacks any fossil content. The overlaying section has a Coniacian assemblage. Variation in thickness across the existing structural elements was found with a clear unconformity within the section in Gebel Rabah around Safaga area. Volcanic activities were seen in parts of the Nubia section suggesting possible rifting during early – Late Cretaceous in this area.

In spite of the Nubian sandstones is considered as the main reservoir of giant oil fields in Egypt especially in Gulf of Suez region, the Nubian sandstones also represent the main water aquifer in Egypt especially in western desert.

In many localities especially in Sinai the Nubian sandstone intercalated with kaolinitic deposits which are of potential economic importance. The Nubian sandstones are the main source of glass sand in Egypt.

The regions of the Gulf of Suez and Sinai have been exposed to extensive investigations for oil exploration. (Fig. 1). Now days, the efforts are directed towards the southern regions (central eastern desert and along the red sea coast. So many series of studies are carried out on the Nubian sandstones to evaluate their oil and water potentiality. The relation between mineralogical characters and the physical and engineering properties of sandstones under study were discussed in detail in the entire research paper. Many author studied this relation in other localities for example Abdel-Wahab & McBride, 1995 and Heidari *et al.*, 2013.

Fig. 1 Diagrammatic cross section showing the distribution of different ages Nubia Sandstones in the Gulf of Suez oil fields and Red sea outcrops (Gapco internal report 2006).

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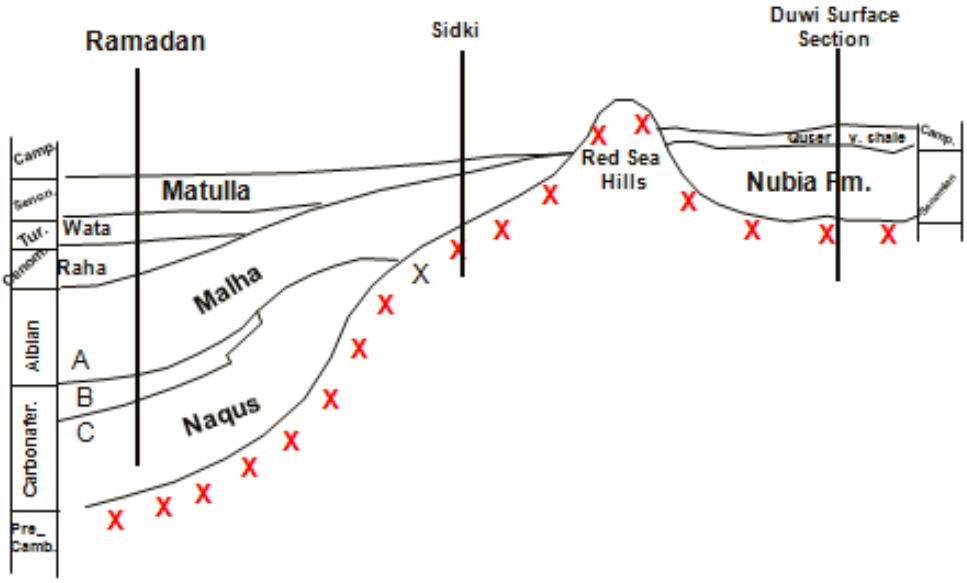

Fig. 1. Diagrammatic cross section showing the distribution of different ages Nubia Sandstones in the Gulf of Suez oil fields and Red sea outcrops (Gapco internal report 2006).

Geologic Setting and Structure Analysis.

Stratigraphically, the northwestern margin of the red sea consists of Precambrian crystalline basement (Akaad & Noweir, 1980 and Said 1990) together with Mesozoic, Cenozoic pre-rift sediment sands and the late Oligocene- Miocene to recent syn-rift sediments. The basement is unconformably overlain by a 500-700 m thick section of pri-rift strata that ranges in age from the late Cretaceous to Middle Eocene. The lower part of the Pre-rift section is the 130 m massive-thick bedded siliciclastic Nubia Formation which overlain by 220-370 m thick sequence of interbedded shales,sandstones, and limestones of Qusseir,Duwi, Dakhla and Esna Formations (Youssef 1957, Abd El-Razik 1967, Iswai *et al.*, 1969 and Khalil & Mc Clay, 2002). The uppermost pre- rift strata consists of 130-200 m of competent, thick - bedded limestones and cherty limestone of the lower to middle Eocene Thebes Formation. The late Oligocene to recent syn-rift strata unconformably overlie Thebes Formation and vary in thickness from less than 100 m on shore to as much a 5 km in offshore basin (Heath *et al.,* 1998).

Geomorphologically, the onshore part can be divided into two parts; the Duwi range and the coastal plain west of Qusier (Fig. 2). The Duwi range consists of a long sharp ridge, elongated in the northwest direction that drops precipitously to the southwest and slopes gently to the northeast (Fig. 3 and 4). The elevation of this ridge ranges between 450 m and 545 m above sea level (ASL). The coastal plain is generally smooth in outline, with no sharp bends or bays. It slopes gently seaward. The relief of the coastal plain is generally low and varies from 6 to 30 m ASL (Salem *et al.*, 2005).

Geologically, the study area is part of the Central Eastern Desert of Egypt. Division of the Eastern Desert of Egypt into northern, central and southern sections is based on basement type (Stern and Hedge, 1985). The Central Eastern Desert was formed by collapse of a small ocean basin or back arc basin (Shackleten *et al.*, 1980).

The structural pattern of the Gulf of Suez and Red Sea Rift is inherited from the basement tectonics. NW-SE faults parallel to the regional elongation of the rift are associated with submeridian (Aqaba direction) and sub-E-W faults (Duwi direction) that also play an important role in the rifting processes. The pre-rift sedimentary cover includes Cretaceous and Eocene platform deposits. It was slightly deformed prior to rifting. The syn-rift sedimentary sequence comprises four major units (groups A to D) delimited by unconformities: Group A (Oligocene to Early Burdigalian), continental to restricted subaquatic deposits; Group B (Burdigalian to Middle Miocene), open marine sediments; Group C (Middle to Upper Miocene), major evaporitic episode; and Group D (Plio-Pleistocene) which returns to an open marine environment (Gupco internal report, 2006).

The major stages of structure are recorded: an initial stage of compressive deformation (direction of shortening close to NW-SE) characterized by strike-slip movements and associated drag folds (early Group A); a tilted block stage (late Group A) corresponding to the period of highest extensional rate; a horst and graben stage (Group B) resulting in the cutting out of the tilted blocks by numerous synthetic faults; Group B corresponds to the period of highest subsidence rate when a flexure stage of the margin, expressed by a uplift

The Sandstone of Nubia in Duwi Surface Section is divided into four lithologic units: Uppermost unit composed of fine to very fine Sandstone, dark grey with black spots, blocky, massive with rippled cross bedding. Upper unit composed of medium to fine Sandstone, yellowish brown with dark lamination, graded bedding. Middle unit is coarse to very Coarse Sandstone, brown, violet and reddish brown, cross-bedded whereas the lower unit composed mainly of yellowish sandstone, pebbly with boulders and chert fragments

Mineral composition, comaction characters and Porosity

Thin sections and Scanning Electron were carried out. Microscopic studies were used to characterize mineral compositions, porosity values and packing parameters to quantify compaction processes as well as to assess burial depth. Both number and types of contacts were dated. Percentages of packing parameters were expressed as; consolidation factor (Cf) ,contact strength (Cs) , packing proximity (Pp), and contact index (Ci). The percentages of porosity values, the pre-cement porosity (PCP) and the loss in porosity were calculated. The mean absolute porosity percent has been detected by (GEOPECNOMETER 1360).

Figure 6 showing Quartz over growth, partially altered feldspars and interstitial clay. Over size pores resulted from altered, partly altered feldspars and dissolved grains. Secondary porosity is due to digenesis processes. Over growth reduces porosity concave-convex contacts elongated & triple point types of contacts. Sometimes carbonate cements reduce porosity. Good porosity-partially altered feldspars-iron oxides and dissolution of feldspar cause oversize pores. Sometimes porosity-quality reduced due to the occurrence of iron oxides.

As shown in Figure 7, authigenic illite as grain coating showing irregular flakes oriented perpendicular to grain surface and some authigenic clay coating grains and fills the interstitial pores are also occurred. Over growth and the interstitial authigenic illite and mixed layer occurred As presented in Table 1, the mean absolute porosity percent has been detected by GEOPECNOMETER 1360 ranged from 14.24 to 32.65% with an average 26.21% whereas the secondary porosity/oversized pores reach up to 8.42% due to the diagenetic process of feldspar to clay minerals. The pre cement porosity values range from 14.7 to 29.02% (Table 1). The loss of porosity values is due to mechanical compaction and cementation processes. Packing parameters are shown in Table 2 and it is a quality control for the compaction process are and burial depth. They include consolidation factor (Cf), contact strength (Cs), packing proximity (Pp) and contact index (Ci) (Table 2).

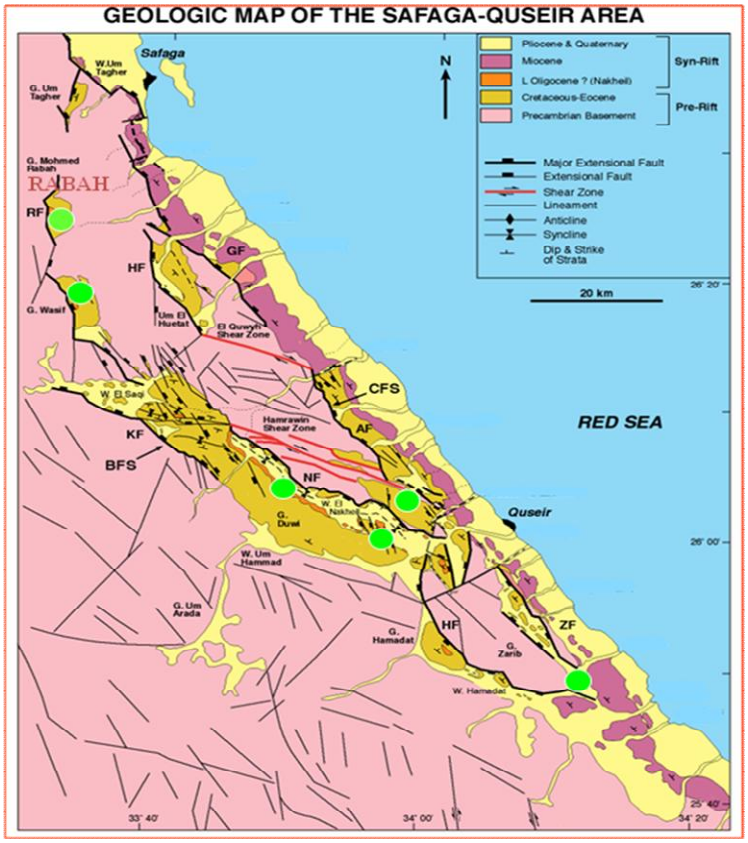

Fig. 2. Location map showing the study area (Said, 1990).

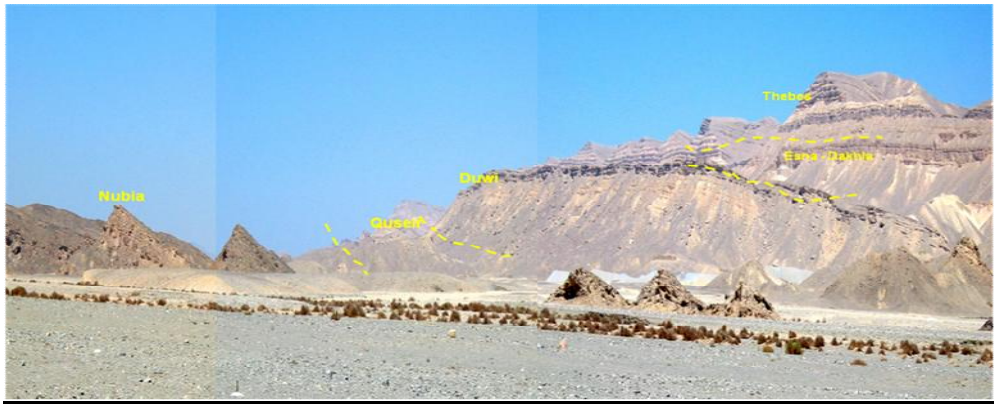

Fig. 3. Field panorama showing the stratigraphic sequences of the study area

Fig. 4. Field panorama showing the contact between Nubia sandstone and Basement in the study area.

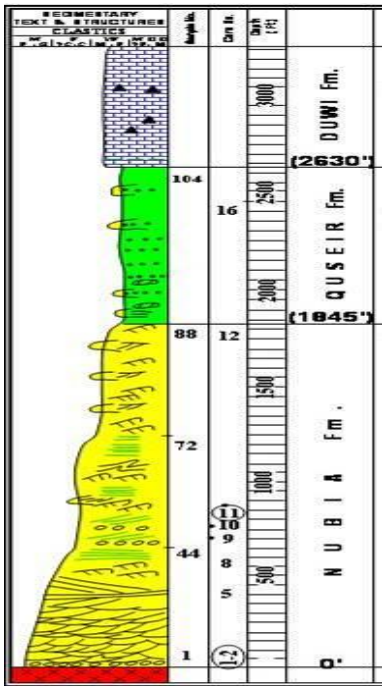

Fig. 5. Stratigraphy of Gebel El Duwi.

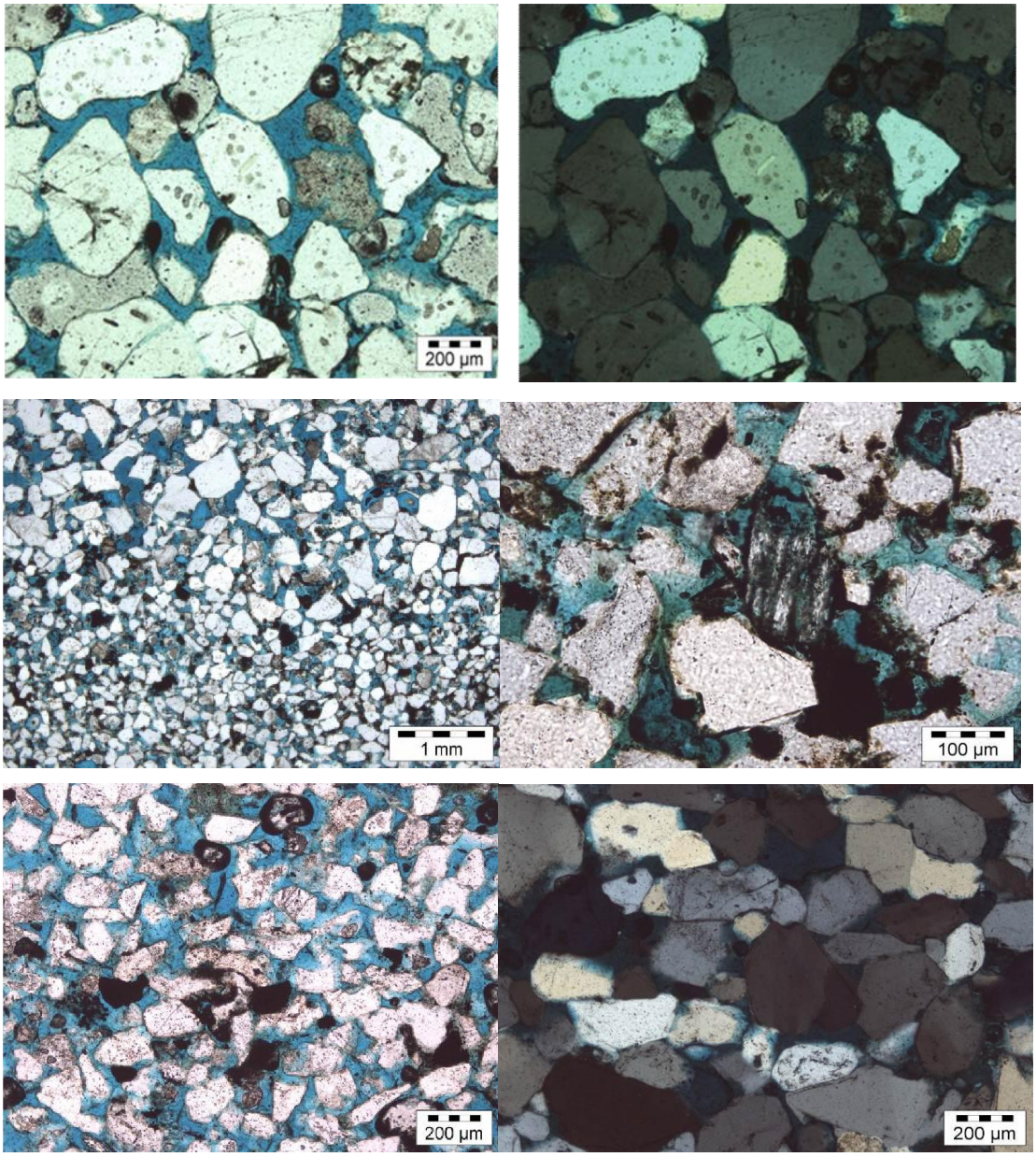

Fig. 6. Petrographic studies of sandstone under investigation

Table 1. Mineral composition and porosity distribution.

Sample no.	Qz%	Fled %	R.F%	Car,%	Clays %	Feo %	Prosites inter	% intra	over	PCP	Por.loss	Absolute P.
7	79.1	0	0	0	1.9	0	12.8	0	6.2	14.7	30.3	14.24
10	71.96	0.8	0	0	3.09	5.08	12.68	0	6.39	20.85	24.15	27.86
12	76.2	2	1	0	5.6	4.7	10.1	0	0.4	20.4	24.6	28.78
15	71.3	0	0	0	6.17	9.11	4.11	0.98	8.42	19.39	25.61	28.75
17	76.14	1.99	0	0	2.99	6.16	11.23	0	1.49	20.38	24.62	32.04
19	71.68	0	0	0	2.31	11.18	10	0	4.83	28.32	16.98	29.03
20	71.68	0	0	0	0.21	16.85	9.1	0	2.16	28.32	16.98	25.7
23	71.08	0.78			5.03	5.83	15.13	0	2.15	28.82	16.18	29.42
26	75.05	0	0	0.4	7.82	0	13.31	0	3.42	24.95	20.05	32.64
31	65.97	5.21	0	0	6.51	8.41	8.5	2	3.4	28.82	16.18	15.92
34	70.12	0.86	0	0	4.58	15.9	6	0	2.54	29.02	10.98	27.84
Average	72.75	1.06	0.10	0.04	4.20	7.57	10.27	0.27	3.76	23.95	20.68	26.51

Explanation:Qz= detrital quartz; feld=feldspar; R.F.=Rock fragments;Car=Carbonates;Clay=detrital clay; Feo = Iron oxide; For porosity inter=intergranular;intra=intragranular pores; over= oversize pores;PCP=precement porosity =(cement%+ intregranular por poers%)=loss in porosity du to compaction and diagenesis processes (45%-PCP);absolute P.=absolute porosity calculated by machine.

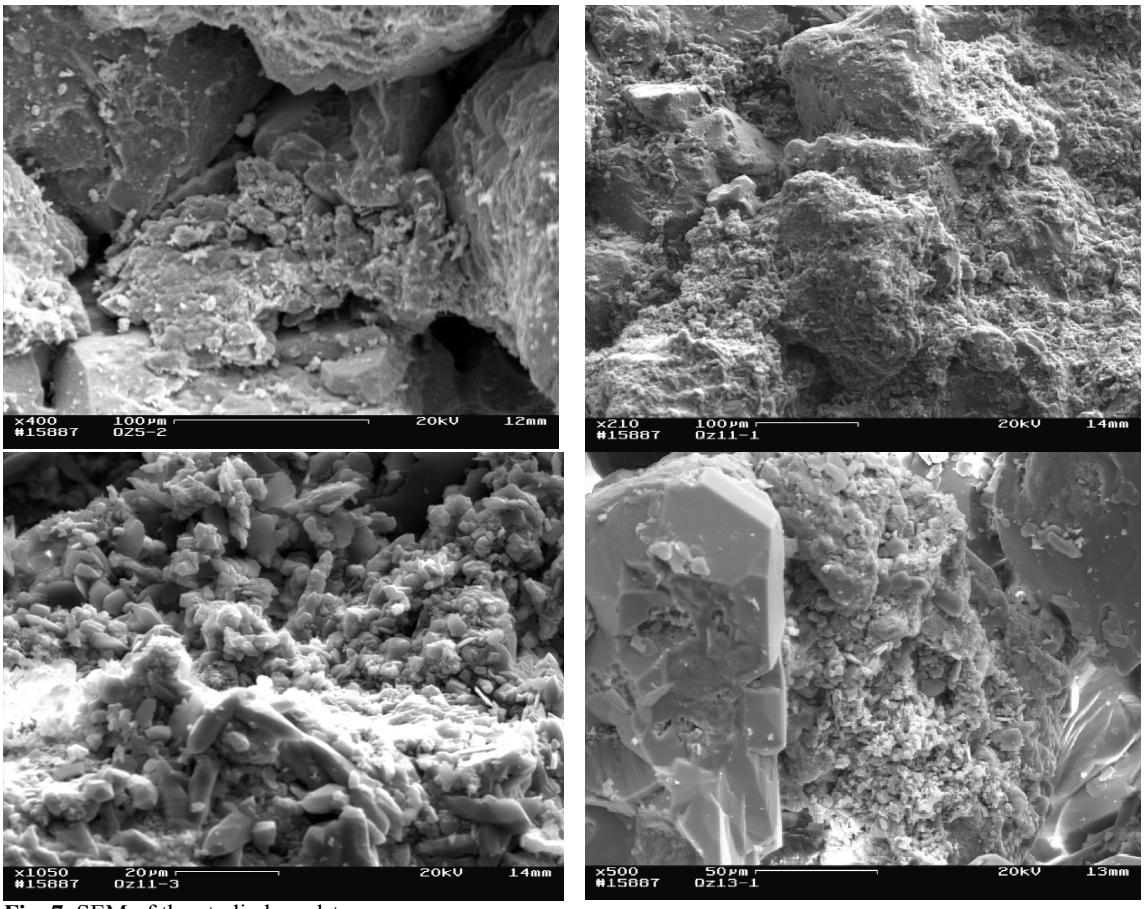

Fig. 7. SEM of the studied sandstone.

Table 2. Packing parameters and type of contacts.

	Types % of	grain	Grain contacts			Packing Parametes			
Sample No.	F	T	L	Con/Vex	Sut	Ci	Cf	Cs	Pp
3	14.39	25.76	42.43	17.42	0	1.89	52.82	1.86	46.38
7	3.2	20.86	65.25	10.69	0	1.86	56.69	2.42	53
10	24.7	16.87	56.02	2.41	0	2.28	47.23	3.18	32.98
12	3.76	33.08	60.9	2.26	0	2.56	52.33	1.68	37.65
15	14.67	32.66	47.33	5.34	0	2.19	48.67	1.9	38.39
17	8.72	30.87	56.38	4.03	0	2.23	51.14	1.71	40.84
19	5.38	42.3	48.46	3.86	0	2.6	50.16	1.59	36.28
20	18.86	28.69	44.26	8.19	0	2.7	48.35	1.75	30.56
23	0	30.21	63.32	6.47	0	2.28	55.25	1.7	43.39
26	3.06	34.36	58.77	3.81	0	2.5	52.67	1.69	28.41
31	0	42.45	45.04	12.21	0	2.3	53.89	1.47	41.99
34	0	26.19	63.49	10.32	0	2.5	56.83	1.84	38.61
Average	8.06	30.36	54.30	7.25	0.00	2.32	52.17	1.90	39.04

Explanation:F=float;T=tangential;L=long;Con/Vex=concavo-convex;Ci=contact index; Cf=consolidation factor; Cs=contact strength Pp=packing density

Ci=total number of contacts/total number of grains

Cf=F+2T+3L+4 (con/vex)+5 sut/5

Cs=T+2L+3 (con/vex)+ 4 Sut/T+L+(con/vex)+Sut

Pp=qx 100/n where q is the no.of contacts and n is the no. of grains, both in one travese

Summary and Conclusions

The results show that the sandstone under study are quartz arenite in composition and it consists mainly of medium to coarse, occasionally medium, fine to very fine grained, rounded to sub-rounded as well as fair to good sorted. Lithologically, the sandstone under investigation was divided into four lithologic units: Lower unit (yellow sandstones, pebbly with boulders and chert fragments). Middle unit (Coarse to very coarse grained S.S brown violet and reddish brown, medium scale crosses bedding). Upper unit. (Medium to coarse grained S.S yellowish brown with dark lamination and graded bedded). Upper most unit (very fine, fine to medium grained

S.S dark grey with black spots; blocky phosphatic). These sandstones were deposited by fluvial systems which were active and energetic at the early phase (lower unit) where the trough bedding were predominated and become more quite at the top where the stratified fine sandstones are present. Algae and wood fragments were recognized in the sandstone which reflects supply of fresh water during the deposition.

Small percentages of detrital and authigenic illite and kaolinite observed in pore spaces between quartz grains. The presence of kaolinite, illite, beside the compaction processes has bad affect on porosity. Illite is found in the pore space as a result of kaolinite alterations.

Porosity is good and represented by elongated, rectangular and over size pores. However the dissolving of feldspars and unstable grains by diagenetic processes produce appreciable amount of secondary porosity as well as the oversize pores up to 8.42%. Quartz overgrowth precipitation owed to be the main factor controlling reservoir quality, it may fill partly or completely the pore space. So the pattern of quartz overgrowth is thus the key issue for reservoir quality prediction. On the other side the warning overgrowth give a new chance to improve the secondary porosity. The pre cement porosity values (PCP) ranges from 14.7 to 29.02% with an average 23.5% indicating that total values of porosity loss range from 27.51 to 35.52% with an average 27.41%. The loss of porosity refers to the fact that most of both original and secondary porosities were partially destroyed by mechanical compaction and cementation processes.

The contact strength (Cs) has positive correlation with packing proximity (Pp) and consolidation factor (Cf) where contact index (Ci) has positive correlation with (Pp), (Cf) and (Cs). There is strong negative correlation between packing and porosity. (Ci) and (PCP) values compared with values obtained from other sandstones of known burial depth and gist their minimum burial depth from about 2.5 km to about 3 km.

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