

Petrography and Probable Reservoir Potentiality of Subsurface Jurassic Rocks at Abu Gharadiq Basin and Shoushan Sub-basin, North Western Desert, Egypt.

A.A. Abdou, M.G. Shehata and M.A.M. Kassab

Egyptian Petroleum Research Institute, Nasr City, 11727, Cairo, Egypt.

Abstract: Core samples representing the Jurassic age from wells Betty-1, Gibb Afia-1 and Mamura-1 were petrographically and petrophysically studied. The sediments represent deposition under various environmental conditions varying from low energy intertidal to energetic shallow water and shallow protected sub-tidal. These sediments were diagenetically affected by cementation, compaction, dissolution and leaching. The study revealed the probability of the effect of a tectonic activity during the lower Jurassic. The studied samples have good storage capacities due to high porosity of different varieties. The porosities which decrease with increasing depth, have originated mainly by leaching processes.

Key words: Petrography, Jurassic Rocks, Abu Gharadiq Basin, Shoushan Sub Basin, Diagenesis, Petrophysics.

INTRODUCTION

Jurassic rocks are known in the surface and subsurface of different localities in Egypt. The most famous and complete section (200 m) is exposed at Gebel Maghara, Sinai.

The continental-marine Jurassic cycles in north Sinai never crossed latitude 30° 15' N. South of this latitude continental facies were developed and Jurassic shorelines were located north of this latitude (Issawi *et al.*, 1999). The dominating facies in Sinai and on the west side of the Gulf of Suez are different from those in the south, also in the subsurface of the northern Western Desert.

Jurassic rocks were studied by many authors among them are the works of Sadek (1926), Farag (1957), Abdallah *et al.* (1963), Abdallah (1964), Al Far (1966), Norton (1967), Weissbrod (1970), Barthel and Boettcher (1978), Schlumberger (1984), El-Dakkak (1987), Hamed (1989), Hantar (1990), Hassouba (1993), Issawi and Osman (1993) and Shehata and Abdou (2007).

The rim of the Mediterranean basin is well known as a prolific source area of oil and gas. Rifting prior to and during the Early Jurassic was followed by a major and significant transgression in the Middle and Upper Jurassic times which contributed to the excellent conditions required for the generation of hydrocarbons within rifted basins. Upper Egypt might have been the site for one of the rift systems during the same time too. In 1985, deep drilling led to a very significant oil discovery in the Jurassic Khatatba Formation in Salam-3x well at the Northern Western Desert. This discovery sparked one of the hottest new oil pays in the Western Desert of Egypt.

Detailed study of sandstones is of importance due to their marked porosity and collector abilities which define good quality sandstone reservoir rocks. The overall goal of the present study is to expand our understanding of the diagenetic changes which affected the Jurassic sandstones encountered in the wells Betty-1, Gibb Afia-1 and Mamura-1 and to determine the effect of these changes on the measured porosity of the studied core samples.

Location of these wells is given in Fig. 1 while the lithology of their studied intervals and selected cores are represented in Fig. 2.

Methods:

Polished stained thin sections of about 30 samples from 13 cores representing Jurassic sandstones at the wells Gibb Afia-1, Betty-1 and Mamura-1 were used to study the texture, mineralogical composition and porosity by polarizing microscope.

Porosity of 47 sandstone samples was measured by the standard gas expansion method using Heise Gauge type helium porosimeter.

Stratigraphy:

The subsurface Jurassic succession of the north Western Desert was assembled from the oldest to the youngest as follows:

The Bahrain (Eghi Group) Formation (Hantar, 1990) Early-Middle ? Jurassic:

It is made up of red clastics, fine to coarse quartzose sandstones with thin pebble interbeds, siltstones and shales which are occasionally carbonaceous or pyritic. A few anhydrite bands were recorded in some wells.

The Wadi Natrun Formation (Norton, 1967) Early ?-Middle Jurassic:

It includes a carbonate-shale sequence. The carbonates are mostly dolomitic and are more frequent in the upper parts while anhydrite is recorded in some localities.

The Khatatba Formation (Norton, 1967; Hantar, 1990) Middle Jurassic:

It is made up of sandstones and shales with a few limestone interbeds which become thicker, argillaceous and more frequent near the upper part. Coal seams are present at different levels of the section.

The Masajid Formation (Al Far, 1966) Middle-Late Jurassic:

It is composed of dolomitic limestone with chert bands changing downward to marl then to shale.

The Sidi Barrani Formation (Hantar, 1990) Middle Jurassic - Early Cretaceous ?:

It is a thick carbonate section.

Petrography of the Lower Jurassic Sandstone:

The Lower Jurassic sandstone was encountered at both Bettey-1 and Gibb Afia-1 wells. The framework quartz grains are subrounded and subangular (Pl.1-A, B), being coarser (medium to coarse) in the sandstones of Bettey-1 well (Pl. 1-C) than in Gibb Afia-1 well (Pl. 1-B), moderately sorted in the sandstone of the former well (Pl. 1-A, C) and ill-sorted in the later well (Pl. 1-B). Generally, the grains show point and straight contacts (Pl. 1-A, B, C).

Chlorite (Pl. 1 -D, E) is the main matrix material filling the pore spaces in most of the studied samples. Partial cementation with chert (P. 1-F), chalcedony (Pl. 1 -G), iron oxides (Pl. 1-H) and carbonate (Pl. 1-I) in addition to complete barite cementation (Pl. 2-

was recorded in the sandstones of Bettey-1 well. On the other hand, quartz grains of the sandstones of Gibb Afia-1 well are floating in the matrix (Pl. 1-E) which sometimes is leached causing the increase of porosity especially in core No. 31. These sandstones also contain mica flakes (Pl. 2-B), gypsum (Pl. 2-C) and fibrous silica (Pl. 2-D).

Petrography of Middle Jurassic Sandstone:

The Middle Jurassic Khatatba Formation is recorded at Bettey-1 well represented by quartz wacke having a matrix of about 15% (Pl. 2-E) and is fine to medium grained, moderately to ill-sorted, ferruginous (Pl. 2-E, F), chloritic (Pl. 2-G) and organically enriched (Pl. 2-G) indicating prevalence of reducing conditions of deposition (Hamed, 1989).

Petrography of the Upper Jurassic Rocks:

The Upper Jurassic Masajid Formation was recorded at the three studied wells represented mainly by carbonate rocks and show the following petrographic features:

In Bettey- 1 well, these rocks are composed of highly fossiliferous lime mud (Pl. 2-H) with fossil remains filled with sparry calcite and ferruginous matter (Pl. 2-H) in addition to diagenetic dolomite filling cracks (Pl. 2-I).

The base of Masajid Formation at Gibb Afia-1 well is dominated with ferruginous micritic poorly sorted sandstone (Pl. 3-A) composed of very fine to fine ill-sorted quartz grains, altered feldspar (Pl. 3-B), gypsum (Pl. 2-C) and fibrous chalcedony (Pl. 3-D). The organic rich clay of the matrix (Pl. 2-G), gypsum, pyrite and ferruginous stains (Pl. 3-E) indicate its deposition in a reducing environment. The sediments of this formation grade upwards to dolomite (Pl. 3-F) with some cloudy dolomite rhombs and stylolitic structures which are filled with very fine quartz grains and organic rich clay.

The sandstone of Masajid Formation at Mamura-1 well is calcareous quartz arenite (Pl. 3-G) with fine to medium occasionally coarse quartz grains, subrounded to subangular and moderately sorted in addition to a

few chert rock fragments (Pl. 3-H). The grains are mostly bounded with micrite which is sometimes affected by leaching processes (Pl. 3-I). Other pore-filling materials such as chlorite (Pl. 4-A), gypsum (Pl. 4) and calcite cement of both spiny (Pl. 4-C) and poikilotopic (Pl. 4-D) varieties are recorded.

Diagenesis of Sandstones:

Three main diagenetic processes affected the Jurassic sandstone rocks of the studied wells as follows:

A - Compaction and pressure solution:

Compaction is attributed to the increase of overburden which consequently changes the rock texture and fabric as well as explosion of pore fluids (McBride, 1987). Compaction is related to the burial depth (McAulay *et al.*, 1993) and results in porosity reduction (Tada and Siever, 1989).

Occurrence of compaction in the present study is marked by the increase of clay matrix (Plates 1 -D, 3-A, E) as a result of clay infiltration (Tucker, 1991), mud clasts among the quartz grains (Plates 3-E and 4-E) formed by mechanical compaction (McAulay *et al.*, 1993), mica flakes which are bent and squeezed between the quartz grains (Plates 2-B and 4-F) and predominance of straight and point grain contacts (Plates 1-A, 1-C and 3-G).

B - Cementation:

Cementation by silica, carbonates, iron and barite was recorded in the studied Jurassic sandstones resulting in partial or complete filling of pore spaces.

Silica cement (Pl. 5-A) and quartz overgrowths (Plates 1-C and 5-B) were recorded in a few samples of the Lower Jurassic sandstones of Bettey- 1 well while chert was recorded in the Lower and Middle Jurassic sandstones of the same well. Moreover, chalcedony in a dendritic form enveloping the quartz grains and other components (sometimes crossing the pore spaces) was recorded in the Lower Jurassic sandstones of Bettey-1 well (Pl. 1-G).

Calcite cement was recorded as translucent micro to cryptocrystalline needles (Pl. 4-C) and poikilotopic blocky crystals (Pl. 4-D) in the Upper Jurassic sandstones of Mamura- 1 well while a mosaic of subhedral sparry calcite cement was recorded in the Lower Jurassic sandstones of Bettey-1 well (Pl. 1-I and Pl. 5-C). Corrosion of the quartz overgrowths by calcite cement (Pl. 1-I and 4-D) indicates that calcite cement postdates silica overgrowths.

Admixture of ferruginous material, clay and micritic matrix in which quartz grains are embedded (Pl. 1-D, E and Pl. 2-E, F and Pl. 3-A) are sometimes corroded by iron oxides (Pl. 5-D). Such ferruginous material may fill the fractures (Pl. 1-H and 2-F) indicating the mobile state of their bearing solutions.

Complete cementation with barite (Pl. 2-A) was recorded in some samples of Lower Jurassic sandstone in the Bettey-1 well.

C - Dissolution:

Evidences of the occurrence of this phenomenon are recorded in the present study and will be discussed later at porosity evaluation.

Diagenesis of Carbonate Rocks:

The study of carbonate samples related to Masajid Formation of the wells Gibb Afia-1 and Bettey-1 revealed the following diagenetic features:

A - Cementation and cavity filling:

The dursy mosaic cement in which moldic cavities are filled with dursy calcite was recorded at the samples of Bettey-1 well (Pl. 2-H). These have been formed by selective solution of the lime mud fossil molds and subsequent deposition of calcite resulting in biomolds, oomolds or pelmolds (Selley, 1996).

B - Dolomitization:

Dolomite appears as irregular fracture filling (Pl. 2-I) or as patches of white dolomite (recrystallized dolomite) intersecting the sedimentary textures and structures (Mattavelli *et al.*, 1969).

C - Stylolitization:

This feature is recorded in the Masajid Formation of Bettey-1 well. The stylolite is filled by the insoluble residue derived from the limestone solution which may be clay or detrital quartz grains (Pl. 5-E). This feature results from pressure solution of the limestone along planes due to overburden or tectonic pressure (Wanless, 1979).

Porosity Evaluation:

Porosity was studied in the Jurassic core samples using two techniques as follows:

I - Petrographic Investigation:

Three types of porosity; mainly interparticle, vugs and channel porosities were microscopically identified in the studied samples following Choquette and Pray (1970) and McBride *et al.* (1996) as illustrated in table (1). These types of secondary porosity are the result of different physical and chemical processes which affected the rocks during its diagenesis (Schmidt and McDonald, 1979 and Bjorlykke, 1980). Criteria denoting the development of secondary porosity in the studied Jurassic sediments are summarized as follows:

Table 1: Types of porosity as microscopically described at the studied core samples:

Age	Well	Formation	Core No.	Type of porosity	Plate No.	
Upper Jurassic	Gibb Afia-1	Masajid	29	1 - Interparticle	5-F	
				2 - Channel	5-D, F	
				3 - Vug (oversize porosity)	3-B	
	Mamura-1	Masajid	5	1 - Vug	4-A	
				2 - Interparticle	4-A, E	
				6	1 - Interparticle	3-I, 4-E
Lower Jurassic	Gibb Afia-1	Bahrain	31	2 - Vug	3-I	
				1 - Interparticle	1-B	
				2 - Vug	1-E	
	Bettey-1	Bahrain	38	1 - Interparticle	1-H	
				40	1 - Interparticle	1-D
				2 - Vug	1-D	

A- Feldspar Dissolution:

Vugs and oversize porosities due to feldspar alteration and dissolution along cleavage planes is recorded in the sediments of Masajid Formation of Gibb Afia-1 well (Pl. 3-B and 5-F).

B- Leaching:

Vugs and channel porosities are mainly due to leaching of micritic matrix of the Lower Jurassic sediments of both Bettey-1 and Gibb Afia-1 wells (Pl. 5-D, F). Interparticle and vug porosities resulted from later stage leaching of calcite which corroded quartz grains in the sediments of Masajid and Khatatba Formations (Pl. 1-I and 4-D). Oversized pores were recorded in the sediments of Masajid Formation of Gibb Afia-1 well (Pl. 3-B and 5-D, F) as a result of cement replacement and pore filling followed by subsequent dissolution.

C - Inhomogeneity of packing and floating grains:

The packing of sediment grains is an important consideration since it affects porosity and permeability (Tucker, 1991). The inhomogeneity of packing and floating grains (matrix support grains) were considered as the criteria for recognition of secondary porosity (McDonald, 1979).

This feature was recorded in a few of the studied Jurassic core samples and helped in forming interparticle porosity (Pl. 1-A, B and Pl. 3-B and Pl. 5-E).

II - Petrophysical Investigation:

Porosity measurement data was statistically treated (Table 2) and interrelations were graphically represented as follows:

I - Distribution of porosity values:

The histogram and box-Whisker plot of porosity values (Figs. 3, 4) show that most of the studied samples have porosities in the range 16-28% with an average value of 17.18%. This means that the studied sandstones have a good storage capacity according to Levorsen (1967). However, the porosity values (table 2) show that the uppermost part of the Mid. Jurassic sandstones of Bettey-1 well and the Upper Jurassic sandstones of Mamura- 1 well are of comparatively low values probably due to either cementation or ill sorting.

2 - Values distribution of grain density (gm/cm³):

Figures (5, 6) show that most samples have grain densities between 2.6 and 2.7 gm/cm³ with an average value of 2.68 gm/cm³. This means that most samples are quartzitic. The higher values in core No. 37 from Bettye-1 well (table 2) may be attributed to the presence of iron and/or carbonate cement.

Table 2: Some petrophysical Parameters of subsurface Jurassic rock samples.

Age	Well Name	Formation	Core No.	Sample No.	Depth	Porosity %	Grain Density, g/cm ³	Bulk Density, g/cm ³
Upper Jurassic	Gibb Afia -1	Masajid Formation	29	1	5502	26.285	2.617	1.929
				2	5502.5	26.076	2.621	1.938
				3	5503	25.580	2.630	1.959
				4	5504	25.243	2.576	1.926
				5	5505	24.539	2.587	1.952
				6	5508	20.030	2.630	2.102
				7	5508.5	19.355	2.611	2.106
				8	5509	19.192	2.602	2.103
				9	5510	18.408	2.554	2.084
				10	5572	26.101	2.641	1.952
				11	5574	24.939	2.643	1.984
				12	5575	24.620	2.610	1.969
				13	11424	0.610	2.700	2.688
				14	12385	12.780	2.560	2.230
Middle Jurassic	Bettye-1	Khatatba Formation	37	15	11510	8.423	3.219	2.948
				16	11519	7.573	3.315	3.064
				17	11526	6.190	3.250	3.049
				18	11532	2.350	3.030	2.957
				19	12041	18.940	2.640	2.144
				20	12046	18.226	2.606	2.131
				21	12052	17.914	2.609	2.142
				22	12057	17.814	2.567	2.110
				23	12061	17.733	2.599	2.138
				24	12062	5.005	2.676	2.542
				25	12065	4.720	2.700	2.574
				26	6074	25.550	2.638	1.964
				27	6074.5	24.970	2.630	1.974
				28	6075	24.966	2.636	1.978
29	6076	24.272	2.625	1.988				
30	6077	24.189	2.628	1.992				
31	6078	22.619	2.624	2.030				
Lower Jurassic	Bettye-1	Bahrain Formation	40	32	12480	17.037	2.643	2.193
				33	12482	16.770	2.640	2.200
				34	12484	16.616	2.621	2.185
				35	12486	16.539	2.624	2.190
				36	12487	16.214	3.056	2.561
				37	12489	16.195	2.618	2.194
				38	12762	12.460	2.630	2.304
				39	12763	11.492	2.610	2.310
				40	12763.5	11.109	2.621	2.330
				41	12764	10.953	2.614	2.328
				42	12765	10.538	2.628	2.351
				43	12771	18.260	2.640	2.155
				44	12771.5	17.831	2.618	2.151
				45	12772	16.947	2.582	2.145
46	12773	16.706	2.596	2.162				
47	12774	16.635	2.579	2.150				

3 - Values distribution of bulk density (gm/cm^3):

Figures (7, 8) show that most samples have bulk densities between 1.8 and 2.4 gm/cm^3 with an average value of 2.22 gm/cm^3 . The low values of some samples of Upper and Lower Jurassic from Gibb Afia-1 well (table 2) may be attributed to higher porosity.

4 - Relation between porosity (%) and bulk density (gm/cm^3):

This relation between porosity and bulk density is represented by the equation $\rho_b = -0.0383\% + 2.8829$. An excellent linear relationship is obtained (Fig. 9) which indicates that rock samples mostly have similar mineralogical composition, grain shape, packing and fabric. Therefore, the pore framework is expected to be uniform and homogenous. This conclusion is confirmed by the grain and bulk densities distribution as well as the petrographic study.

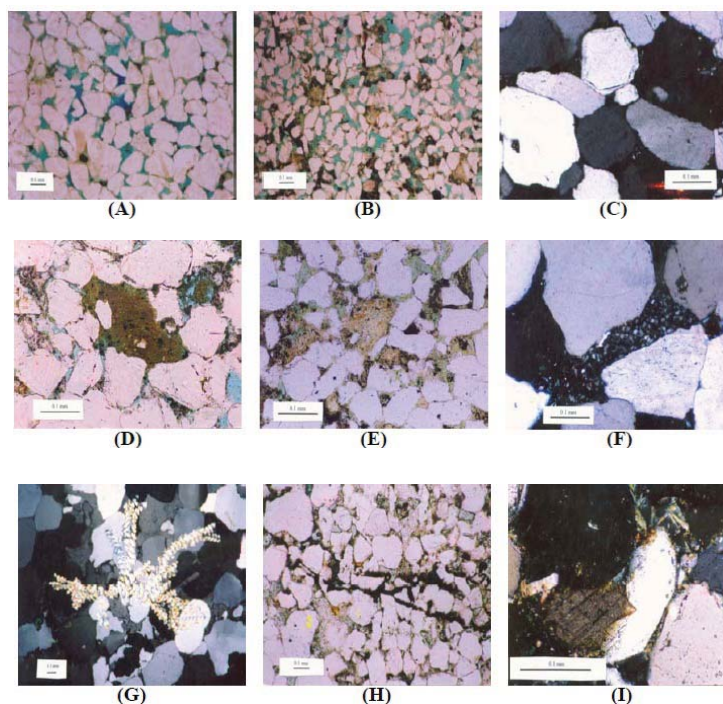


Plate (1):

- (A) Sandstone texture and interparticle porosity, Betty-1 well, C. No. 41, PPL.
- (B) Sandstone texture and interparticle porosity, Gibb Afia-1 well, C. No. 31, PPL.
- (C) Straight contacts and quartz overgrowths, Betty-1 well, C. No. 41, C.N.
- (D) Rims of iron oxides and/or clays in chlorite matrix which are leached to form interparticle porosity, Betty-1 well, C. No. 40, PPL.
- (E) Matrix support with interparticle and channel porosities, Gibb Afia-1 well, C. No. 31, PPL.
- (F) Chert filling the pore spaces, Betty-1 well, C. No. 41, C.N.
- (G) Dendritic chalcedony in the sandstone, Betty-1 well, C. No. 39, C.N.
- (H) Iron oxides cement and vuggy porosity, Betty-1 well, C. No. 38, PPL.
- (I) Peripheral corrosion of the quartz grains by calcite cement, Betty-1 well, C. No. 38, C.N.

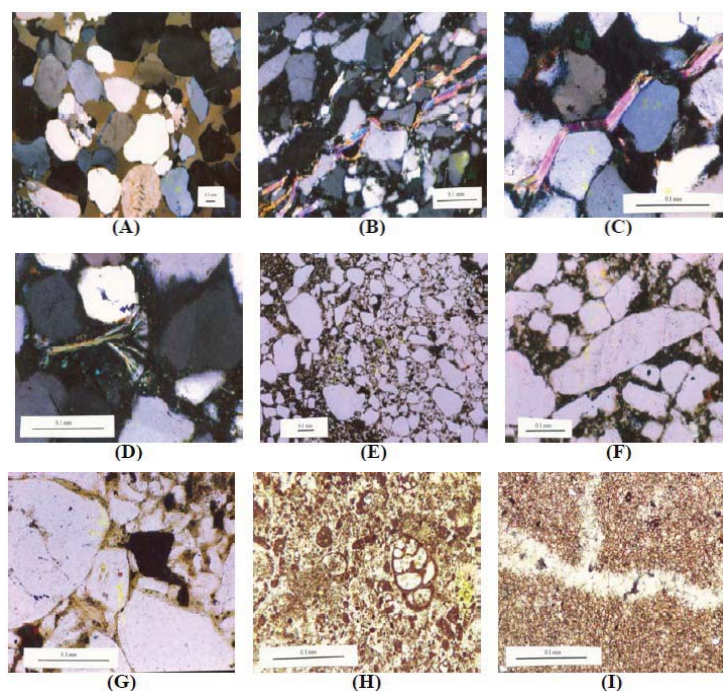


Plate (2):

- (A) Barite cement, Bettyey-1 well, C. No. 39, C.N.
- (B) Mica flakes bent and squeezed between quartz grains, Gibb Afia-1 well, C. No. 31, C.N.
- (C) Gypsum filling the pore spaces between the quartz grains, Gibb Afia-1 well, C. No. 31, C.N.
- (D) Fan like silica fibrous, Gibb Afia-1 well, C. No. 31, C.N.
- (E) Poorly sorted sandstone, ferruginous, Bettyey-1 well, C. No. 37 PPL.
- (F) Ferruginous poorly sorted sandstone, Bettyey-1 well, C. No. 37, PPL.
- (G) Chloritic poorly sorted sandstone, rich with organic matter, Bettyey-1 well, C. No. 37, PPL.
- (H) Sparry calcite filling the molds of fossil remains in micrite, Bettyey-1 well, C.No. 36, C.N.
- (I) Cracks filled by coarser saccaroid dolomite crystals, Bettyey-1 well, C. No. 36, C.N.

5 - Relation between porosity (%) and depth (m):

The depth and porosity of the studied sandstone samples (Fig. 10) are inversely related with a high correlation coefficient ($r = 0.71$). This relation is represented by the equation: $\text{Depth} = -337.142 (\sim\%) + 15571.096$

This means that porosity decreases with increasing depth due to increasing cementation and compaction as the depth increases.

6 - Relation between bulk density (g/cm^3) and depth (m):

The depth is directly related to the bulk density (Fig. 11) showing a fair relationship with the correlation coefficient ($r = 0.54$). This relation is represented by the equation: $\text{Depth} = 5893.114 (\text{ób}) - 3330.703$

This means that bulk density was partially affected by depth as it increases with increasing depth due to compaction.

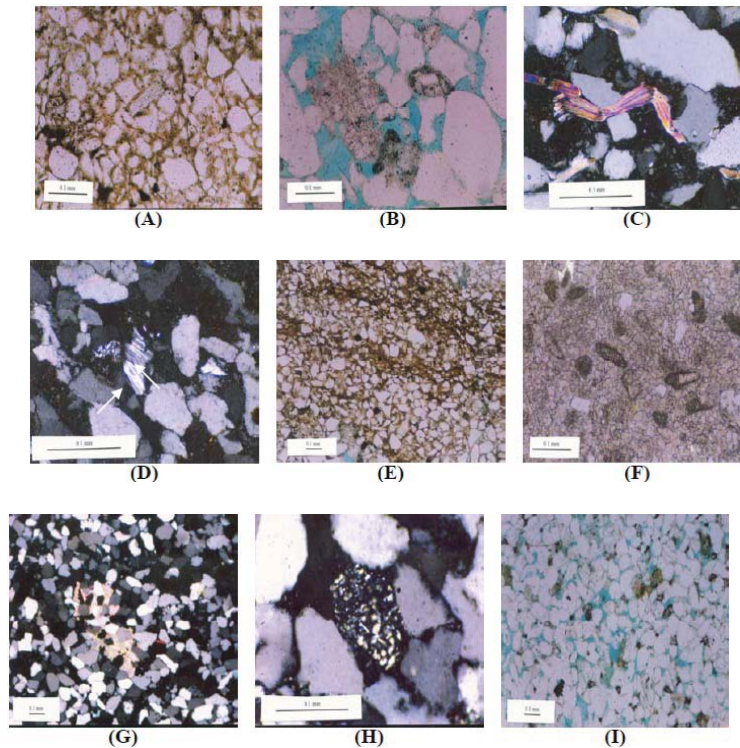


Plate (3):

- (A) Poorly sorted ferruginous sandstone, Gibb Afia-1 well, C. No. 29, PPL.
- (B) Altered feldspar, interparticle and oversize porosities, Gibb Afia-1 well, C. No. 29, PPL.
- (C) Gypsum between the quartz grains, Gibb Afia-1 well, C. No. 39, C.N.
- (D) Chalcedony fibrous (see arrows), Gibb Afia-1 well, C. No. 30, C.N.
- (E) Ferruginous micritic poorly sorted sandstone, Gibb Afia-1 well, C. No. 29, PPL.
- (F) Cloudy dolomite rhombs, Gibb Afia-1 well, C. No. 39, PPL.
- (G) Calcareous quartz arenite, Mamura-1 well, C. No. 5, C.N.
- (H) Chert rock fragment, Mamura-1 well, C. No. 5, C.N.
- (I) Interparticle and vug porosities formed due to leaching, Mamura-1 well, C. No. 6, PPL.

7 - Relation between porosity (%) and grain density (g/cm^3):

The grain density values are inversely related to the rock porosity (Fig. 12) showing a weak relationship with the correlation coefficient ($r = 0.49$). This relationship is represented by the equation: $\rho_g = -0.0128 (\sim\%) + 2.899$

This relation shows that the porosity was slightly affected by grain density.

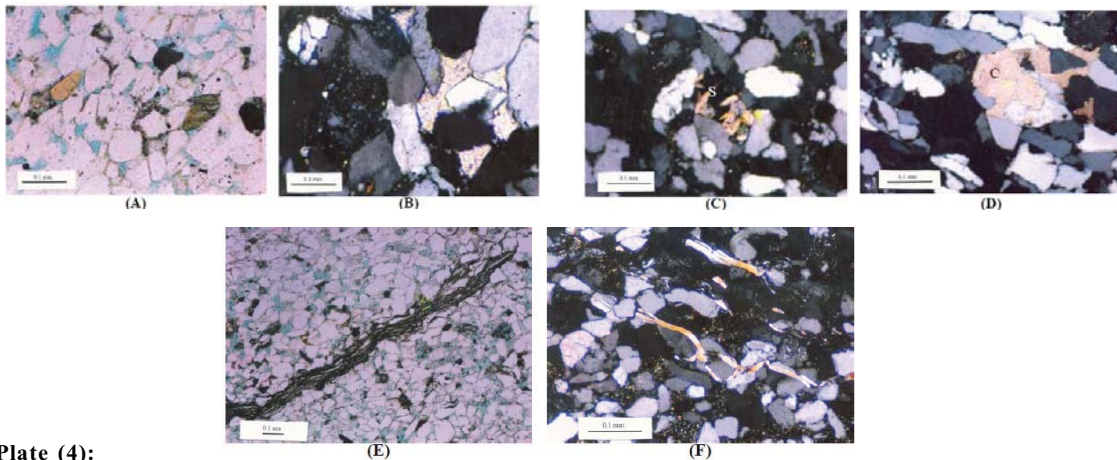


Plate (4):

- (A) Chlorite between quartz grains also interparticle porosity formed due to the leaching of the matrix, Mamura-1 well, C. No. 5, PPL.
- (B) Gypsum filling the pore spaces reducing the porosity, Mamura-1 well, C. No. 5, C.N.
- (C) Spiny calcite cement (S), Mamura-1 well, C. No. 5, C.N.
- (D) Poikilotopic calcite cement (C), Mamura-1 well, C. No. 6, C.N.
- (E) Mud clasts among the quartz grains, Gibb Afia-1 well, C. No. 31, PPL.
- (F) Mica flakes bent and squeezed between quartz grains, Gibb Afia-1 well, C. No. 31, C.N.

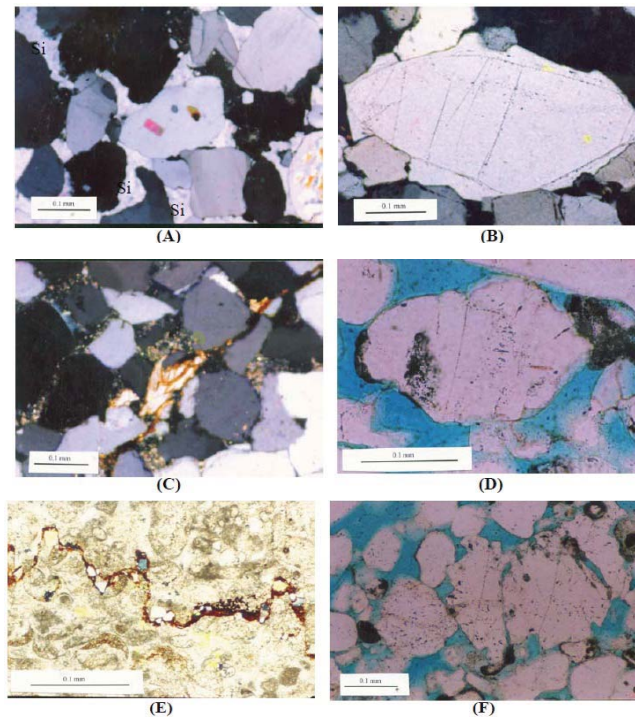


Plate (5):

- (A) Silica cement (Si), Betty-1 well, C. No. 38, C.N.
- (B) Quartz overgrowths, Betty-1 well, C. No. 40, C.N.
- (C) Calcite cement, Betty-1 well, C. No. 38, C.N.
- (D) Quartz grain corroded by iron, Gibb Afia-1 well, C. No. 29, PPL.
- (E) Stylolite, Gibb Afia-1 well, C. No. 36, C.N.
- (F) Oversize porosity, Gibb Afia-1 well, C. No. 29, PPL.

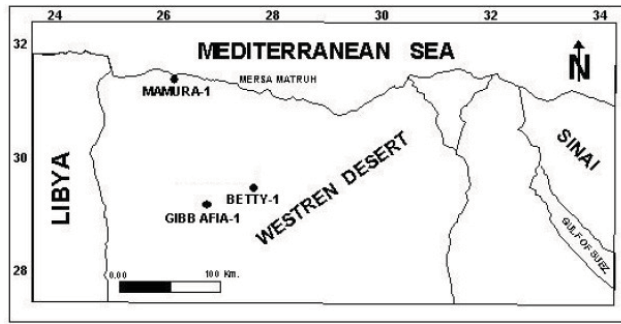


Fig. 1: Location map of studied wells.

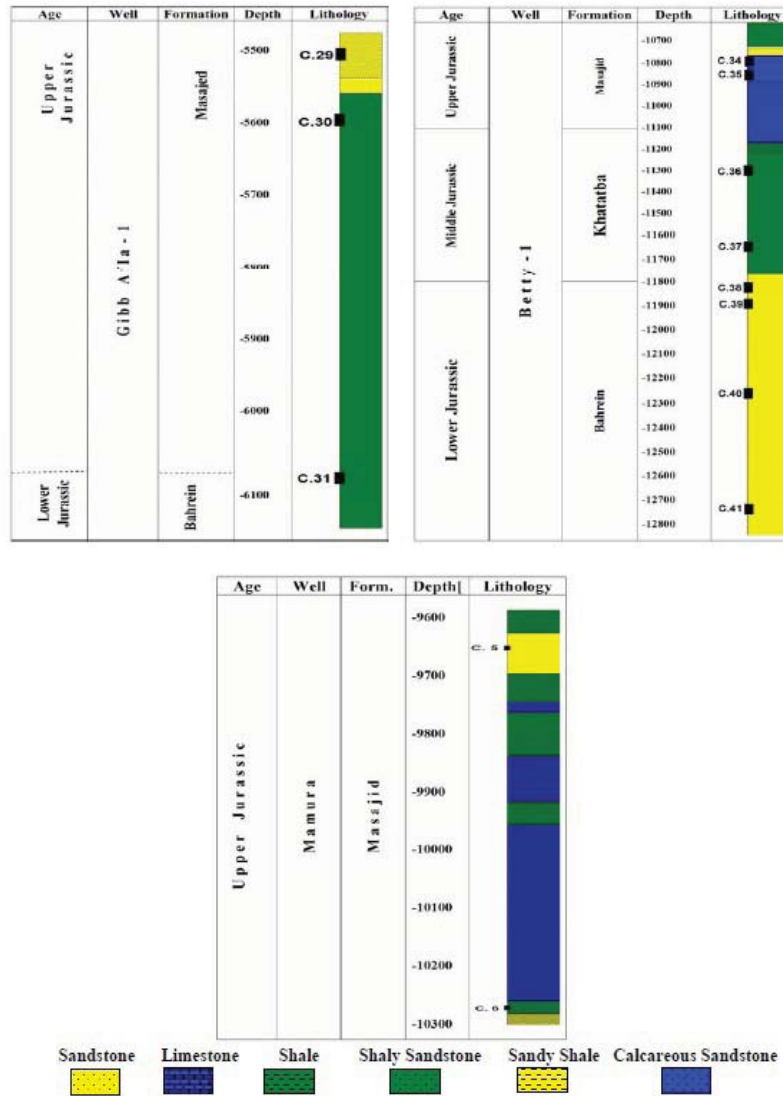


Fig. 2: Lithological sections of the studied wells.

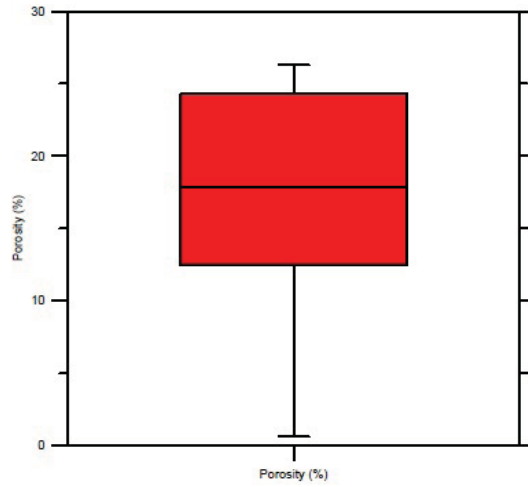


Fig. 3: Distribution of porosity, according to box- Whisker plot.

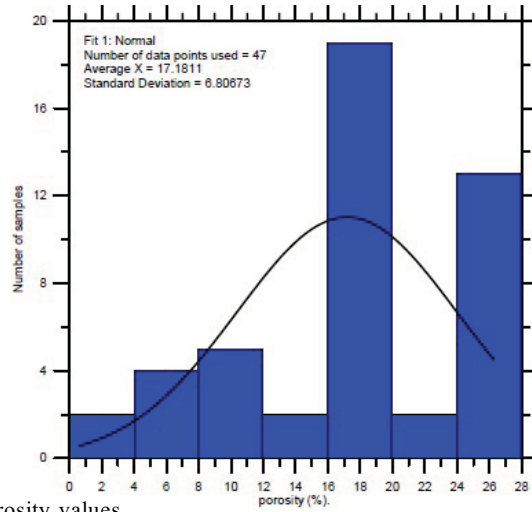


Fig. 4: Distribution of porosity values.

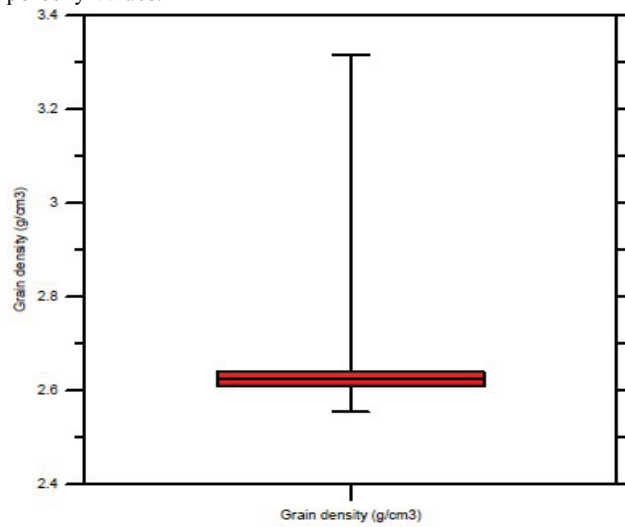


Fig. 5: Distribution of Grain density, according to box- Whisker plot.

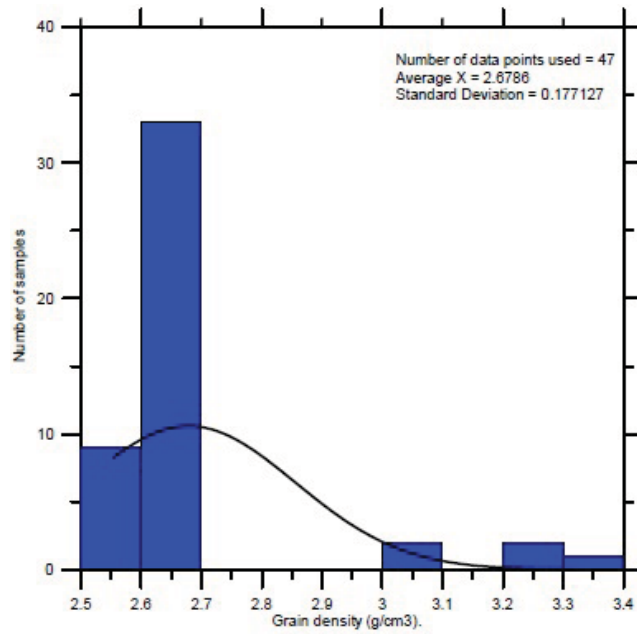


Fig. 6: Distribution of Grain density

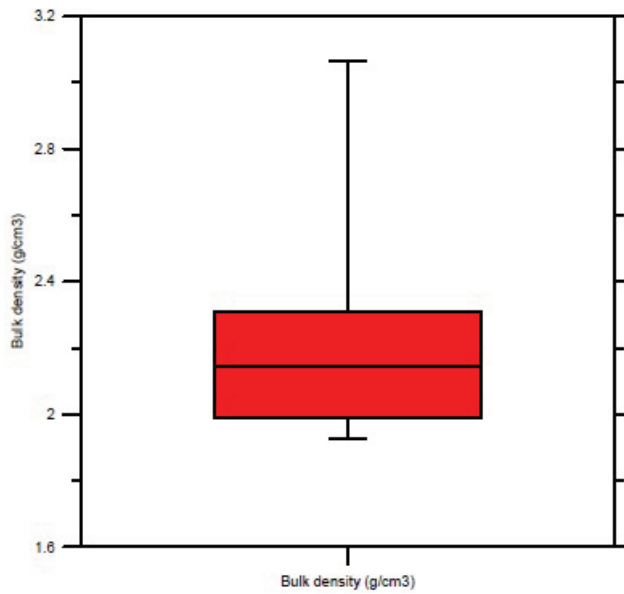


Fig. 7: Distribution of Bulk density, according to box- Whisker plot.

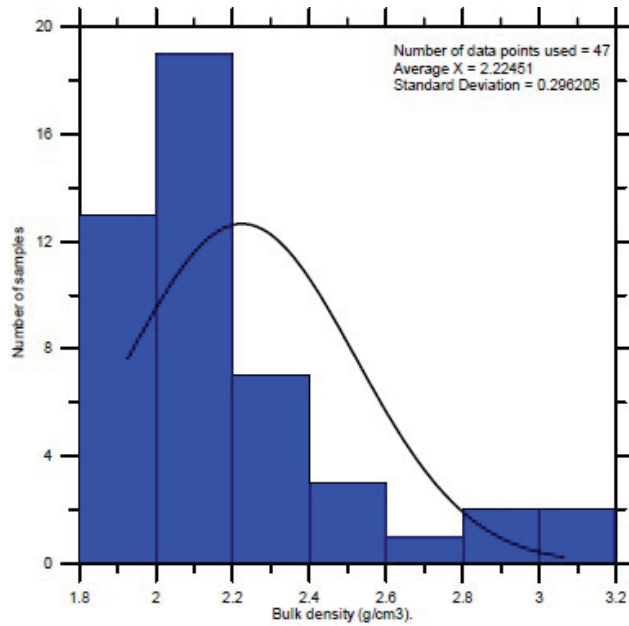


Fig. 8: Distribution of Bulk density values.

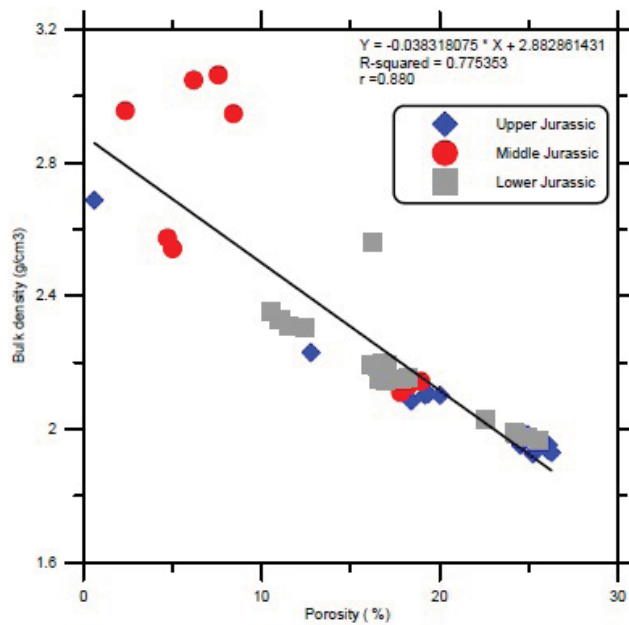


Fig. 9: Relation between Porosity (%) and Bulk density (g/cm³).

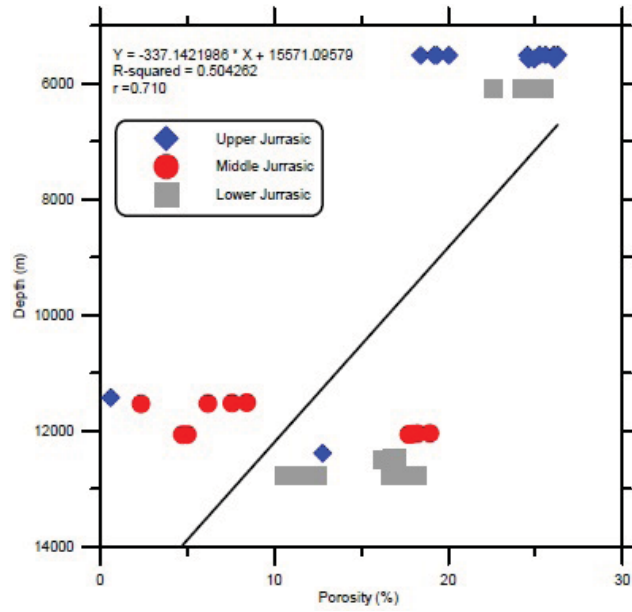


Fig. 10: Relation between Porosity (%) and Depth. (m).

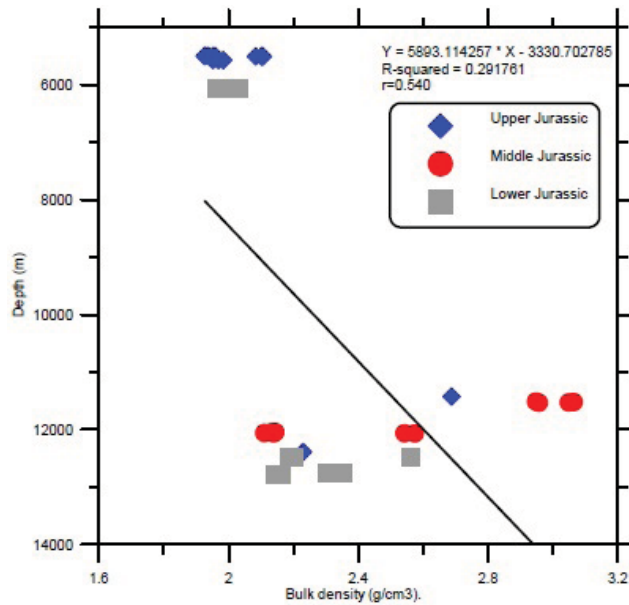


Fig. 11: Relation between Bulk density (g/cm3) and Depth (m).

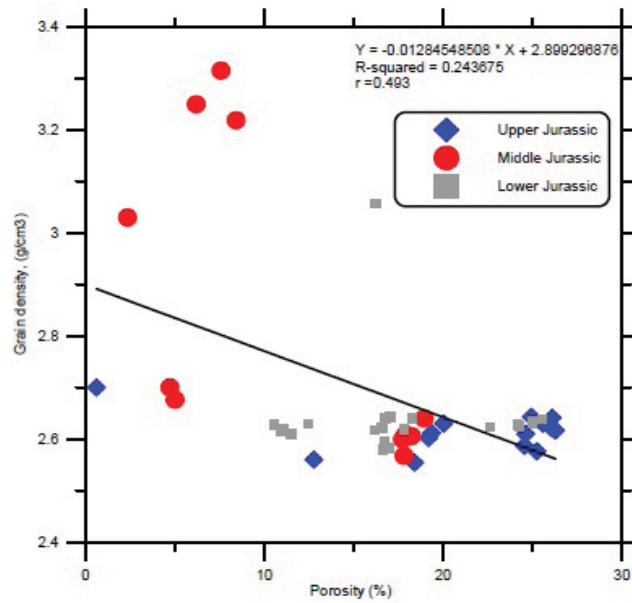


Fig. 12: Relation between Porosity (%) and Grain density (g/cm³).

8 - Relation between grain density (g/cm³) and depth (m):

There is no relation between the grain density and depth, the correlation coefficient is $r = 0.205$ Fig. (13) which means that, grain density was not affected by depth probably due to little or no change in mineral composition. This relation is represented by the equation: $\text{Depth} = 3739.067(\delta g) - 236.847$.

Conclusions:

The petrographic study of Jurassic sandstones and carbonate rocks from the studied wells revealed that these sediments were deposited under various environmental conditions varying from low energy intertidal (wackes), energetic shallow water conditions (arenites) and shallow protected subtidal (carbonates) depending on their textural characteristics.

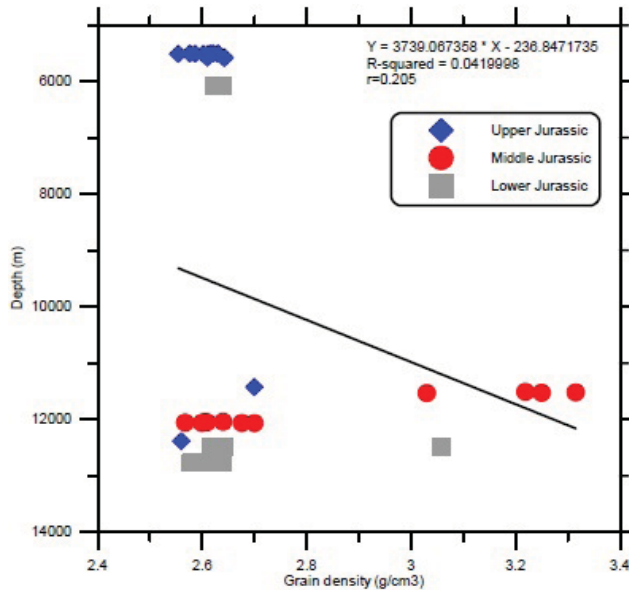


Fig. 13: Relation between Grain density (g/cm³) and Depth (m).

The studied sediments were affected by diagenetic processes represented by cementation, compaction, dissolution and leaching. Silica overgrowths (and cement), carbonate, iron oxides and barite cementing materials were recorded.

Although the studied sandstones showed evidences of low grade compaction represented by point, elongate and rarely concavo-convex grains contacts; stylonitic structures were recorded in the carbonate rocks.

The occurrence of dissolution and leaching processes is documented by corrosion of quartz grains by carbonate cement, altered feldspar grains, high intergranular porosities, oversize pores and vugs.

Complete cementation with barite in addition to chalcedonic material with a dendritic shape enveloping the rock components of the Lower Jurassic sandstones suggest that braium and silica have emanated from a hydrothermal source accompanying a tectonic activity that probably affected the area (Nagati, 1986).

The studied sandstones have high porosity values of intergranular, vuggy and channel types. Porosity values decrease with increasing depth. These sandstones have good storage capacities with the exception of the uppermost part of the Middle Jurassic at the Betty-1 well and the Upper Jurassic rocks of Mamura-1 well which are of negligible values.

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