Petrographic Studies of the Alamein Dolomite (Lower Cretaceous) in El-Razzak Oil Field, Western Desert, Egypt.

by

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ABSTRACT

The origin and environment of deposition of the Alamein Dolomite in the El-Razzak Oil Field have been investigated by means of petrographic, chemical and X-ray analysis.

The studied rocks are composed of dolomite with variable amounts of calcite, with anhydrite and iron oxide as minor minerals.

Alamein Dolomite has been formed by replacement of limestones under a variety of conditions either penecontemporaneously or soon after deposition, or later through the action of ascending solution of either meteoric water or by hydrothermal solutions. Dolomitization took place in shallow, warm, Mg-rich environment under favourable pH, Eh, salinity, and temperature conditions. The low SiO_2 content, absence of fossils, and the association of anhydrites with dolomites reflect a restricted, shallow-marine, low energy environment, interrupted in parts, by high-energy level environment in which microsparites and sparites were formed.

Qatar Univ., Sci. Bull. Vol. 2, No. 1, 1982

Introduction

El-Razzak Oil Field is located in the north central part of the Western Desert of Egypt. It lies about 270 km west-north-west of Cairo and about 60 km south of the Mediterranean sea coast, and is delineated by latitudes 30° 30′ 10″ and 30° 34′ 16″ North and longitudes 28° 24′ 49″ and 28° 34′ 17″ East (Fig. 1). The studied field covers an area of about 105 km^2 being 15 km long and 7 km wide.

El-Razzak Oil Field lies on a northeast plunging anticline in a large faulted structural nose of one of a series of structural highs forming the Alamein-Qattara Ridge, which forms a part of the unstable (mobile) shelf of Egypt (Said, 1962). In general, regarding their oil potential, the most extensive deposits of the unstable shelf area are those of the Cretaceous System, of which the lower Cretaceous Aptian rocks are considered of prime interest and importance. The Aptian Alamein Dolomite is considered the most important and interesting within the lower Cretaceous sediments due to two facts, firstly it is oil bearing in Alamein, Yidma, and El-Razzak Oil Fields and secondly, it has a widespread lateral extent over most of the northern part of the Western Desert.

Since the discovery of the Alamein Oil Field in 1966 many geological and geophysical works have been devoted to the lower Cretaceous in general, and to the Alamein Dolomite in particular, of which the following can be mentioned: Abdallah (1966), Babaev (1966), Brooks (1966), Beckmann (1967), Norton (1967), Vollenweider (1967.b), El-Banbi (1970), Abdine and Deibis (1972), Hamed (1972), Mohsen et al (1973), Abdine (1974), Ezzat and Dia El-Din (1974), Abd El-Azim (1974 and 1975), Girgis (1975), Metwalli and Abd El-Hady (1973 and 1975), Nour et al (1977), etc.

In the present study most of the drilled wells in El-Razzak Oil Field penetrating the Aptian Alamein Dolomite were examined. Coincidentally, the distribution of the wells was sampled in such a manner to provide good coverage of almost all characteristics of the studied rocks. The sedimentologic and petrophysical characteristics of the Alamein Dolomite are based on careful megascopic and microscopic investigation of the core samples. A portion of the original core test plugs was used for thin section studies, chemical analysis and X-ray diffraction analysis.

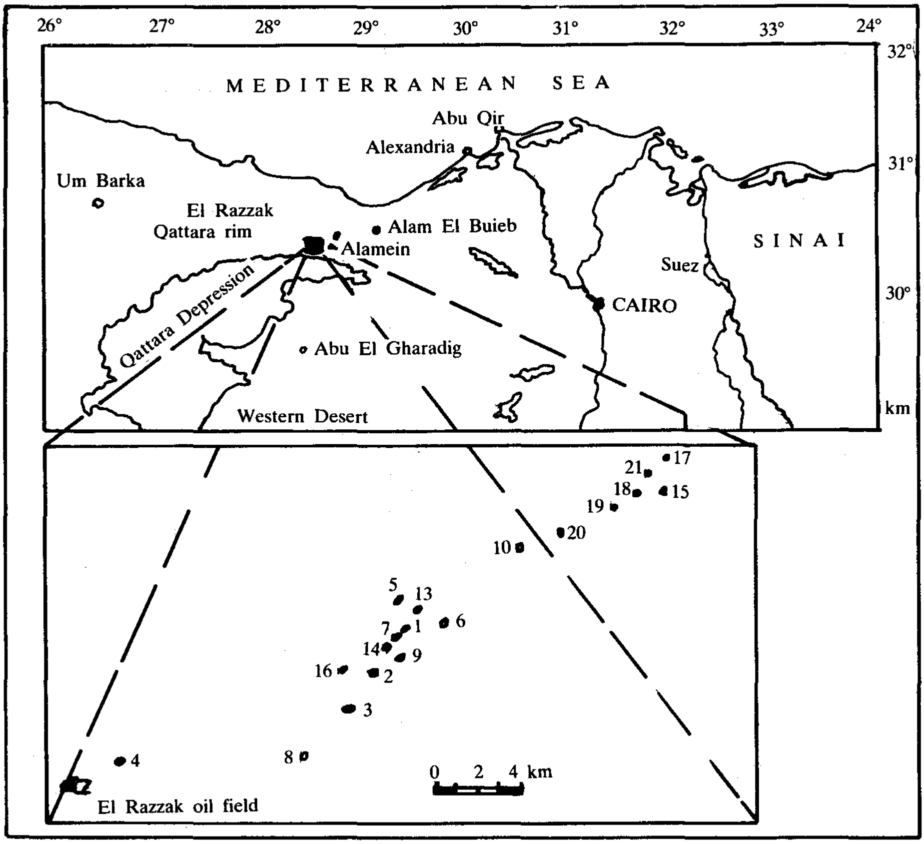

Fig. 1: Location map of the El-Razzak Oil Field.

Microfacies Studies

Microfacies study is the most important of the various levels of observation in the broad field of carbonate petrography. Despite the advantages offered by the identifiable carbonate particles towards environmental interpretation, detailed petrographic study of limestones and dolomites may be difficult because of their susceptibility to diagenetic alteration.

However, carbonate rocks have been extensively studied in recent years, especially because of their economic importance as oil reservoirs. Many authors, e.g. Pettijohn (1957), Folk (1959, 1962), Frolova (1959), Dunham (1962), Plumley et al (1962), Powers (1962), Friedman (1965), Chilingar et al (1967) and others proposed different carbonate classifications and stressed the importance of the textural parameters as indicators of the depositional conditions, although dolomitization in places has obliterated the original textures and fabrics. In the present study thin sections representing core samples of the Alamein Dolomite in El-Razzak Oil Field were prepared for the microscopic examination to determine the different characteristics of the studied rocks vertically and horizontally. This greatly helped in deciphering the petrographic characteristics, the paleoecologic conditions, the environment of deposition, the origin of rock constituents, and the relationship between the petrographic characteristics and the petrophysical properties (porosity and permeability) of the Alamein Dolomite.

The nomenclature of the dolomite rock is given according to Pettijohn's classification (1957), while the terminology of crystallization texture and fabric is according to Friedman (1965), whereas the size of the crystals is given according to Folk's classification (1962).

Petrographically, the Alamein Dolomite shows no great variation in the examined thin sections. The main rocks are highly dolomitic and are speckled with calcite. The dolomite crystals are most subhedral to euhedral, ranging in size from medium to coarse (Fig. 2), with cloudy (Fig. 3) to dark inner cores (Fig. 4) of variable widths and may attain gradually a subrhombic or rhombic outline towards the exterior. The inner cores (iron oxide) are parallel to the external rhombic outlines, and are light to dark brown. In places, the cores of the dolomite crystals are of clear pattern (Fig. 4) and the different patterns may be related to slight variation in the chemical composition of the original sea-water, particularly the iron concentration, which changes the colour pattern (Borahey, 1976). The zonation in the core of the dolomite crystals increases vertically with increasing depth, and decreases laterally to the south in El-Razzak Field. The inner core is formed early in diagenetic processes when water percolates through the porous carbonate sediments (Murray, 1964) where it is concentrated in the central part of the crystals, and is related to the iron variation between the core and the periphery of the dolomite crystals. Euhedral and large dolomite crystals show clear zones whereas anhedral and small dolomite crystals do not. Iron oxides occur at crystal boundaries and locally occupy the micropore spaces between the dolomite crystals (Fig. 3) and may spread as tree-shaped veinlets (Fig. 5). In many thin sections, where the dolomite crystals are rhombic to subrhombic and scattered throughout a microsparry calcite matrix, zoning is not displayed (Fig. 6).

The microsparry calcitic matrix suffered extensive dolomitization and is in places fractured. Recrystallization of the original micritic matrix obliterated its primary textures. This is exemplified by the presence of patches of microsparry and sparry calcite filling irregular cavities and fissure-like structures in hypidiotopic dolomite (Figs. 2 and 7). It is very remarkable that the Alamein Dolomite is generally devoid of any kind of fossils. A very low content of terrigenous material is also reported. This terrigenous material was determined by acid-insoluble residue analysis and consists essentially of grayish green, light brown clay, blocky, locally fissile, papery with rare pyrite fragments and minor amounts of yellow to light brown sand-size particles, slightly ferruginous, fine to medium-grained, subrounded to subangular.

Microsequence

The recognized microfacies were carefully examined for their crystal sizes and crystal shapes by modal analysis (point counting study). The important terminology, introduced by Friedman (1965) based on the distribution of various crystal sizes and shapes has been used. For each slide, an average of 500 counts has been made for its crystal constituents including shapes and sizes. The results are given in percentages, and the data are represented in Tables 1 to 4, and are plotted on Figures 8 and 9.

The study of the dolomite crystals revealed the predominance of subhedral crystals indicating a hypidiotopic inequigranular type of fabric partly porphyrotopic in a finer dolomite matrix (Fig. 10). Locally idiotopic dolomite crystals are enclosed in poikilotopic microsparry (Fig. 11) to sparry calcite crystals filling vugs and are partly replaced by dolomite in early stages of dolomitization. Some relicts of anhedral (xenotopic) dolomite crystals occur in low concentrations. Generally, the shape of the dolomite crystals is a very important factor in finding the relation between fabric and porosity (Murray, 1964). The predominance of hypidiotopic fabric (Fig. 12) may indicate the conversion of idiotopic crystals (Fig. 13) by

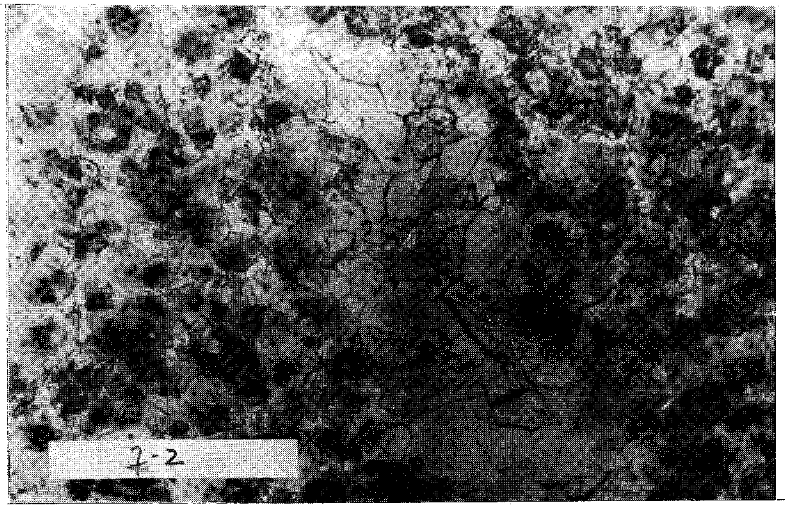

Fig. 2: Photomicrograph showing a veinlet relict of sparry calcite imbedded within a finer matrix of rhombic dolomite crystals. Aptian Alamein Dolomite, El-Razzak well No. 3, Core #2, 7899-7902 feet, P.P.L.; bar scale 1 mm.

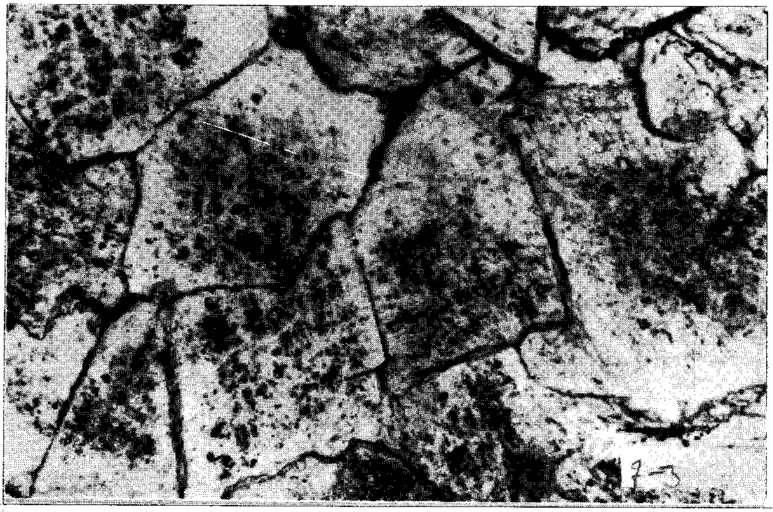

Fig 3: Photomicrograph showing the cloudy type of zonation. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7708-7711 feet, P.P.L.; bar scale 0.1 mm.

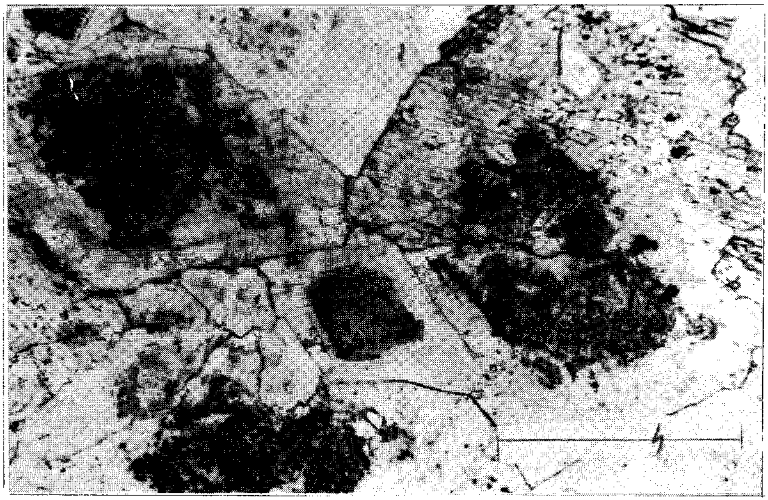

Fig. 4: Photomicrograph showing the recrystallized dolomite with clear dark cores of iron oxides. Aptian Alamein Dolomite, El-Razzak Well No. 3, Core #2, 7890-7893 feet, P.P.L.; bar scale 0.1 mm.

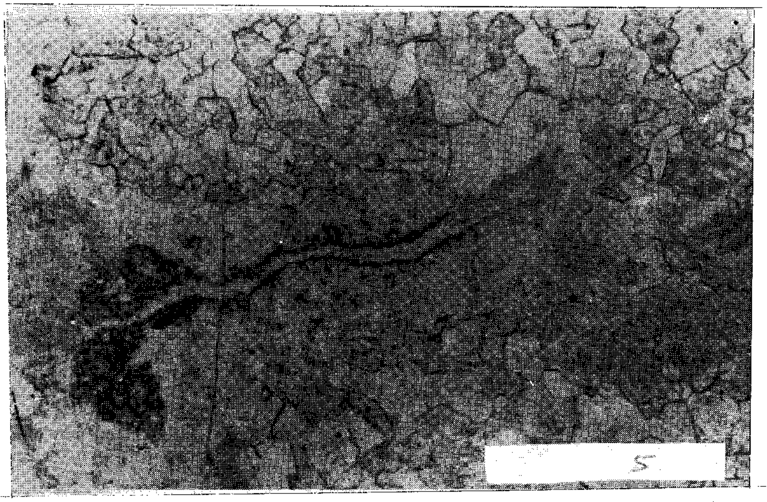

Fig. 5: Photomicrograph showing a tree-shape veinlet of iron oxides produced in late diagenetic stages. Aptian Alamein Dolomite, El-Razzak Well No. 3, Core #1, 7840-7845 feet, P.P.L.: bar scale 1 mm.

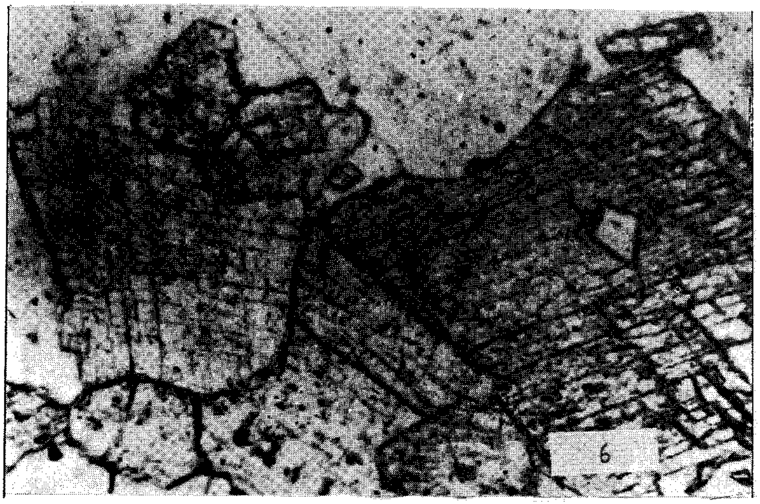

Fig. 6: Photomicrograph showing sparry calcite in the upper part of the Alamein Dolomite, El-Razzak Well No. 3, Core #2, 7893-7896 feet, P.P.L.; bar scale 0.1 mm.

Fig. 7: Photomicrograph showing relict veinlet of calcite in a macrocrystalline dolomite matrix. Aptian Alamein Dolomite, El-Razzak Well No. 3, Core #2, 7893-7896 feet, P.P.L; bar scale 0.1 mm.

Table 1
Shape Analysis of Aptian Alamein Dolomite in El Razzak Well No. 1

Core No.	*Depth in feet*	*Direction*	*Distribution of Dolomite Crystals of Various Shapes (Per Cent)*		
			Euhedral	*Subhedral*	*Anhedral*
1	7687-7690	V	31.9	54.0	14.1
		H	21.1	67.8	11.1
	7690-7623	V	36.5	58.8	4.7
		H	30.1	62.2	7.7
	7693-7696	V	34.6	59.3	6.1
		H	38.2	56.4	5.5
	7696-7699	V	28.2	59.8	12.0
		H	33.5	55.3	11.2
	7699-7702	V	35.5	55.5	9.0
		H	31.8	60.5	7.7.
	7702-7705	V	32.6	54.2	13.2
		H	34.9	53.6	11.5
	7705-7708	V	23.3	60.7	16.0
		H	24.1	70.2	5.7
	7708-7711	V	24.0	66.2	10.8
		H	27.0	68.1	4.9
	7714-7714	V	21.7	72.2	6.1
		H	11.0	78.8	10.2
	7714-7717	V	35.5	56.5	8.0
		H	33.3	61.0	5.7
	7717-7720	V	51.9	40.7	7.4
		H	56.4	35.9	7.7
	7720-7723	V	42.2	49.3	8.5
		H	48.6	45.3	6.1
	7723-7726	V	58.0	34.3	7.3
		H	50.3	6.7	3.0
	7726-7729	V	57.0	41.0	2.0
		H	46.8	48.1	5.1
	Average	V	36.6	54.5	8.9
		H	34.8	57.9	7.4

* V. (Vertically) * H. (Horizontally)

Table 2
Shape Analysis of Aptian Alamein Dolomite in El Razzak Well No. 3

Core No.	*Depth in feet*	*Direction*	*Distribution of Dolomite Crystals of Various Shapes (Per Cent)*		
			Euhedral	*Subhedral*	*Anhedral*
1	7840-7843	V	33.1	54.2	12.7
		H	35.6	53.6	10.8
2	7890-7893	V	21.2	64.6	14.2
		H	23.3	60.0	10.7
	7893-7896	V	24.0	68.3	7.7
		H	30.0	63.2	6.8
	7896-7899	V	21.1	67.0	11.9
		H	22.0	63.8	14.2
	7899-7902	V	24.8	65.6	9.6
		H	29.3	62.4	8.3
	Average	V	24.8	63.9	11.2
		H	28.0	61.8	10.2

* V. (Vertically)
* H. (Horizontally)

Table 3
Size Analysis of Aptian Alamein Dolomite in El Razzak Well No. 1

Core No.	Depth in feet	Direction	Distribution of Dolomite Crystals of Various Sizes (Per Cent)		
			Macrocrystalline	Mesocrystalline	Microcrystalline
			> 0.50 mm	0.25-0.50 mm	0.15-0.05 mm
1	7687-7690	V	31.5	61.9	6.6
		H	26.0	68.4	5.6
	7690-7693	V	30.2	64.4	4.7
		H	26.6	64.7	8.7
	7693-7696	V	28.1	67.2	4.7
		H	31.0	63.9	5.1
	7696-7699	V	33.9	64.5	1.6
		H	29.9	66.7	3.4
	7699-7702	V	32.1	66.3	1.6
		H	37.2	60.4	2.4
	7702-7705	V	36.8	54.6	8.6
		H	34.6	55.9	9.5
	7705-7708	V	29.6	63.1	7.3
		H	25.8	64.7	9.5
	7708-7711	V	25.5	69.3	5.2
		H	32.9	60.8	6.3
	7711-7714	V	33.1	64.3	2.6
		H	29.9	62.3	7.8
	7714-7717	V	34.0	64.8	1.2
		H	28.6	66.4	5.0
	7717-7720	V	35.0	62.7	2.3
		H	27.4	64.9	7.7
	7720-7723	V	26.8	68.4	4.8
		H	26.1	67.2	6.7
	7723-7726	V	33.4	63.2	3.4
		H	31.7	66.2	2.1
	7726-7729	V	27.3	68.1	4.6
		H	27.0	69.9	3.1
	Average	V	31.3	66.9	4.7
		H	29.6	64.4	6.0

* V. (Vertically) * H. (horizontally)

Table 4
Size Analysis of Aptian Alamein Dolomite in El Razzak Well No. 3

Core No.	*Depth in feet*	*Direction*	*Distribution of Dolomite Crystals of Various Sizes (Per Cent)*		
			Macrocrystalline	*Mesocrystalline*	*Microcrystalline*
			> 0.50 mm	*0.25-0.50 mm*	*0.15-0.05 mm*
1	7840-7843	V	47.1	50.8	2.1
		H	41.7	54.2	4.1
2	7890-7893	V	56.3	42.2	1.5
		H	61.9	36.2	1.9
	7893-7896	V	57.8	40.7	1.5
		H	52.1	45.3	2.6
	7896-7899	V	53.7	44.1	2.2
		H	56.2	41.3	2.5
	7899-7902	V	52.4	46.3	1.3
		H	51.6	46.0	2.4
	Average	V	53.5	44.8	1.7
		H	52.7	44.6	2.7

* V. (Vertically)

* H. (Horizontally)

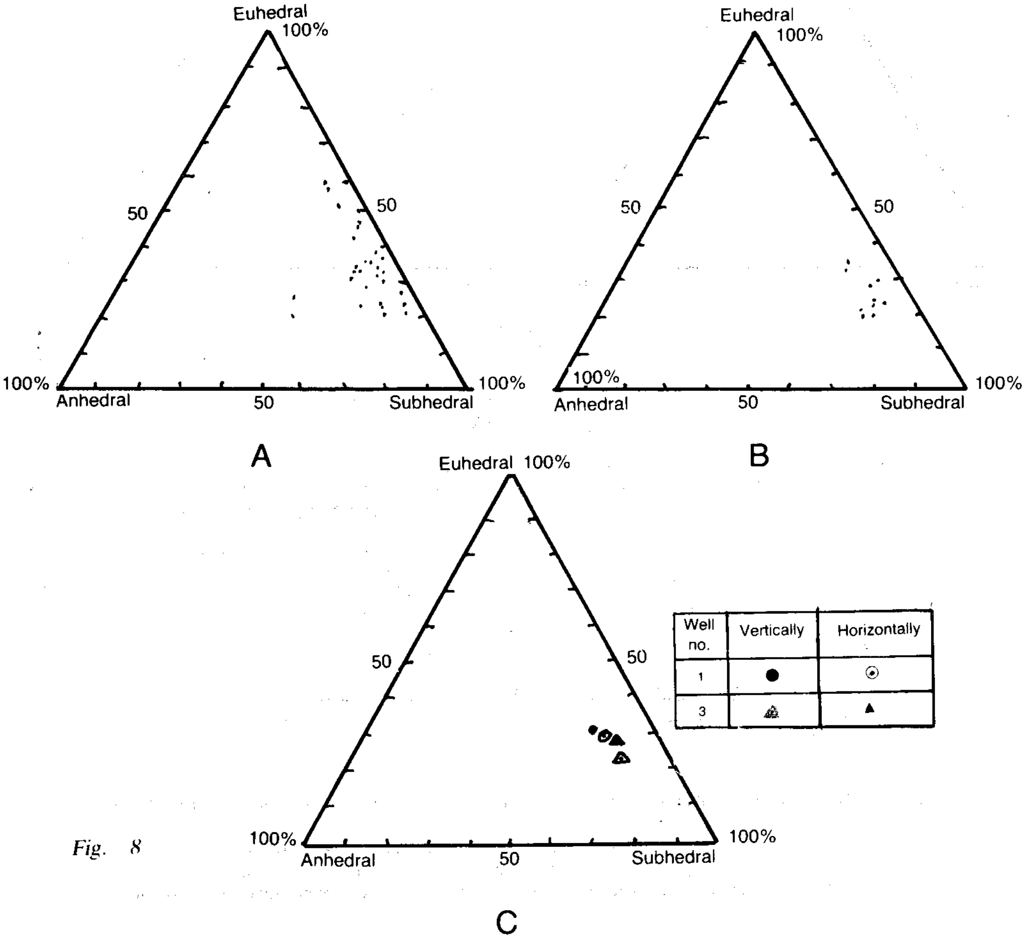

Fig. 8

Fig. 8: Distribution of Dolomite Crystals of Various Shapes and Sizes in Alamein Dolomite of El-Razzak Oil Field.

A. Distribution of shapes of crystals in Well No. 1.

B. Distribution of shapes of crystals in Well No. 3.

C. Distribution of sizes of crystals in Well No. 1 and Well No. 3.

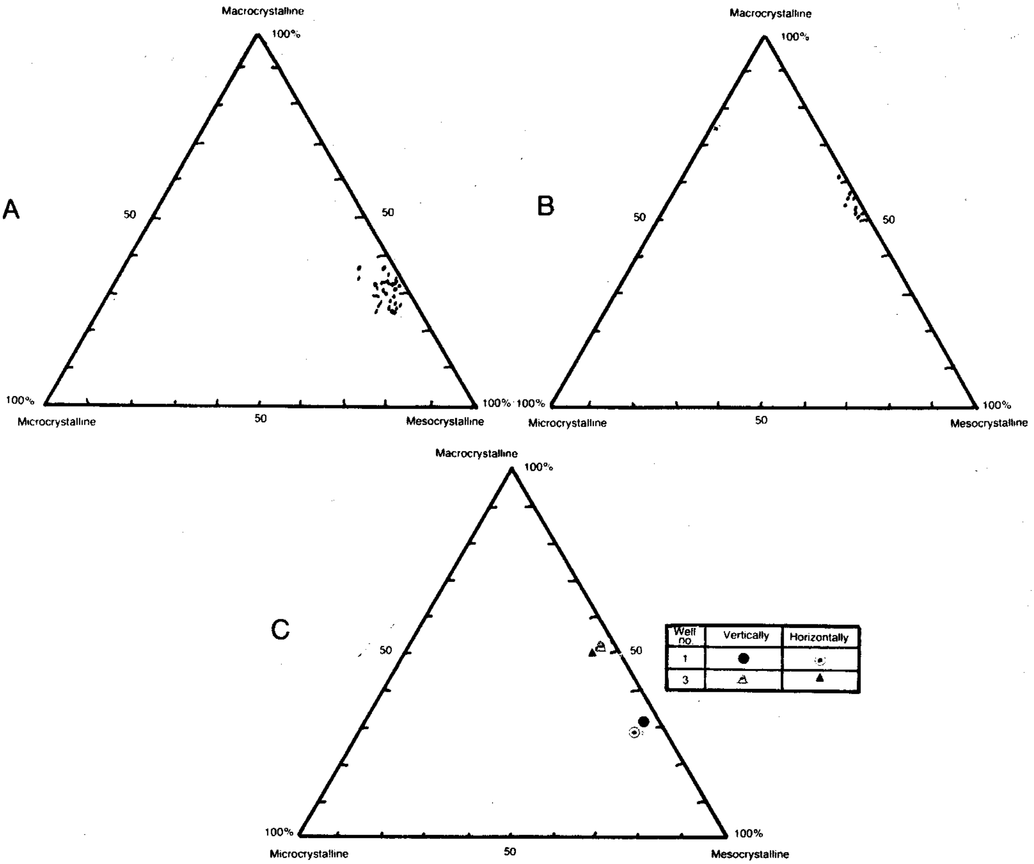

Fig. 9

Fig. 9: Distribution of Dolomite Crystals of Various Size Grades in Alamein Dolomite of El-Razzak Oil Field.

A. Distribution of size grades of crystals in Well No. 1.
B. Distribution of size grades of crystals in Well No. 3.
C. Distribution of average size grades of crystals of the Aptian Alamein Dolomite.

continuing growth of the dolomite crystals due to the effect of diagenetic processes. This is exemplified by the presence of dark brown cores of dolomite crystals showing rhombohedral outlines, suggesting a possible original idiotopic fabric. This process has led to the reduction of porosity with dolomite development.

The dolomite crystals are mostly medium to coarse crystalline ranging in size from 0.25 mm to 1 mm. Minor concentrations of smaller dolomite crystals (0.20 mm — 0.25 mm) occur in places. Calcite crystals range in size from 0.25 mm to 0.50 mm and are present in the form of microsparry to sparry calcite (Fig. 6). A sharp contact is noticed between calcite crystals and the dolomite matrix, where the calcite appears in the form of rhombic to subrhombic crystals. A slight variation in the size of the dolomite crystals was noticed towards the southern part of the field where they appear as macrocrystalline dolomite. This may be related to the slight variation in the chemical parameters within the environment of deposition and/or to post-depositional changes. The size of the dolomite crystals indicates that the original calcium-carbonate sediments were dolomitized due to replacement (Folk, 1965). In addition, anhydrite crystals were reported in minor amounts as veinlets or cavity filling associated with highly dolomitized matrix (Figs. 14 and 15) indicating a hypersaline, restricted and low-energy environment (Moorehouse, 1959). Dolomitization usually takes place under tropical to subtropical climatic conditions. This is in agreement with the well-known aspects of the climatic condition prevailing during Aptian deposition in Egypt and agrees with the studies of Hamed (1972).

In the lower part of the dolomite sequence, microstylolites were reported (Fig. 16). These seem to be caused by pressure-solution processes along zones of textural or mineralogical heterogeneity and started forming early and continued late in the diagenetic history of the sediments (Park and Schot, 1968). Locally the corroded dolomite matrix reflects the effect of late diagenetic processes (Fig. 17).

The study of the Alamein Dolomite pore system greatly helped to elucidate both depositional and postdepositional events that affected the porosity pattern of the studied rocks. The terminology of porosity pattern and stage is given according to Choquette and Pray (1970), whereas the size of the pores is according to Teodorovich (1949).

Petrographically, the following kinds of pore systems are present in the Alamein Dolomite rocks :

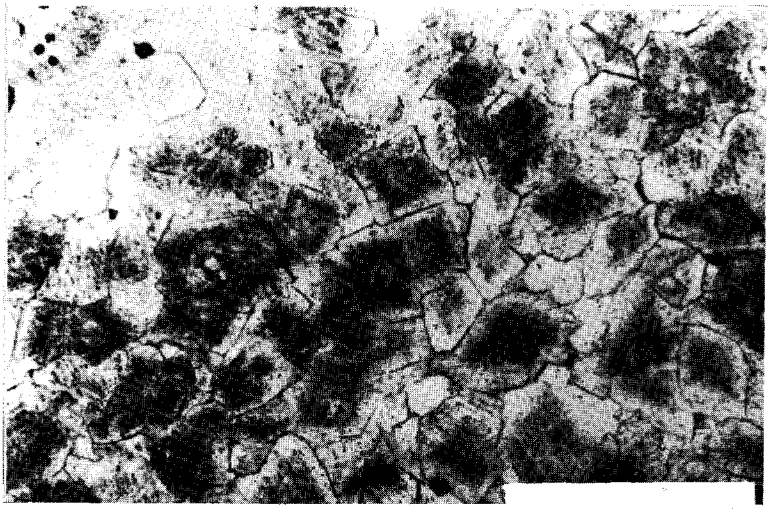

Fig. 10: Photomicrograph showing mosaic texture of micromesocrystalline dolomite. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7702-7705 feet, C.N.; bar scale 1 mm.

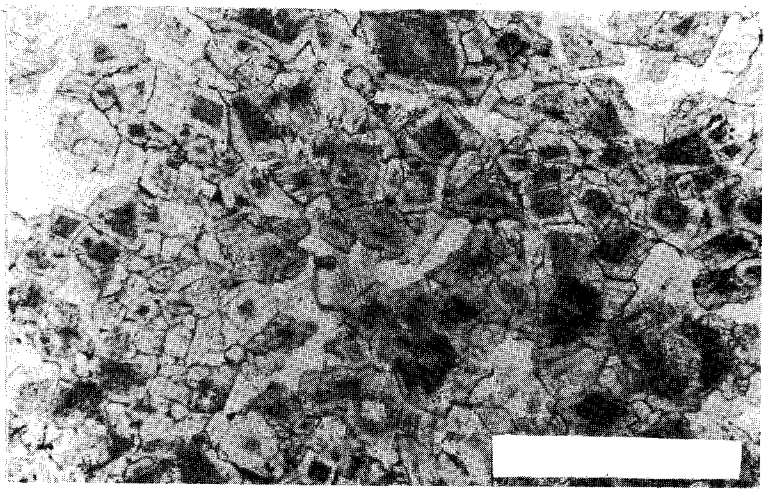

Fig. 11: Photomicrograph showing dolomite rhombs enclosed in poikilotopic sparry calcite makes up vug filling and is replaced by dolomite crystals. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7699-7702 feet, P.P.L.; bar scale 1 mm.

Fig. 12: Photomicrograph showing subhedral to euhedral, rhombic to subrhombic dolomite crystals forming an interlocking mosaic texture (hypidiotopic dolomite). Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7687-7690 feet, P.P.L.; bar scale 1 mm.

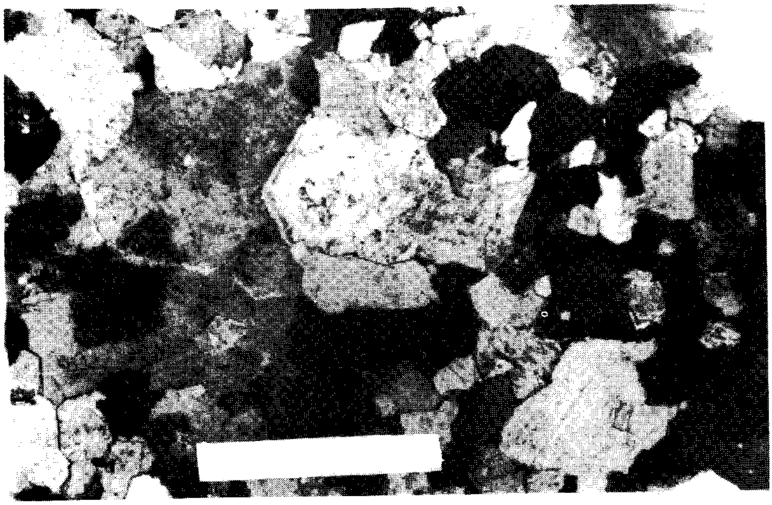

Fig. 13: Photomicrograph showing sucrose dolomite, meso - to macrocrystalline, euhedral zoned rhombs with dark cores, idiotopic dolomite. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7690-7693 feet, P.P.L.; bar scale 1 mm.

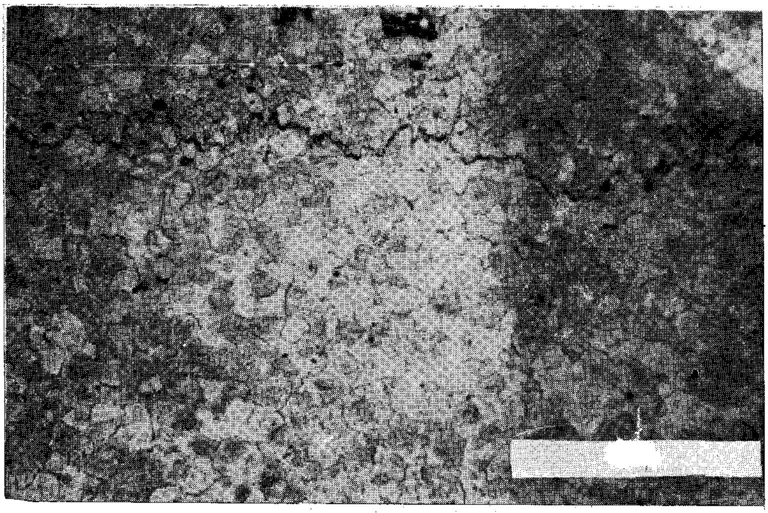

Fig. 14: Photomicrograph showing sparry dolomite veinlet with anhydrite crystals in a finer crystalline matrix. Aptian Alamein Dolomite, El-Razzak Well No. 3, Core #1, 7840-7843 feet, C.N., bar scale 1 mm.

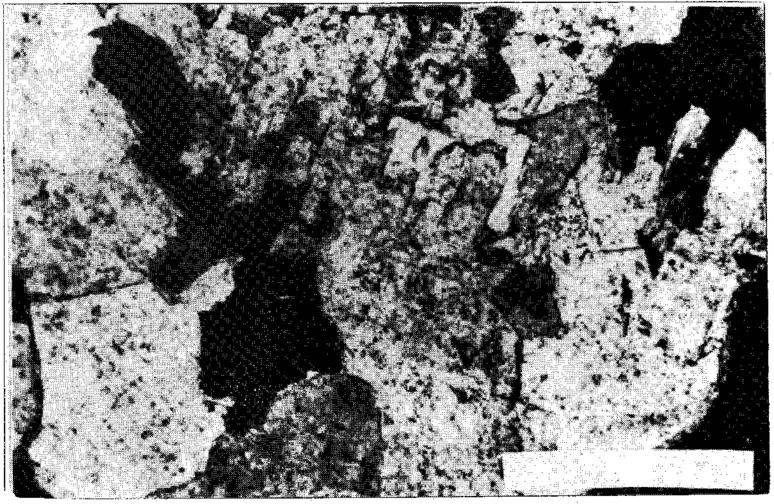

Fig. 15: Photomicrograph showing anhydrite flakes imbedded in a dolomite matrix. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7720-7723 feet, C.N.; bar scale 1 mm.

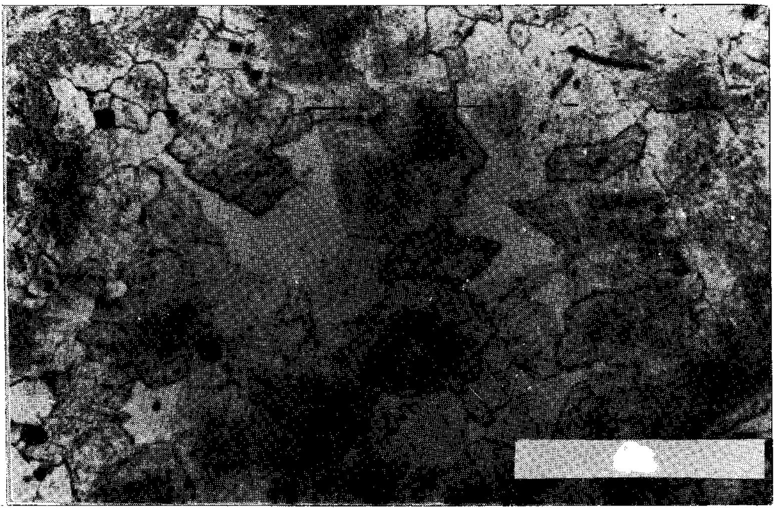

Fig. 16: Photomicrograph showing microstylolite filled with iron oxides and produced by solution along zones of weakness. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7723-7726 feet, P.P.L.; bar scale 1 mm.

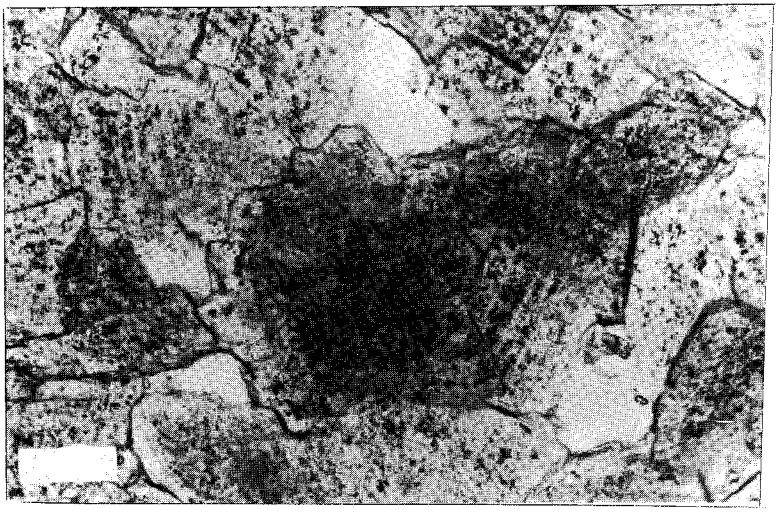

Fig. 17: Photomicrograph showing highly corroded dolomite matrix (epigenetic dolomite). Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7726-7729 feet, C.N.; bar scale 1 mm.

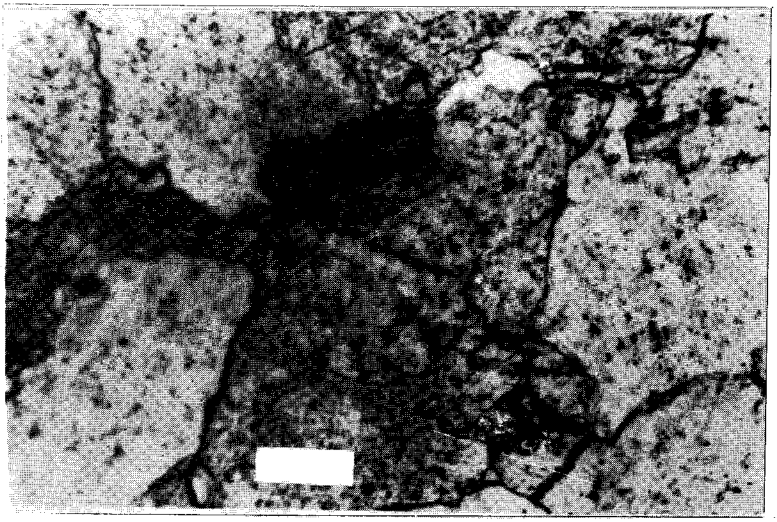

Fig. 18: Photomicrograph showing the moldic type of porosity. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7699-7702 feet, P.P.L.; bar scale 1 mm.

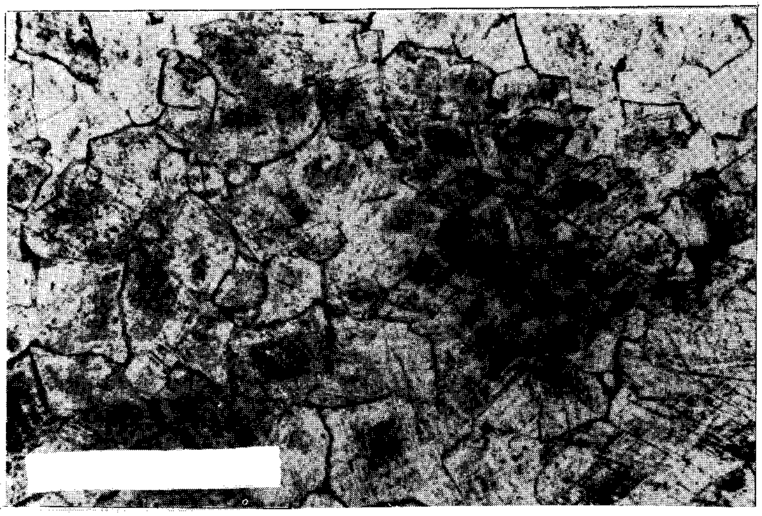

Fig. 19: Photomicrograph showing isolated intercrystalline type of porosity. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7702-7705 feet, P.P.L.; bar scale 0.1 mm.

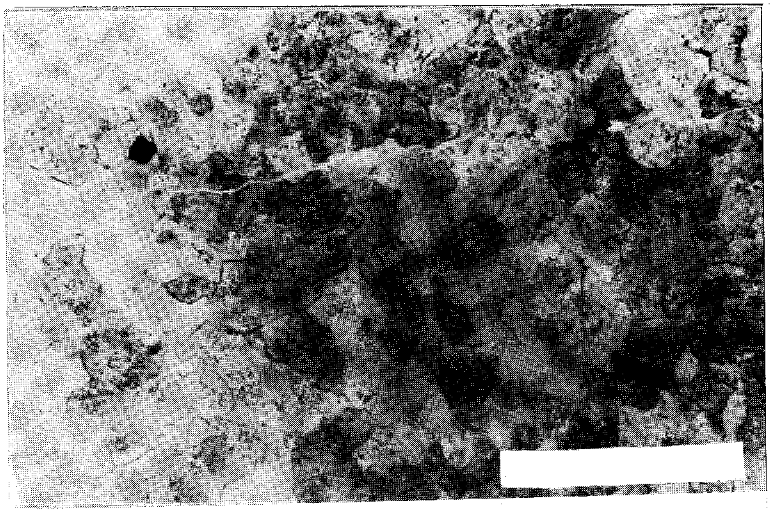

Fig. 20: Photomicrograph showing incompletely filled vug, birds-eye structure, as a result of dissolution processes of eogenetic stage. Aptian Alamein Dolomite, El-Razzak Well No. 3, Core #2, 7893-7896 feet, P.P.L.; bar scale 0.1 mm.

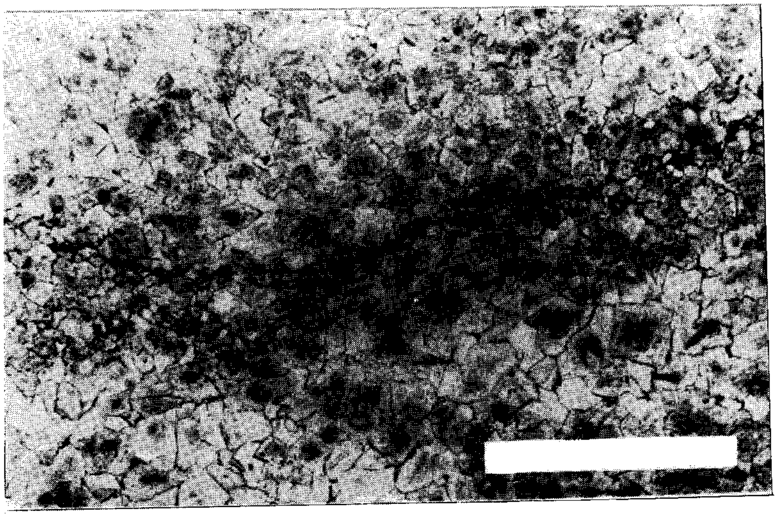

Fig. 21: Photomicrograph showing iron cement filling the interstices between the dolomite crystals in compact crystalline matrix. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7717-7720 feet, P.P.L.; bar scale 1 mm.

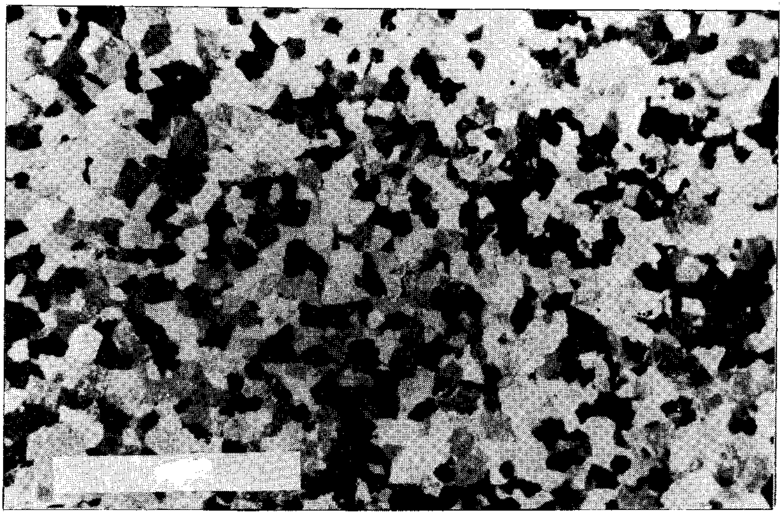

Fig. 22: Photomicrograph showing the channel type of porosity, the channel is empty. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7896-7899 feet, P.P.L.; bar scale 1 mm.

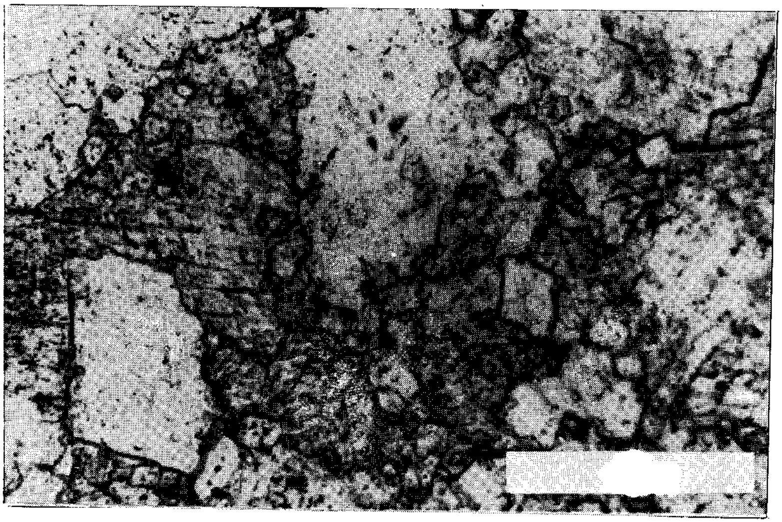

Fig. 23: Photomicrograph showing the channel type of porosity filled with iron oxide obliterating the porosity. Aptian Alamein Dolomite, El-Razzak Well No. 1, Core #1, 7708-7711 feet, P.P.L.; bar scale 1 mm.

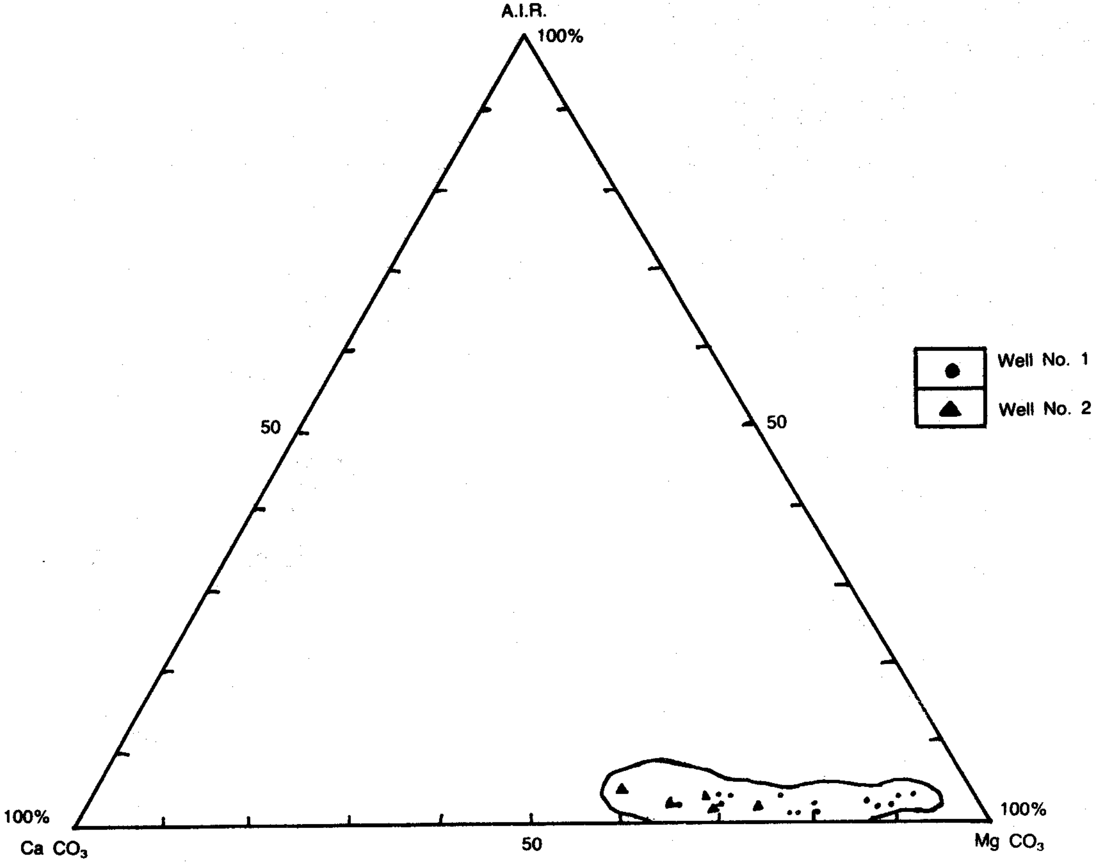

Fig. 24: Relationship between Distribution of $CaCO_3$, Acid Insoluble Residues (A.I.R.) and $MgCO_3$ of the Aptian Alamein Dolomite in El-Razzak Well No. 1 and well No. 3.

Fig. 24

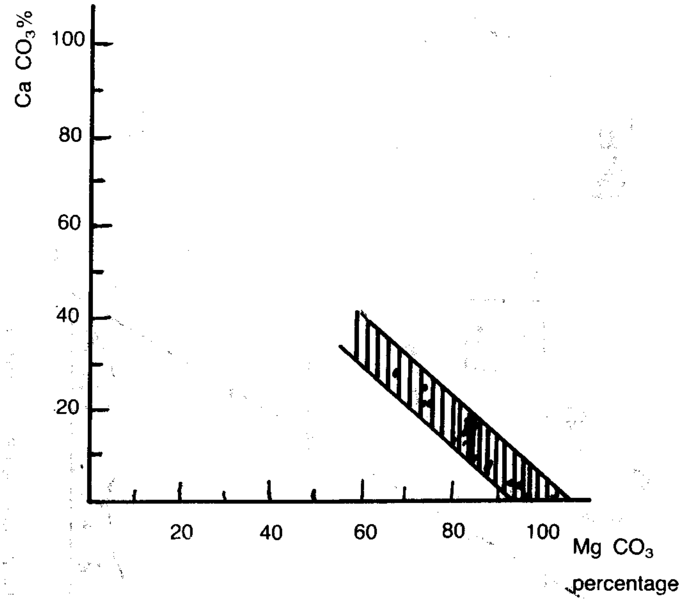

Fig. 25: Relationship between Distribution of $CaCO_3$ and $MgCO_3$ of the Aptian Alamein Dolomite in El-Razzak Well No. 1.

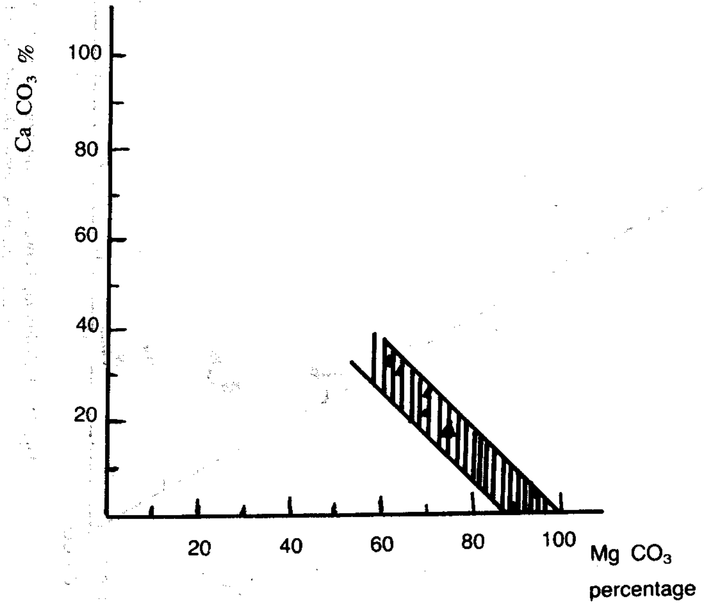

Fig. 26: Relationship between Distribution of $CaCO_3$ and $MgCO_3$ of the Aptian Alamein Dolomite in El-Razzak Well No, 3.

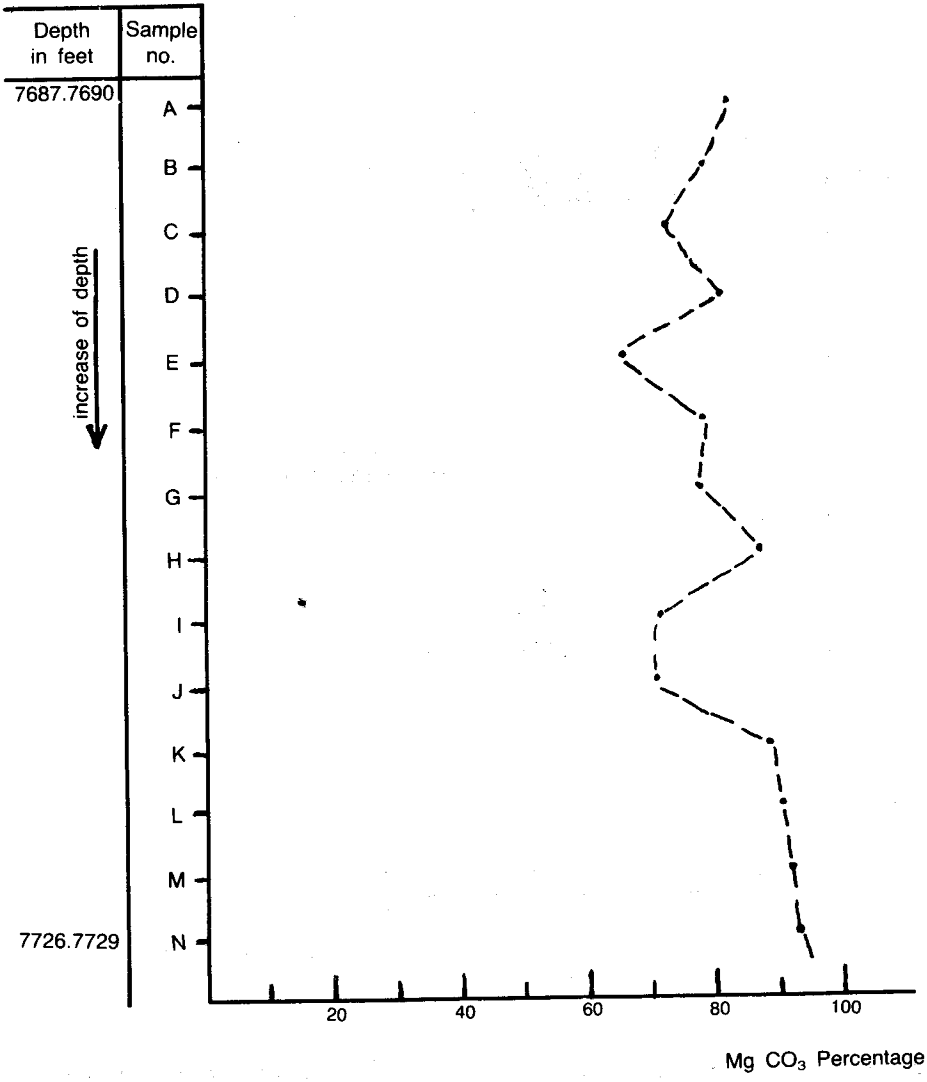

Fig. 27: Diagram showing Increase in Dolomitization ($MgCO_3$) with Increasing Depth in El-Razzak Well No. 1.

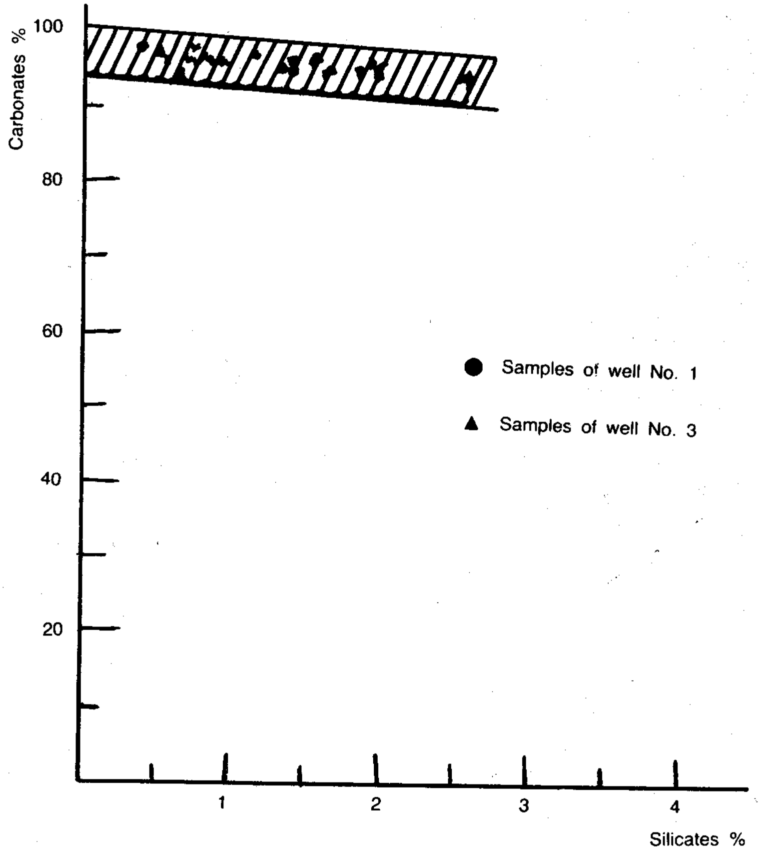

Fig. 28: Relationship between Carbonates and Silicates in the Aptian Alamein Dolomite of El-Razzak Wells No. 1 and 3.

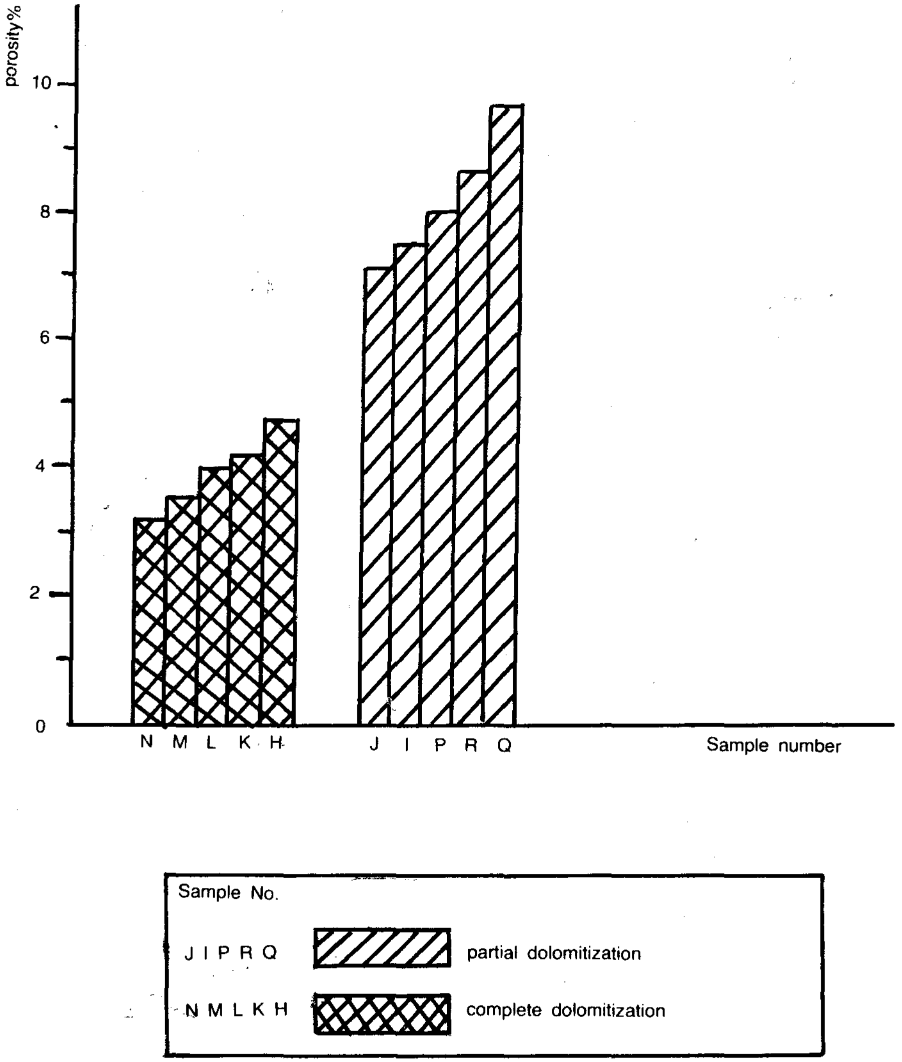

Fig. 29: Diagram showing the Effect of Dolomitization on the Porosity of the Alamein Dolomite in El-Razzak Oil Field.

I. Moldic porosity :

In the examined rocks, the presence of moldic pores, (Fig. 18) suggests that calcium-carbonate dissolution is a part of the dolomitization processes (Weyl, 1960).

II. Intercrystalline porosity :

This type of porosity, (Fig. 19) was noted where the pores range in size from micropores (less than 0.30 mm) to mega pores (0.80 mm) and in places appears filled with iron oxides. Intercrystalline pores partly were modified to form vuggy porosities of more than 1.0 mm. In the studied samples it was observed that these vugs do not lead to effective porosity and mostly were filled with dolomite crystals of late diagenesis. The incompletely filled vugs show birdseye structure (Fig. 20). Petrographically the dolomite matrix is of two major kinds, (1) a compact crystalline matrix made up of tightly interlocking dolomite crystals with no visible to fine pore space between the crystals (Figs. 12 and 21), and (2) a matrix composed of crystals partially in contact with each other and less tightly interlocking than the above, leaving mesopore to megapore space between the crystals, (Fig. 13).

The intercrystalline porosity can be considered as secondary porosity formed postdepositionally.

III. Fracture and Microchannel porosity :

Robinson (1966), stated that tectonic movements may create or modify porosity and permeability patterns in carbonate rocks as a result of the creation of fractures or the development of structurally controlled or tectonic dolomite.

Such types of porosity are present in some of the examined rock samples (Fig. 22) in El-Razzak Oil Field where they are represented by micro-channels elongated in tubular form, (width less than 0.05 mm). These kinds of porosities may originate by indiscriminate dissolution along fractures as solution-created porosity (Howard and David, 1936) and/or related to tectonic deformation (Waldschmidt, 1956). The microchannels are locally filled with iron-oxides.

Despite the different kinds of pores present, the Alamein Dolomite reflects a low effective porosity caused by late diagenetic cementation with iron oxides (Fig. 23) and random anhydrite cement (Fig. 15) and the masking effect of interlocking dolomite crystals.

Chemical analysis of representative samples taken from the available cores from the Alamein Dolomite in El-Razzak Oil Field (from wells No. 1 and 3) followed that of Vogel (1964), and lead to similar conclusions.

Figure (24) illustrates the triangular representation for the A.I.R. (Acid insoluble residues) $CaCO_3$-$MgCO_3$ of the Aptian Alamein Dolomite in the studied field. Figures (25 and 26) show the relationship between $CaCO_3$ in these rocks. These figures show that most of the studied rocks are mainly dolomites; likewise these rocks contain a very low concentration of A.I.R. However, some of these dolomites are enriched in $CaCO_3$ in variable amounts within the dolomite strata of the same as well as different wells, resulting in calcitic dolomites. A linear relationship can be traced between the amounts of $CaCO_3$ and M_gCO_3, where an increase in $M_gCO_3$is associated with a decrease in $CaCO_3$. Figure (27) shows the relationship between the $MgCO_3$ and depth in the well in the investigated rocks. It seems that the amount of dolomite increases with depth as reflected by well No. 1. Figure (28) shows the relationship between carbonates and silicates in the studied samples. A very low content of silicates is reported. An increase in the total amount of carbonates is associated with a decrease in the total amount of silicates. This may explain the scarcity of sandy dolomite rocks within the Aptian Alamein Dolomite in El Razzak Oil Field. Hence, it can be assumed that the deposition was in shallow marine environment with no terrigenous input. This confirms that Alamein Dolomite in El Razzak Oil Field is of pure carbonate facies-free of sands.

Diagenesis

The results of petrographic study, X-ray diffraction analysis (19 samples) and chemical analysis (available cores from wells No. 1 and 3 and given in Table 5) on the carbonate rocks of the Alamein Dolomite illustrate their complex diagenetic history which involves early diagenetic (shallow diagenesis) as well as late diagenetic stages (deep diagenesis.)

Early diagenetic (penecontemporaneous) dolomitization :

Petrographically, there is no evidence whether the dolomite replaced carbonate mud or lithified micrite, and direct evidence is also lacking whether the pre-existing calcium-carbonate mineral was aragonite or calcite. Further the Alamein dolomites are devoid of fossils. However, there is some evidence that dolomitization has undergone by replacement shortly or soon after the deposition of pre-existing carbonate sediments. Several factors should be taken into consideration to explain the early diagenetic processes affecting the textural and mineralogical history of the

Table 5
Chemical Analysis of Studied Rock Samples of The Aptian Alamein Dolomite in El Razzak Oil Field

Well No.	*Core*	*Depth in feet*	*Direction*	*Percentage*							
				SiO_2	R_2O_3	CaO	$CaCo_3$	M_gO	M_gCO_3	CO_2	*A.I.R.*
1	1	7687-7690	A	1.89	2.98	7.28	13.00	39.05	82.09	41.79	2.44
		7690-7693	B	1.43	2.50	9.57	17.08	37.56	78.95	41.60	1.80
		7693-7696	C	0.85	2.40	13.27	23.70	34.76	73.00	42.55	3.63
		7696-7699	D	0.76	2.64	8.31	14.83	38.87	81.66	42.98	1.48
		7699-7702	E	1.96	3.75	15.44	27.57	31.76	66.69	41.63	2.00
		7702-7705	F	0.69	2.10	10.10	18.02	37.66	79.10	43.02	1.86
		7705-7708	G	1.41	3.32	9.18	16.40	37.53	78.81	41.11	3.60
		7708-7711	H	1.87	2.56	3.42	6.11	41.91	88.60	41.92	3.56
		7711-7714	I	1.98	2.05	12.77	24.59	33.96	71.36	42.50	2.90
		7714-7717	J	0.81	2.44	14.13	25.23	34.02	71.45	43.89	3.20
		7717-7720	K	0.90	2.72	4.10	7.10	42.47	89.22	42.92	2.60
		7720-7723	L	1.30	1.71	3.37	6.02	43.21	90.73	42.92	2.31
		7723-7726	M	0.36	1.41	2.77	4.94	44.05	92.50	43.30	3.39
		7726-7729	N	1.16	1.75	2.55	4.55	44.47	93.38	44.10	3.91
	1	7840-7843	S	1.65	2.9	18.85	33.66	29.36	61.7	41.99	4.54
3	2	7890-7893	O	0.68	4.70	10.43	18.63	35.71	75.99	43.92	2.40
		7893-7896	P	1.56	1.90	14.67	26.20	33.48	70.30	43.11	2.10
		7896-7899	Q	0.53	2.28	17.44	31.15	31.35	65.92	44.40	2.80
		7899-7902	R	2.56	3.68	13.24	23.65	33.35	70.04	41.20	3.41

* R_2O_3 = (Fe_2O_3 + Al_2O_3)

* A.I.R. = (acid insoluble residue)

Aptian Alamein Dolomite :

1. The paleotopography of the North Western Desert was irregular due to the differential uplift and erosion of the pre-Aptian sediments.

2. The study of the different microfacies proved the existence of land oscillations associated with downward movements during the time of deposition of the Aptian carbonates. These land oscillations were

responsible for the creation of unique physicochemical conditions during the diagenetic history of the Alamein Dolomites in the Northern Western Desert of Egypt, (Hamed, 1972).

We believe that the Alamein Dolomite in El Razzak Oil Field represents a marine transgressive period. This facies seems to have been deposited under shallow marine conditions within the shelf area (supratidal). In the early stages of formation of the original limestones, turbulence and water agitation prevailed and well-sorted carbonate particles accumulated. In scattered banks and ridges, particularly towards the north of the El Razzak area, some parts of the shelf were protected from turbulence offering favourable conditions for the accumulation of lime-mud facies (microcrystalline limestone-micrite).

Partial to complete recrystallization was observed in most of the remnants of the original matrix, which has been obliterated in parts by dolomitization. Two kinds of calcite crystals were recorded :

A. Microspars: this type of calcite is believed to have been originated by recrystallization of lime mud resulting in the formation of microspars, consisting of crystals ranging from four to thirty microns in size (Folk, 1965) and locally having an interlocking mosaic texture within the dolomite matrix.

B. Coarse crystalline calcite: this type of crystal is larger than thirty microns in size. In some parts, coarse crystalline calcite appears as true pore filling sparry calcite.

At certain stages, during the deposition of the original sediments or closely after deposition and before lithification under favourable arid conditions, dolomitization occurred associated with the formation of evaporites by the action of capillary evaporation of saline marine water from semi-isolated arms of the sea. Hypersalinity precipitates anhydrite or gypsum; this removal of calcium raises the Mg:Ca ratio to high levels (Friedman and Sanders, 1967). This process of dolomitization was slow and the increase of Mg ions would favour the conversion of the original calcium carbonate.

$$Mg_{aq} + 2\ CaCO_3 \rightleftharpoons CaMg\ (CO_3)_2 + Ca_{aq}.$$

Several environmental parameters seem to have promoted early diagenetic dolomitization. These are manifested by high magnesium content in the supernatant sea water (Table 6), high salinity, favourable pH, high temperature, slow subsidence or elevation, and the presence of carbon dioxide in sea water which enhanced the partial solution of the limestones and favoured the chemical interchange between the Ca^{-2} and Mg^{-2} ions. During this stage evaporites were deposited from sea water indicating the presence of hypersaline water during dolomitization and explains the absence of fossils in the Alamein Dolomite of El Razzak Oil Field.

Late-Diagenetic (Epigenetic) Dolomitization :

Behre and Garrels (1943) stated that the ascending solutions tend to have lower Ca/Mg ratio than the descending ones. Changes by circulating Mg-rich underground waters took place after deposition. This stage includes cementation, compaction, lithification and dolomite recrystallization. It is suggested that the magnesium rich underground waters moved vertically via deep-seated joints, fractures and faults caused by late Cretaceous tectonism; these waters spread laterally along porous zones and bedding planes. The upward migration of the magnesian water was arrested by impervious shales.

This was responsible for the high degree of dolomitization in the lower parts of the Alamein Dolomite rocks. The original depositional textures and fabric have been, in most parts, progressively destroyed as the dolomite concentration increased.

The epigenetic stage of dolomitization in the Alamein Dolomite was characterized by :

1. The presence of hypersaline water exemplified by the detected concentrations of magnesite, barite and siderite (Friedman and Radke, 1979) and the increase of evaporites in the lower parts of the dolomite sequence.
2. The increase of the Mg/Ca ratio of the brines above that of sea water to a ratio greater than that which would be in equilibrium with both calcite and dolomite (Halla and Ritter 1935).
3. High temperatures, pH and alkalinity.
4. The development of microstylolites, especially in the lower part of the studied rocks. These structures are oriented at various angles and have

Table 6
$M_gCO_3/CaCO_3$ Ratio and Kind of Carbonates in the Rock Samples of the Aptian Alamein Dolomite Member in El Razzak Oil Field

Well No.	*Sample No.*	*$MgCO_3/CaCO_3$*	*Carbonates*	*Silicates*	*Carbonate/ Silicate Ratio*	*Kind of Rock*
1	A	5 : 1	95.09	1.30	50 : 1	Dolomite
	B	5 : 1	96.03	1.43	67 : 1	Calcitic Dolomite
	C	3 : 1	96.70	0.85	114 : 1	Calcitic Dolomite
	D	6 : 1	96.69	0.76	127 : 1	Calcitic Dolomite
	E	2 : 1	94.26	1.96	48 : 1	Calcitic Dolomite
	F	4 : 1	97.10	0.69	141 : 1	Calcitic Dolomite
	G	5 : 1	95.10	1.41	68 : 1	Calcitic Dolomite
	H	15 : 1	94.71	1.87	51 : 1	Dolomite
	I	3 : 1	95.95	1.98	48 : 1	Calcitic Dolomite
	J	3 : 1	96.68	0.81	119 : 1	Calcitic Dolomite
	K	13 : 1	96.32	0.90	107 : 1	Dolomite
	L	15 : 1	96.75	1.89	74 : 1	Calcitic Dolomite
	M	19 : 1	97.44	0.36	273 : 1	Dolomite
	N	20 : 1	97.93	1.16	84 : 1	Dolomite
	S	2 : 1	95.36	1.65	58 : 1	Calcitic Dolomite
3	O	4 : 1	94.62	0.68	139 : 1	Calcitic Dolomite
	P	3 : 1	96.50	1.56	62 : 1	Calcitic Dolomite
	Q	2 : 1	97.07	0.53	183 : 1	Calcitic Dolomite
	R	3 : 1	93.69	2.56	37 : 1	Calcitic Dolomite

originated from pressure solutions along heterogenic textural and mineralogical zones and have been developed in late diagenetic stages (Park and Schot, 1968).

The diagenetic processes which affected the Alamein Dolomites had been porosity destroyers rather than porosity builders. A remarkable decrease in porosity of the studied rocks parallels increasing dolomite concentration (Fig. 29), where the matrix in the Alamein Dolomite is mainly of two types, as follows :

1. Compact crystalline matrix made up of tightly interlocking dolomite crystals with slight to non-visible pore spaces between them.

2. Dolomite crystals merely partially in contact with each other, less tightly interlocked than the above type, leaving pore spaces between the crystals.

Most of the original intergranular, moldic, and shrinkage porosities have been converted, during late diagenesis, into intercrystalline micro-vuggy, fracture and micro-channel porosities. The presence of anhydrite association, compaction, iron oxides filling pores as cement, and dolomite recrystallization have been responsible for the reduction of the porosity in the investigated rocks.

As dolomitization directly affected the porosity of the Alamein Dolomites, its permeability is expected to be controlled by the presence of secondary open fracture and continuous channel porosity rather than by a non-effective intercrystalline and discontinuous vuggy system. Hence, the diagenetic processes were responsible for considerable lateral and vertical changes either in lithological character or petrophysical properties of the Aptian Alamein Dolomite in El Razzak Oil Field.

So, it can be concluded that Alamein Dolomite has been formed by replacement of limestones under a variety of conditions either penecontemporaneously or soon after deposition, or later through the action of ascending solution of either meteoric water or by hydrothermal solutions. Replacement in the studied dolomite is evidenced by :

1. The absence of evidences supporting the fact that the Alamein Dolomite is of syngenetic origin.
2. The presence of the Aptian Alamein Dolomite with approximately uniform character over wide areal extent on the northern part of the Western Desert, supported the replacement shortly after deposition of the original sediments (Hatch, et al, 1971).
3. Petrographically, two main types of dolomite crystals are developed namely mesocrystalline and macrocrystalline with sub-ordinate amounts of smaller dolomite crystals. These may indicate an advanced stage of dolomitization. It seems that slight variation in the chemical parameters may explain the difference in the crystallinity of dolomite crystals and can also be related to post-depositional variations.

However, all dolomite crystals in the studied rocks are more than 0.03 mm in size, hence it is most probably a replacement dolomite (Folk, 1965).

4. The presence of unreplaced patches of calcite within the dolomite matrix and the gradational contacts between the dolomite matrix and the remnants of the original matrix, not completely obliterated, can prove the replacement origin of Alamein Dolomite in El Razzak Oil Field. In addition, X-ray analysis and chemical studies confirm the presence of limestones as the original rocks in parts not completely dolomitized.

Acknowledgements

The authors are greatly indebted to the managements of the Egyptian General Petroleum Corporation (EGPC) and the Gulf of Suez Petroleum Company (GUPCO), Cairo, Egypt for providing the necessary material used in this study. Special gratitude is expressed to Prof. Dr. Gerald M. Friedman, Professor of Geology, Rensselaer Polytechnic Institute, Troy, New York for revising the manuscript and useful suggestions.

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دراسة بتروجرافيه لدولوميت العلمين (الكريتاوى السفلى) في حقل الرزاق ، الصحراء الغربية - مصر

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ملخص

يتضمن هذا البحث دراسة أصل وظروف الترسيب لدولوميت العلمين بحقل بترول الرزاق وذلك عن طريق التحاليل البتروجرافيه والكيميائية وكذلك الأشعه السينه .

ولقد تم استنتاج أن الصخور قيد الدراسة تتكون من الدولوميت كما أن صخور دولوميت العلمين هي صخور جيريه متدلمته تحت ظروف مختلفه تمتد من تغير متزامن مع الترسيب إلى تغير متأخر بعد الترسيب كما توجد في صخور الدولوميت بقايا مختلفة الأحجام من الصخور الجيريه غير المتدلمته . وأمكن تحديد النسيج المميز لهذه الصخور وتأثيره على الخواص البتروفيزيائية لها ، والاستدلال على المسام الموجوده داخل تلك الصخور وأحجامها وطرق توزيعها وتأثير عملية الدلمته والضغط والمادة اللاحمه واعادة التبلور عليها ، هذا بالاضافة إلى التوصل إلى العديد من الاستنتاجات الخاصة ببيئه الترسيب والظروف غير الملائمة لنمو الاحياء البحرية .

كما تمت دراسة كيميائية لصخور الدولوميت في الحقل قيد الدراسه حيث أمكن استنتاج بيئة الترسيب ومعرفة المناخ السائد أثناء الترسيب ودرجة الحراره والمؤثرات الكيميائيه في بيئة الترسيب وعملية اعادة التبلور والتغيرات اللاحقة للترسيب .

وقد تبين أن نتائج التحاليل بواسطة الأشعة السينيه للمعادن غير الطينيه تؤيد الدراسات الصخرية والكيميائيه من خلال معرفة المعادن المكونه لتكوين العلمين واستنتاج نوع الصخور والتغيرات اللاحقة للترسيب وبعض الدلائل على بيئة الترسيب .