ASSESSMENT OF FORMATION DAMAGE OF SANDSTONE RESERVOIRS IMPACT OF FINES MIGRATION AND SOLIDS PLUGGING ON SANDSTONES' RESERVOIR QUALITY, SARIR

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Abstract: Fundamental controls on formation damage and reservoir quality of Sarir Formation Sirt Basin Libya are authigenic clay mineral types and their distributions. However, petrologies investigation obtained from the study area in five wells and concentrated on main rock components and the parameters that may have impacts on reservoirs. The petrographic observation shows the main authigenic clay minerals are kaolinite and dickite, these investigations have confirmed by X.R.D analysis. Clay fraction. mainly kaolinite and dickite were extensively presented in all wells as high amounts. As well as traces of detrital semictite and less amounts of illitized mud-matrix can be seen using SEM. Thin layers of clay is also present as clay-grain coatings in local depth interpreted as remains of dissolved clay matrix which is partly transformed into kaolinite adjacent and towards pore throat. This also may have impacts on most of the pore throats of this sandstone which are open and relatively clean with some of fine material have been formed within these pores. This material is identified by EDS analysis to be collections of not only kaolinite booklets but also small disaggregated kaolinite platelets derived from the disaggregation of larger kaolinite booklets. These patches of kaolinite not only fill these pores, but also coat some of the surrounding framework grains. Quartz grains often enlarged by authigenic quartz overgrowths partially occlude and reduce porosity. Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS) was conducted on the post-test samples to examine any mud filtrate particles that may be in the pore throats. Semi-qualitative elemental data on selected minerals observed during the SEM study were obtained through the use of an Energy Dispersive Spectroscopy (EDS) unit. The samples showed mostly clean open pore throats, with limited occlusion by kaolinite. The EDS analysis confirmed the identification of the fine grained disaggregated material as mainly kaolinite, though sample from well VV6-65 (8912.70 feet) did show some other very fine-grained elemental combinations (Si/Al/Na/Cl, Si/Al Ca/Cl/Ti, and Qtz/Ti).

Keywords: Pore throat, fines migration, formation damage, quartz overgrowths, porosity loss, Sarir Formation.

INTRODUCTION

This research has gathered three stages of study including sedimentology, petrology, and advanced core analysis and Mud Lake Off test to explicate the importance of studying the diagenetic clay menials alteration; and thus what is their impact reservoir quality. Sedimentology and petrology study both are always taking the first place in this study considering the variation in sediment's lithology reflects the different mineralogy. Sandstone reservoirs of five oil wells in Sarir Formation, Sirt Basin Libya have been strongly affected by fine kaolinite migration and less impact of solids plugging. The main diagenetic mineral of studied sandones is kaolinite which presented as kaolinite fines booklet like. Normally, transport of kaolinite fines in the silisclastic reservoirs at low temperatures is dependent on both hydrodynamic and colloidal forces. Colloidal forces dominate except near the wellbore where fluid velocities are the highest. Mobilization of kaolinite fines controlling by the water chemistry and is favored by high Ph and low salt concentration, whereas hydrodynamic kaolinite migration can be occur during oil production.

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METHODOLOGY

Sedimentology study: Five well cores representing the subjected reservoirs have been sedimentologically described and defined the fluvial sandstone sediments. 25 sandstone samples were collected based on variation porosity and permeability in studied wells for petrographical and geochemical analyses. Petrographic analyses were performed on thin-sectioned samples, which were prepared subsequent to impregnation with Blue Dyed Epoxy under a vacuum. The modal compositions of the sandstones were obtained by counting 300 points per thin section. The investigation of textural habits and diagenetic alterations was performed on ten sandstone samples using a Scanning Electron Microscope (SEM) equipped with a digital imaging system. The samples were coated with a thin layer of gold and examined under an acceleration voltage of 20kV. Chemical analysis of the clay diffraction using XRD was performed on 15 samples.

Advanced core analysis study: Sample was loaded into the CMS-300TM for determination of permeability and porosity. Net confining pressures were applied. The sample was placed into a rubber sleeve between stainless steel end pieces and confining pressure applied. Helium was injected into the sample from reference cells of known volume and pressure. A direct pore volume was determined using Boyle's Law of gas expansion, then pressure was vented at a known rate and unsteady-state Klinkenberg permeability was determined by pressure decay. Porosity was calculated for the sample as the pore volume fraction of the summation (grain volume + pore volume) bulk volume.

Mud Lake off test : Four (4) samples were submitted for regain permeability to oil after oil-based or water-based mud circulation and mud lake off. The core plugs were injected with kerosene (in the production direction) at the temperature of 230°F and permeability to oil was measured. Oil-based mud was circulated across the face of samples 3 (8869.60 feet) and 5 (8912.70 feet) for 4 hours at 300 psi overbalance and water-based mud was circulated across the face of samples 4 (8726.30 feet) and 8 (8806.30 feet) for 4 hours at 300 psi overbalance (Table 1). The samples were then locked in for 16 hours. Each sample showed an immediate drop in permeability after mud circulation and lock-in, with slight increases in the permeability observed in the test results as kerosene injection continued (increases did not reach initial permeability levels).

RESULTS OF PETROGRAPHIC STUDY

Rock Texture: From the petrographic observation the sandstone seems to be fine to medium grained with medium-grained dominance. Grains are characterised by sub-rounded to less common rounded and sub-angular; they are contacted as point contact to concave-convex mud supporting grains in local depths.

Framework Composition: Sarir Formation in studied area presented by sandstones which are very fine-to medium grained quartz arenite with an average modal composition of Q100,F00, L00 (Fig.1A) in VV4 and VV5 wells. Quartz grains (69-80 vol.%, av. 74.22%); (Table 2) are dominantly monocrystalline (av. 65%) and less commonly polycrystalline (av. 4%); however, sandstones in wells VV1and VV2 are argillaceous as mud rich and calcified as quartz wacky (Fig.1B) where mud to sand ratio is up to (20-vol. 50%.) (Table 2). Mica mainly muscovite (0-1 vol. %,

Table 1 Shows results of Mud Lake off test for one of samples and permeability change at mud or water injection.

Fluid Injected	Cumulative Fluid Injected, pore		Apparent Permeability to Liquid,	Permeability/ Permeability Initial
	Fluid	Total		
Treated Kerosene	1.68	1.68	293.	1.00
Permeability before mud	4.67	4.61	289.	0.988
injection	5.81	5.73	293.	1.00
4 hour mud injection at 300psi overbalanced. Then sample was locked in for 16 Hours				
	0.047	5.78	4.48	0.0153
	0.142	5.87	4.97	0.0170
Treated Kerosene	0.236	5	6.83	0.0233
	0.330	6	8.79	0.0300
Permeability after mud	0.425	6	17	0.0597
injection	0.519	6.25	18	0.0646
	0.614	6	22	0.0759
	0.708	6.44	27	0.0933
	1.27	7	39	0.136
	1.84	7	46	0.158
	2.41	8	56.4	0.192
	2.97	8	56	0.192
	3.54	9	57.2	0.195
	4.11	9	57	0.195
	4.6	10.4	57	0.195
	5.24	11.0	57	0.195
	5.81	11.5	57	0.195
	6.94	12.7	57	0.195
	8.07	13.8	57	0.197
	9.20	14.9	57	0.197
	9.77	15.5	58	0.200
	10.3	16.1	58	0.200
	11.5	17.2	58	0.199
	12.0	17.8	58	0.200
	13.2	18.9	58	0.200
	13.7	19.5	59	0.202
	14.3	20.0	59	0.204
	15.4	21.2	55	0.188
	16.0	21.7	57	0.198
	17.1	22.9	59	0.204
	18.3	24.0	59	0.204
	19.4	25.1	59	0.204
	20.5	26.3	59.6	0.204

Fig.(1A) Classification of quartz arenite of sandstone samples after Pettijohn. (1987)

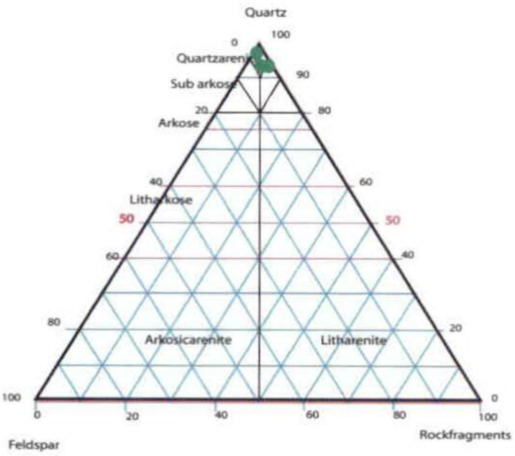


Fig.(1B) Classification of quartz wacky of sandstone samples after Pettijohn. (1987)

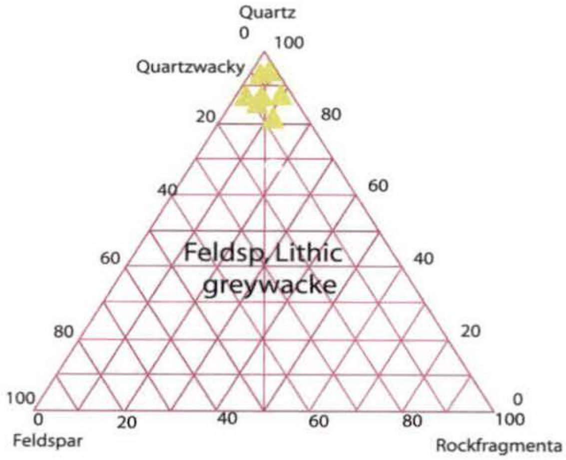


Fig.1(A and B) Detrital composition of selected sandstone samples from the Sarir Formation in VV-65 area, plotted on a Pettijohn. (1987) triangular classification diagram.

av. 0.11%) is more abundant within the matrix. Mud matrix is presented by different amounts that made up to (0-20% vol. av.7.22%), clay matrix where dominated in certain interval that shows very low to nil porosity. Clay matrix partly to completely altered into kaolinite and in rare cases replaced by dolomite (Fig. 5B). Remains of dissolved clay appears coating quartz grains which replaced by kaolinite. (Fig. 4B). Matrix not only muddy or silt, however, occasionally displays a few amounts of very fine martial appears plugging pore throats (Moraes and De Ros, 1990). EDS signature identifies not only kaolinite ($Al_2Si_2O_5(OH)_4$), but also very fine–grained zones. For example, various elemental combinations of silicon, aluminum, calcium, sodium, titanium, oxygen, and chlorine are detected by EDS. (Fig. 2A & B) as well as traces of anhydrite also present (Fig. 3B). The EDS tool has a spatial resolution of about 2μm and so can record X–ray photons from nearby material when focused on very fine–grained material (<2 μm) such as seen in one of the pores from the sample at depth 8912.70 feet (Plate 4).

DISCUSSION

Petrographical and geochemical analyses of the studied Sarir Formation samples show that the sandstones have various maturity classification as facies controlled and classified to quartz arenite and quartz wacky (Pettijohn *et al*, 1981); and have undergone various stages of diagenetic alterations (Morad *et al*, 1994).

Authogenic Components

Kaolinite

Kaolinite and less common dickite are very common in this area that made up (vol. 0-20%; av.6% with SD. 5.1). Kaolinite formation is the most common diagenetic mineral that mainly replacing mud matrix, feldspars, and less common mud clasts (Fig. 4C). Kaolinite is engulfed by; and thus predated quartz cementation (Fig 2A). Vermicular kaolinite-like is filled number of pore throats (Fig.4B) and also smaller particles whose morphologies appear to be individual platelets of kaolinite derived from the disaggregation of larger kaolinite booklets (Fig. 2A). This visual is confirmed by Energy Dispersive Spectroscopy analysis. EDS analysis identifies the fine–grained disaggregated material as kaolinite.

Dolomite

Dolomite in studied sandstone with variation in habits and types (trace–2 vol.%, av.0.1%; Table 3). It is occurred as cement with microcrystalline quartz habit (5-50μm across); and occurs as scattered patches that have replaced, pervasively to nearly completely, mud matrix, and in less common micas and feldspars (Fig. 3A). Dolomite in certain depth occurred as saddle dolomite in late digenetic stage that extensively replacing mud matrix (Radke and Mathis, 1980). Dolomite engulfs; and thus post-dating, quartz over growth; and completely replaced mud matrix and partly quartz grains (Fig 5B) and kaolinite (Fig. 3A). Dolomite is closely

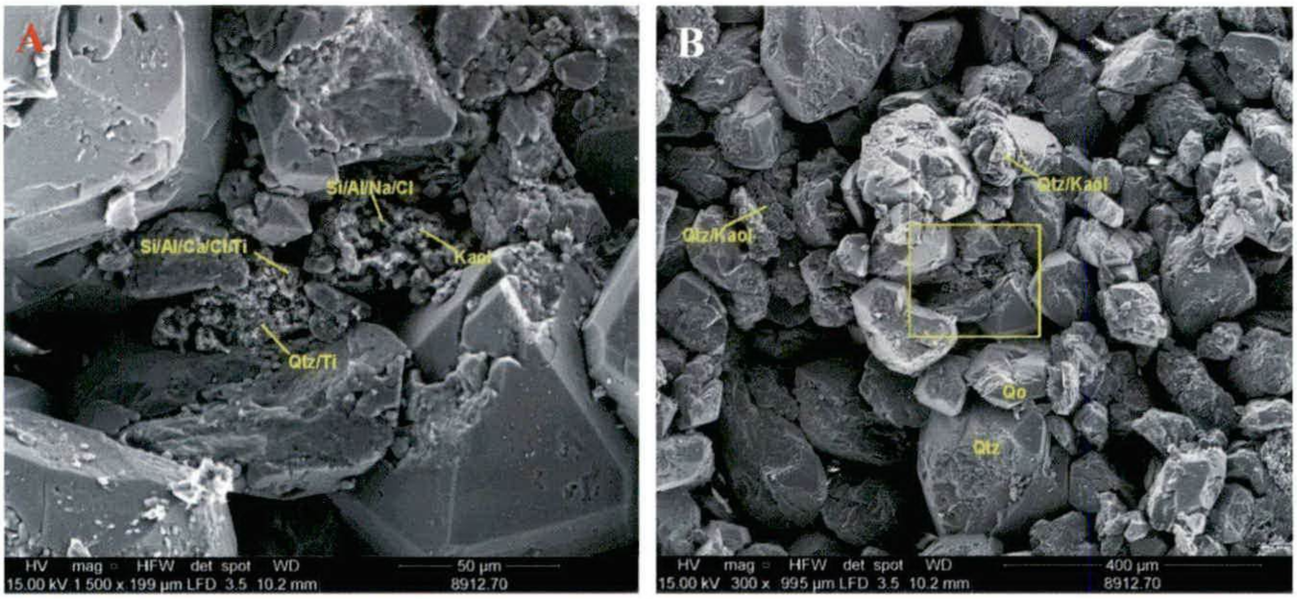


Fig. 2 SEM: photo (A) depicts a sample that contains mostly clean, unconcluded pores. Quartz grains (Qtz) and quartz overgrowths (Qo) are visible. few grains appear coated with small platelets of kaolinite, although EDS analyses of these areas produce a mixed signature of quartz and kaolinite (Qtz/Kaol) because of the intimate association of the two materials. In the higher magnification of Photo B, the material in the pore is featured. Using the EDS tool, not only is kaolinite (Kaol) identified, but also very fine-grained material that produces variously elemental signatures of Si/Al/Na/Cl, Si/Al Ca/Cl/Ti, and a combination of quartz and titanium (Qtz/Ti) less than 2µm in size.

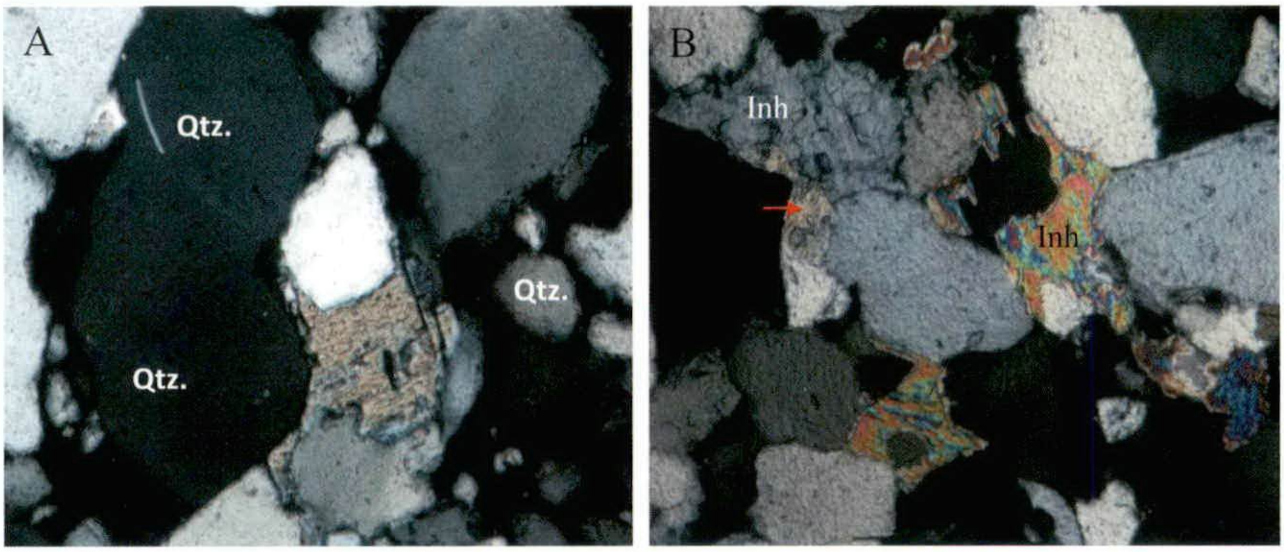


Fig.3. Both are polarized microscopic image (A) poorly sorted sandstone note that quartz grains has wide size range (Qtz); the brownish grains in center is originally feldspar mostly replaced by dolomite, partly grain dissolution porosity (the blue). (B) in this sample trace amount of anhydrite (Inh.) is taken place that formed as cement; its engulfed by and thus predate dolomite (red arrow).

associated with kaolinite; thin kaolinite crystals have been displaced by dolomite which has formed in intercrystalline spaces. Optical micrographs (x-nicols) imaging may suggest that kaolinite is replaced by dolomite (Fig. 4D). In some cases dolomite crystals are arranged perpendicular to framework grains; this siderite may partly fill mouldic porosity formed by dissolution and/or kaolinitization of framework grains (Fig. 4E).

Quartz Cement

Quartz cement (0-9.7vol. %, av. 4.8%; Table 3) occurs mainly as euhedral syntaxial overgrowths (30µm thick) around detrital quartz grains. Overgrowths are highly discontinuous or absent when the quartz grains are coated by thick layers of clay minerals (Fig. 4D); whereas, quartz overgrowths are extensive to complete when quartz grain surfaces are clean (Worden and Morad,

Table 2 Data summary of petrography study shows average, maximum, and minimum of studied sandstone composition

Distributions of the main detrital and authigenic components of five studded wells															
VV65 AREA	VV1-65 Well			VV2-65 Well			VV3-65 Well			VV4-65 Well			**VV5-65 Well**		
	AV.	MAX	MIN.	AV.	MAX	MIN.	AV	MIN	MAX	AV	MAX	MIN.	AV	MAX	MIN.
Main detrital components															
Quartz	74	80	69	71.5	85	50	74	78	72	76	78	73	82	80	**79**
Feldspar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Mica	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Rock frag.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**0**
Clay mat.	7	20	0	7.7	50	0	0	1	0	1	3	0	3	3	**2**
Mud clas.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Heavy. M.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Authigenic components															
Kaolinite	6	20	1	4.5	9	0	2	5	0	1	3	0	3	3	**2**
Semictite	2	8	0	0	1	0	3	1	0	1	4	0	4	3	**3**
Q.OV	2	6	0	3	5	0	5	6	2	6	7	4	10	9	**8**
Dolomite	0	0	0	0.4	2	0	0	0	0	0	0	0	0	0	**0**
Calcite	0	0	0	0.5	3	0	0	0	0	0	0	0	0	0	**0**
Anhydrite	0	0	0	0.7	7	0	3	11	0	0	0	0	0	0	**0**
Types of porosity															
Integrin.	3	7	0	5	7	0	6	7	5	6	7	5	8	8	**7**
Grain dis.	5	10	0	6.1	9	0	8	9	7	9	11	7	13	12	**11**
Micro frac.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**0**

2000). Quartz overgrowths may fill intergranular pores (Fig. 5A) which have resulted from partial to extensive dissolution of feldspars. In a few cases, quartz can occur as outgrowths which fill partly to extensively adjacent pores. In addition to syntaxial quartz overgrowths quartz cement occurs as small (< 15μm) discrete crystals that are randomly-orientated or aligned parallel to each other, and which cover quartz grain surfaces. These crystals developed on quartz grains coated by micro-quartz, which are in turn frequently coated by clay. Quartz overgrowths are typically engulfs; and thus postdating kainite, and engulfed by and thus predating dolomite (Fig 5C).

RESERVOIR QUALITY AND ZONATION

Porosity in thin-section of the studied Sarir Formation sandstones varies from (zero to 22%; av. 15,3%; Table 3). It is more abundant in wells VV4 and VV5 (18-20% vol.%, av. 18%) respectively than in VV1 and VV2 wells (0-17 vol.%, av. 8%, Table 2). Thin section porosity types are intergranular, grain dissolution and micro fracture pores and includes both micro-(< 10μm) and macro-sized pore spaces. Intergranular porosity (trace -8%vol; av. 7% with SD.2.4) is more common than molodic dissolution porosity (trace – 13 vol. %, av. 8.2% with SD. 3.8). However, micro fracture porosity is less abundant (trace – 1 vol.%, av. 0.1% with SD.0.2). (Table 3). Grain dissolution porosity is the most common abundant in well VV5 (11-13%, av. 12%) (Table 2). This is due to partially dissolution of mud matrix; and partially or completely dissolution of feldspars and less common mud interclasts. Lack correlation between porosity and permeability in some reservoirs intervals (Fig. 6) is attributed to abundance of grain dissolution porosity as well as micro porosity distribution due to formation of kaolinite and dissolution; whereas, nil or lack of intergranular porosity is due to abundance of mud matrix particularly in well VV2 which is depositional controlling (El-Ghali, *et al*; 2006). The extent of framework grain dissolution was greater in the coarser-grained of studied samples than in finer-grained.

FORMATION DAMAGE CONTROLLING

In the majority of these oil sands reservoirs, the most abundant clay mineral present is kaolinite. Kaolinite has two different types of formation damage, both leading to permeability change, at low temperatures, kaolinite contributes to fines migration or transport; at the high temperatures accompanying steam

Table 3 Shows average, maximum, minimum, and SD. of framework grains, diagenetic grains and pore types distributed of all studied area

VV65 AREA	AV.	MAX	MINA	SD
		Framework components		
Quartz	70.0	85.0	0.0	**8.0**
Feldspar				
Mica	0.1	1.0	0.0	**0.2**
Rock fragments				
Clay matrix	6.1	50.0	0.0	**13.1**
Mud clasts				
Heavy minerals	0.0	0.0	0.0	**0.0**
		Diagenetic components		
Kaolinite	3.7	20.0	0.0	**5.1**
Semictite				
Q.OV	4.8	9.7	0.0	**2.8**
Dolomite				
Calcite	0.2	3.0	0.0	**0.8**
Anhydrite				
intergranular	5.3	8.0	0.0	**2.4**
Grain dissolution				
micro - fracture	0.1	1.0	0.0	**0.2**

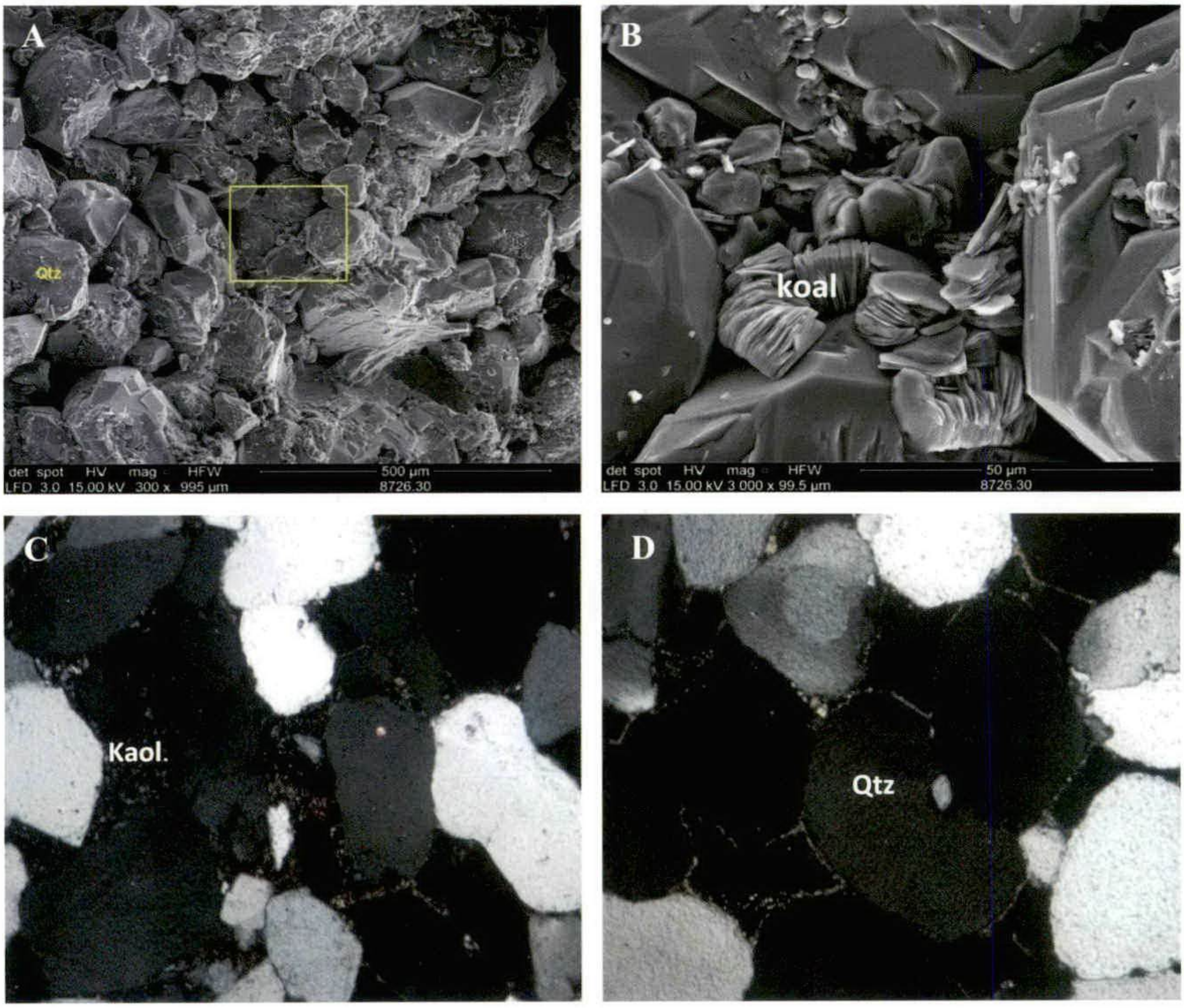
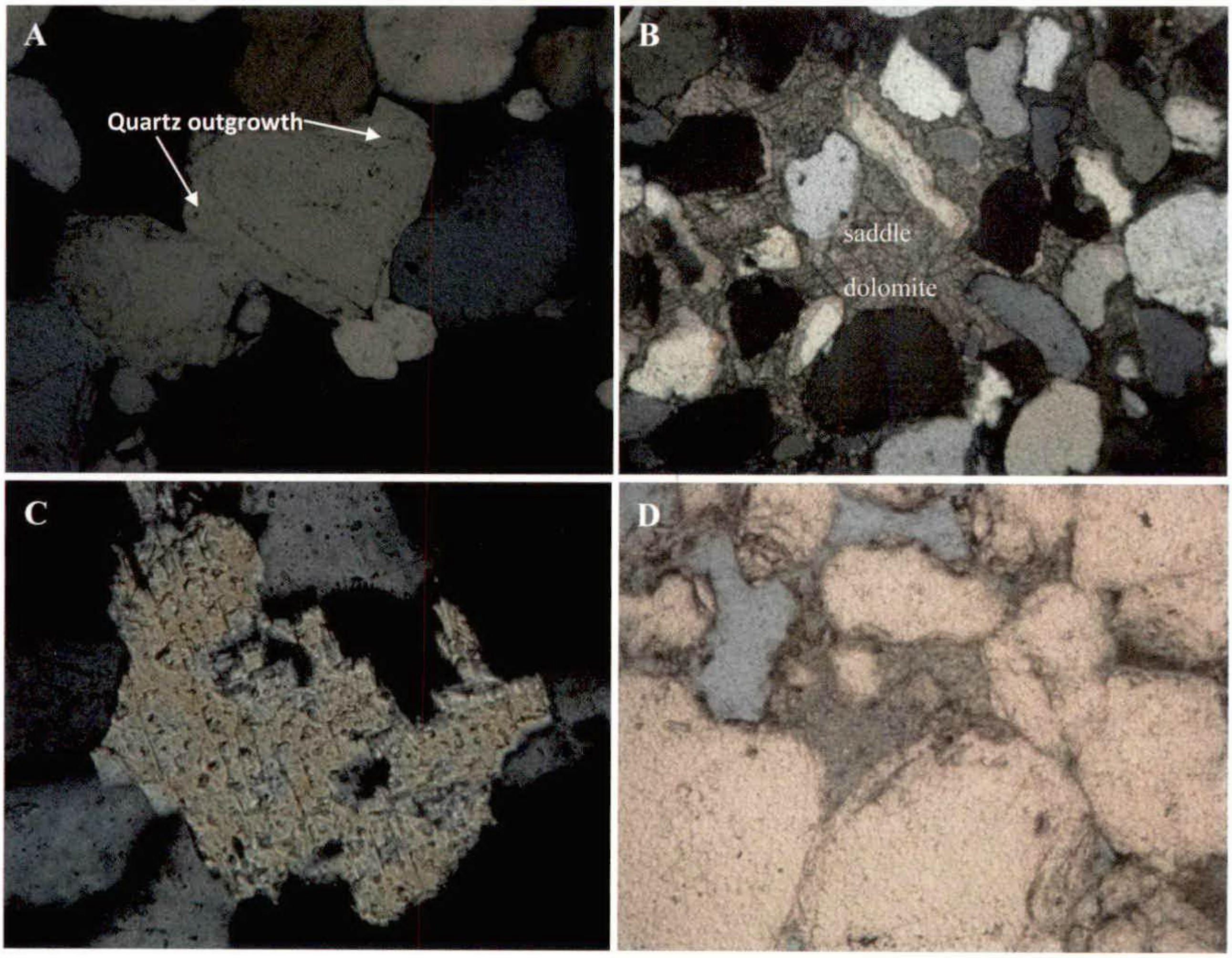


Fig.4 A and B are represent low and high magnification SEM images. In photo (A), the image is centered in the (yellow outline) which is Kaolinite very fine within the pore throat; quartz grains is the main component. (Qtz) identified by EDS (Energy Dispersive Spectroscopy). Photo B is higher-magnification and focuses on an occluded pore at the center Photo A. This pore is filled with kaolinite (Kaol).Kaolinite is vermicular like. (C and D) are polarized microscopic image (C)formation of Kaolinite that replacing mud matrix (kaol);and sandstone is poorly sorting. (D) Photo B depicts a sample that contains mostly quartz dominated and pores are mostly clean (unconcluded pores). Quartz grains (Qtz) and quartz overgrowths are visible and grains appear coated with thin layers of semictite and small platelets of kaolinite.

recovery. Kaolinite reacts with other minerals and condensed steam to form smectite (Hayatdavoudi and Ghalambor, 1998). Transport of kaolinite fines in the reservoir at low temperatures is dependent on both hydrodynamic and colloidal forces. Colloidal forces dominate except near the wellbore where fluid velocities are the highest.

BASIC PROPERTIES AND PERMEABILITY TO OIL AT SWI

Basic rock properties measurements (permeability, porosity, and grain density) were performed on the seven (7) suitable samples at 800 and 3300 psi net confining stress. The Klinkenberg permeabilities ranged from 1.65 to 501 millidarcies (md) at 3300 psi and the porosities ranged from 10.6 to 18.4 percent. Grain densities for these samples ranged from 2.64 to 2.67 g/cm^3. After basic properties measurements, the seven (7) samples were vacuum saturated with 190,000 ppm sodium chloride brine and then spun in a high speed centrifuge to establish initial water saturation (Swi). Permeability to oil at Swi was measured at two flow rates. This permeability is at ambient temperature and pressure and is not representative of the reservoir conditions. The permeabilities to oil (kerosene) ranged from 1.13 to 416 md.



(Fig.5). Photomicrographs in X-polarized light (A) quartz outgrowths, which partly fill intergranular pore; and later-formed discrete quartz crystals completely fill intergranular pore. (B) Grain-replacive saddle dolomite engulfs, and thus post-dating, quartz over growth saddle dolomite is completely replaced mud matrix and partly quartz grains. (C) Example of dolomite completely replace large feldspar grains, dolomite engulfs; and thus postdate quartz overgrowth. (D) Completely grain dissolution (presumably mud-clasts) which has abundant grain dissolution-porosity.

CONCLUSION

Authigenic kaolin which is the main diagenetic mineral developed within the sandstone will depend upon the breakdown of the unstable grains; that mainly replaced mud matrix, and less common feldspars. Permeability changes are mainly attributed to fines kaolinite migration and less impact soiled plugging. Kaolinite is pore-filling and grain-coatings adjacent to the pore throat; kaolinite pore-filling have strong impact on formation damage by pulging pore space. Smaller particles of kaolinite whose morphologies appear to be individual platelets of kaolinite derived from the disaggregation of larger kaolinite booklets is the most impact and casing formation damage when its movement and migrated toword the pore throat. Lack of porosity and permeability (in local depth) of sandstone is attributed to high amounts of mud matrix and/or to poorly sorting grains these are controlled by depositional facies. As facies controlling solids plugging is another factor of formation damage in poorly argillaceous sandstone; but it is less impact than fines migration kaolinite

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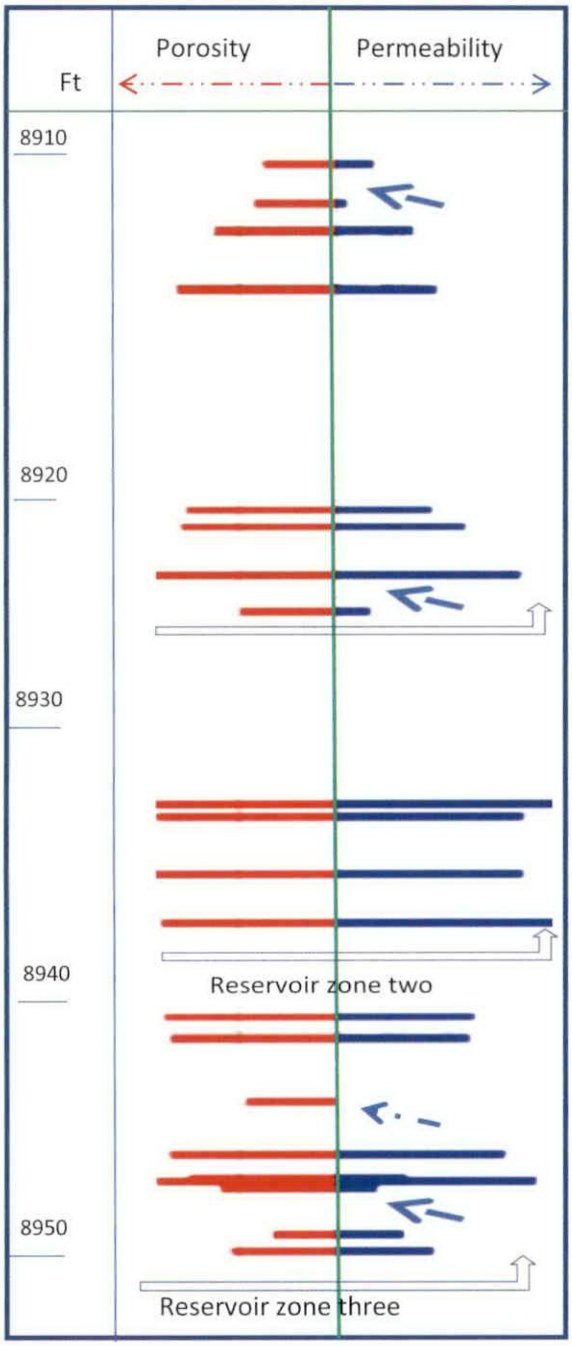

Fig. (6) reservoir quality is strongly controlled by fines migration and les common solids plugging.(zone one) shows porosity values is more higher than permeability values, there is low of permeability values for each porosity (arrows); these are attributed to formation of micro crystals of kaolinite. (Zone three) permeability in certain depth has destroyed note that nil to zero permeability for each porosity value (arrows); both of Solids plugging and fines migration are main controlling.

REFERENCES

El-Ghali, M. A. K., Mansurbeg, H., Morad, S., Al-Aasm, H., and Ramseyer, K. (2006). Distribution of Diagenetic Alterations in Glaciogenic Sandstones within a Depositional Facies and Sequence Stratigraphic Framework: Evidence From The Upper Ordovician of The Murzuq Basin, SW Libya. *Sedimentary Geology*, ***V. 190 (1)***: 323–351.

Hayatdavoudi, A. and Ghalambor, A. (1998). A Description of Chemical Precipitation Mechanisms and their Role in Formation Damage During Stimulation by Hydrofluoric Acid. *Journal Of Petroleum Technology*, ***V. 34***: 2097-2112.

Morad, S. Mcaulay, G. E, Burley, S. D., Fallick, A. E. and Kusznir, N. J. (1994). Palaeohydrodynamic Fluid Flow Regimes During Diagenesis of the Brent Group in the Hutton-NW Hutton Reservoir, Constraints from Oxygen Isotope Studies of Authigenic Kaolin and Reserves Flexural Modeling. *Clay Minerals*, ***V. 29***: 609-629.

Moraes, M. A. S. and De Ros, L. F. (1990). Infiltrated Clays in Fluvial Jurassic Sandstones of Recôncavo Basin, Northeastern Brazil. *Journ. Sedim. Petrol.*, ***V. 60***: 809-819.

Pettjohn, F. J. Potter, P. E. and Siever, R. (1981). Sands and Sandstone. Springer, Verlag, New York, 262p.

Radke, B. M. and Mathis, R. L. (1980). On the Formation and Occurrence of Saddle Dolomite. *Journ. Sedim. Petrol.*, ***V. 50, 238***, In: Lower Cretaceous Nubian Sandstone Formation, Sirt Basin, Libya: 1149-1168.

Worden, R. H. and Morad, S. (2000). Quartz Cement in Oil Field Sandstones: a Review of the Critical Problems. In: R. H. Worden and S. Morad (Eds), Quartz Cementation in Oil Field Sandstones. *Spec. Publ. Int. Assoc. Sedimentol.*, ***V. 29***: 1–20.