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Post-Miocene Sedimentation in the Gulf of Suez, Egypt

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ABSTRACT. Stratigraphic correlation of Post-Miocene sediments penetrated by two deep wells (BB-80 and GS-78) drilled in the northern part of Gulf of Suez exhibited marked lithological and thickness variations from one locality to another. Representative bulk samples from the two sections under consideration, were mineralogically and chemically analysed using the X-ray diffractometry, X-ray fluorescence and polarizing microscope.

The obtained data revealed that the studied Post Miocene subsurface sediments are mainly represented by two facies: terrigenous and chemical facies. Terrigenous facies is composed of interbedded alluvial sand, gravels and shales probably delivered into the gulf by its affluents of which the fans play the most important role. Its sedimentation was rapid and took place to some extent in small active fault-controlled basins. The chemical facies consists mainly of evaporates; represented by anhydrite and gypsum minerals and limestones (calcite and dolomite).

Geochemical investigation indicates that the chemical facies shows usually high CaO, MgO and Sr contents. The fact that high Sr-concentration associated with high sulfate content indicates marine and/or coastal sabkhas (supratidal flats) where no organisms could survive in supersaline environment. The contents of other major oxides and Ba, Zr, Rb, Cr, Ni and Zn increase considerably with increase of the terrigenous constituents.

I. Introduction

The Gulf of Suez is an area of subsidence within the stable shelf and the northern part of the Arabo-Nubian massif. It began to form during Early Paleozoic time as a narrow embayment of the Tethys and was rejuvenated during the rifting phase of the great East African Rift system during lower to middle Tertiary time.

Great accumulation of sediments from this continuously subsiding depression was interrupted at times by a regional uplift with subsequent erosion. Its connection with the Mediterranean Sea to the north and with the Red Sea to the south is established during Early Miocene (Schlumberger 1984).

The Gulf of Suez is viewed upon as a region composed of a large number of tilted fault blocks that were continuously rising and sinking at different rates.

II. Stratigraphy

The stratigraphy of the Gulf of Suez can be differentiated into three distinct phases (Barakat 1982). The lower Miocene clastics were laid unconformably over Pre-Miocene formation in structural lows. High energy carbonate build-up developed along the high edges of the uplift fault blocks.

The Middle Miocene is characterized by the immense development of evaporitic series especially in the graben area of the Gulf of Suez and the Red Sea.

Late Miocene and Pliocene sequences represent the final phases of depositional history in this region. Late Miocene crustal movements most likely led to the formation of large lagoons in eastern Mediterranean and Red Sea. Crustal movements continued from late Miocene into Early Pliocene, these were followed by a renewed and short-lived transgression which affected the relatively narrow coastal area of northern Egypt, Gulf of Suez and the Red Sea. It is most likely during the Pliocene-Recent time that the connection with the Mediterranean Sea was disrupted perhaps by an arm of an ancestral Proto-Nile.

III. Tectonic History of the Gulf of Suez

The Gulf of Suez is an important area in the plate tectonic interpretation. It is bordered by the Arabian, Nubian and Sinai plates. The relative movements between them caused the formation of the Gulf of Suez, the Gulf of Aqaba and the Red Sea. The movements between the Sinai and the Nubian plates resulted in the formation of the Gulf of Suez (McKenzie *et al.*, 1970; Girdler and Styles 1974).

The Gulf of Suez is broken by many smaller normal faults into several hundred fault blocks of varying size. These movements have affected the Miocene stratigraphic succession that differ considerably in both facies and thickness from one block to another. Thus deep water deposition took place on the lower blocks while shallow water deposition occurred on the higher blocks.

IV. Pliocene-Recent Subsurface Sediments in the Gulf of Suez

Recent drilling in many of the coastal areas of the Gulf of Suez show that the Pliocene-Pleistocene deposits form an extremely thick series of gravels and sands with marl, shale, limestone and anhydrite (Said 1962).

The Pliocene and younger sediments encountered in the subsurface may attain a thickness of 500 m. The sediments are generally marine in the south and are usually composed of fluvial or other continental gravels and sands in the north (Khalil 1975).

V. Scope and Purpose of Study

Many deep wells have been drilled in Gulf of Suez and much subsurface information is available for this region. No attention has been given to the relatively thin Post-Miocene sediments in the Gulf of Suez.

The Present study is planned to provide information on the depositional history of Post-Miocene sequences in the Gulf of Suez and to elucidate their lithological and mineralogical composition. The authors were provided with ditch samples, unfortunately core samples from shallow depths were not available.

The Pliocene-Recent sediments in the Gulf of Suez have been studied from two deep wells drilled in the Gulf of Suez namely; GS-78 and BB-80 (Fig. 1). Lithology is mainly composed of sandstone interbedded with thin layers of limestone and shale especially in well BB-80 (Fig. 2). Away from the sand influx, the Pliocene-Recent deposits seem to be composed of evaporites interbedded with thin layers of limestone, chert and shale in well GS-78 (Fig. 3).

The following main steps have been undertaken :

1. Lithostratigraphical analyses including the carbonate, sand and mud contents.
2. Grain-size analysis for selected sand samples and determination of graphic grain size parameters of Folk and Ward (1957).
3. Heavy minerals identification of the sand sediments for provinces and source rock interpretation.
4. Bulk mineral content was determined in some selected samples of limestone and evaporite composition by X-ray diffraction analysis.
5. Geochemical analysis of some selected samples for major and trace elements determination using the X-ray spectrometer technique.

Results and Discussion

Lithology

The samples of Post Miocene sediments studied from well BB-80 show variable carbonate content between 58% and 11.2% while sand content shows ranges between 81.2% and 10.7%. Otherwise, the mud content shows lower amounts, it varies between 50.6% and 6%. Both sand and carbonate fractions are thrown in opposite rhythmic variation (Fig. 4). Where the supply of sands and gravels from the higher areas increases, the chemical sediments (evaporites) are prevailed in well GS-78.

It is interesting to notice that thin evaporites beds in well BB-80 interdigitate with non-evaporitic sediments such as sandstone, limestone and shale. This reflects a sub-

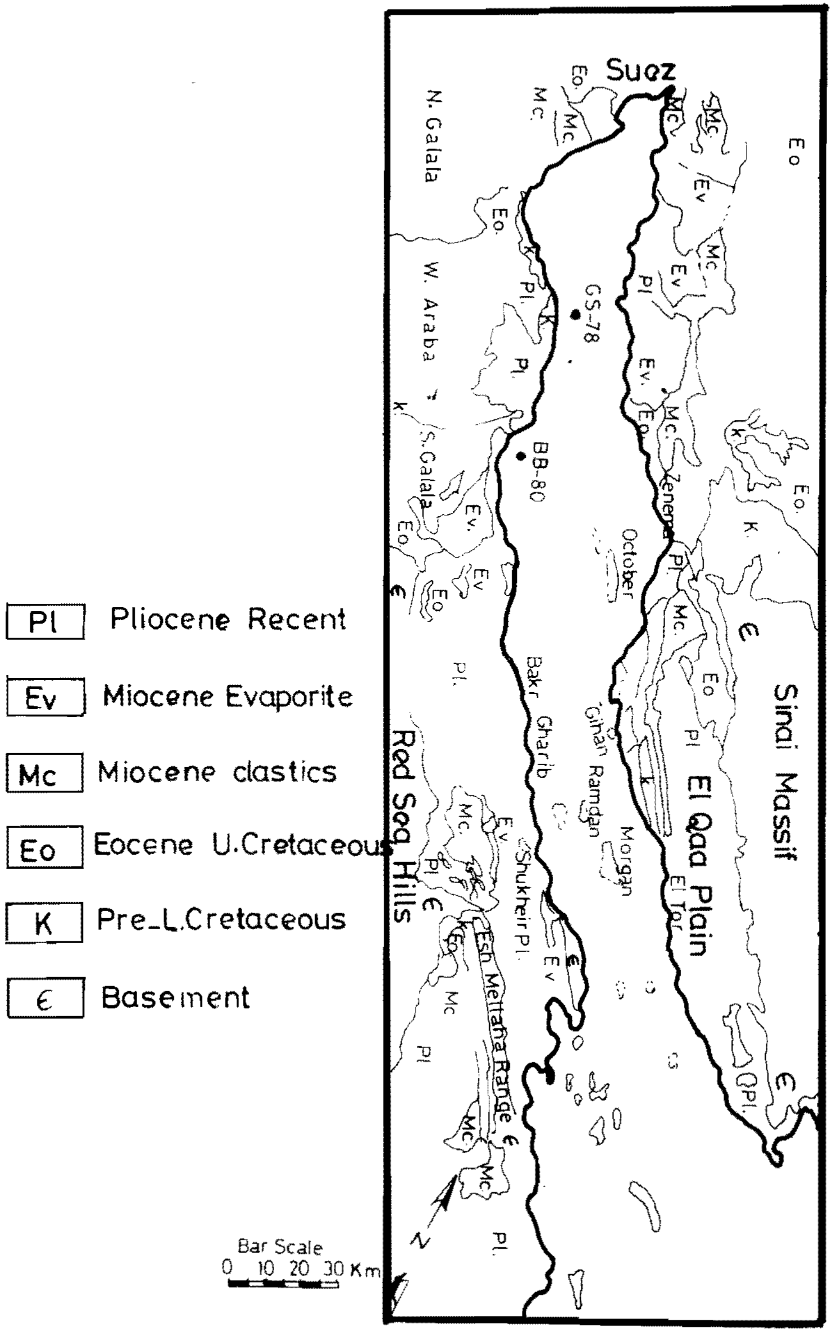


FIG. 1. Surface geologic map (• Studied wells) (after Fawzy and Abdel Aal 1984).

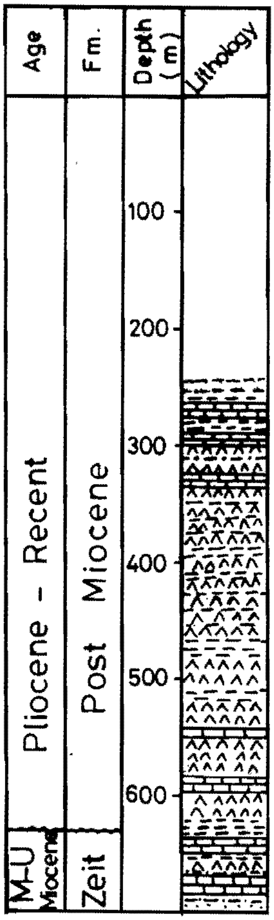
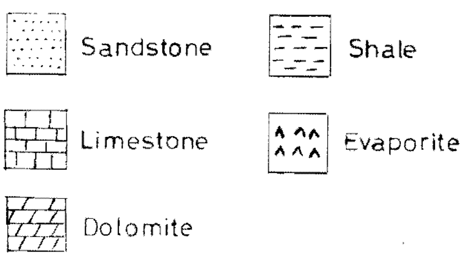


FIG. 3. Lithologic log of well GS-78.



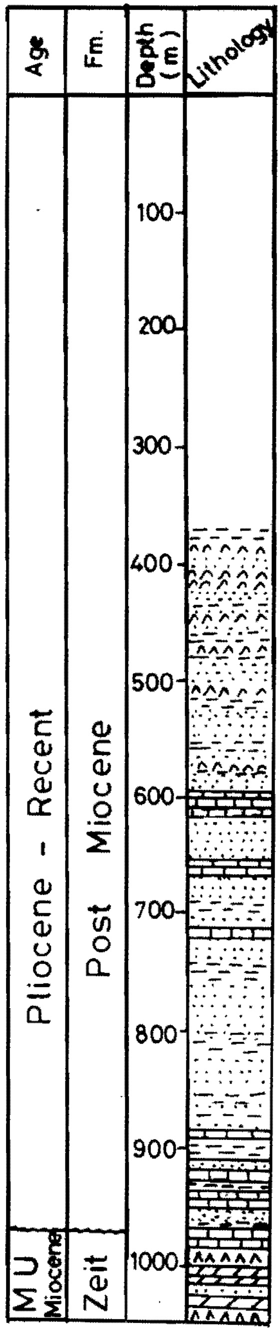


FIG. 2. Lithologic log of well BB-80.

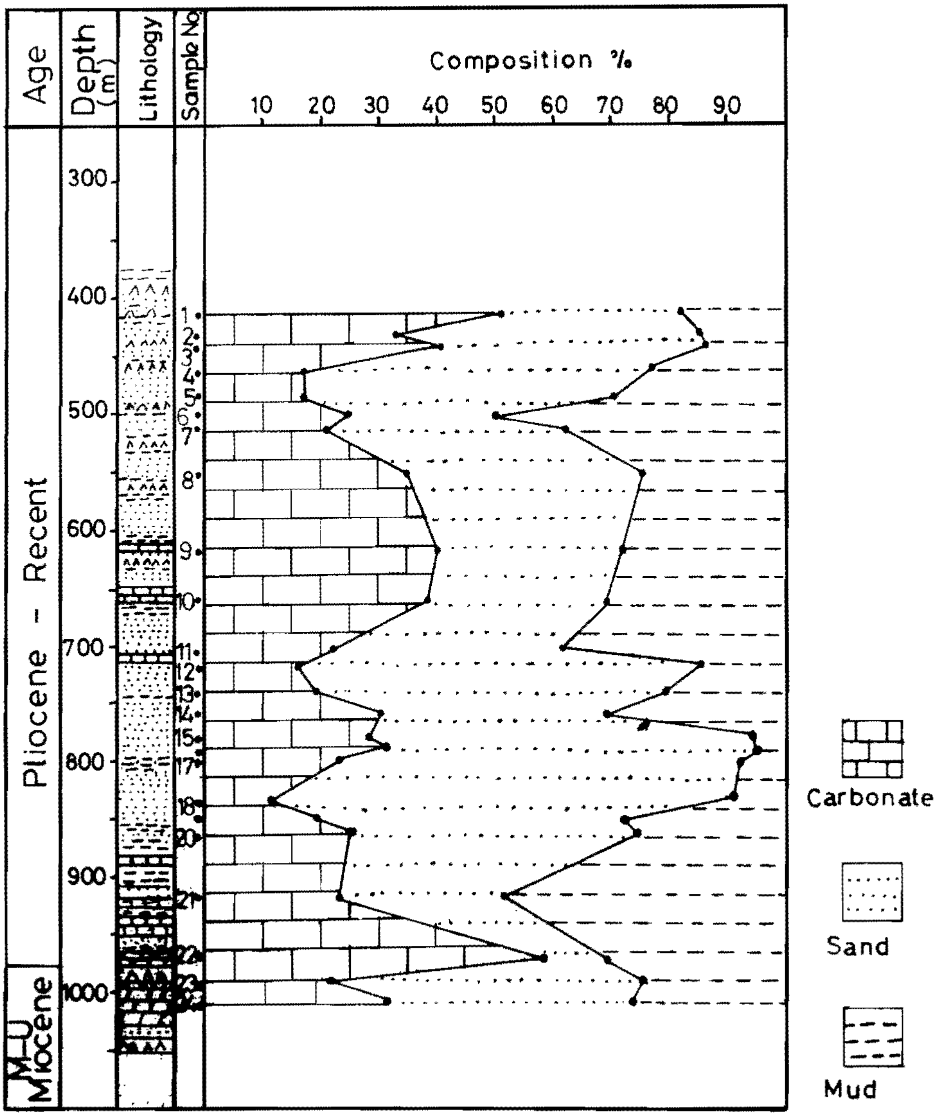


FIG. 4. Variation of carbonate, sand and mud content with depth for Post-Miocene sediments in Gulf of Suez (Well BB-80).

siding basin. While at well GS-78 common evaporite sequences are precipitated from a shallow to deep standing body of water with replenishment by fresh or marine water. Thus considerable sinking of the gulf area persisted during the Pliocene and Pleistocene as evidenced by deposits of these periods.

Graphic Grain-Size Significances

Investigation of the graphic grain-size parameters of Folk and Ward (1957), indicates that the sands are mainly coarse to very coarse-grained and well to moderately sorted and sometimes poorly sorted. Variation of M_z is similar to that of δ_I (Fig. 5). Very coarse and coarse-grained sand correspond to well and moderately well sorted while medium sand corresponds to poorly sorted. This type of sand alteration in size and sorting most probably favour an oscillating near-shore environment of deposition.

Skewness distribution being strongly fine skewed then becomes coarse to near symmetrical downward, while kurtosis varies from platykurtic (deficiently peaked) to very leptokurtic (excessively peaked).

The Post Miocene sediments documented in the Gulf of Suez are of two facies (Fig. 6); a clastic sand facies commonly developed in the eastern side of the gulf coastal plain and a chemical facies mainly consisting of limestone, evaporite and shale mostly developed in the western side of the gulf coastal plain (Fawzy and Abdel-Aal 1984).

During the Pliocene-Recent time a phase of subsidence took place; ephemeral rivers have been developed from heavy seasonal rainstorms. An alluvial fan deposits of coarse-grained sediments, immature and poorly sorted have been influxed to these subsiding areas. Thus the tectonic movements controlled the accumulation of the Pliocene-Recent sand and gravel in the Gulf of Suez. Otherwise, the shallow sites in the other parts of the gulf suffered evaporation and subaqueous precipitation of evaporite deposits occurred.

A generalized litho-stratigraphic section has been furnished for Post Miocene sediments in the Gulf of Suez (Fig. 7).

Mineralogy of Post Miocene Sediments

Mineralogy of Sand

In general, the most non-opaque heavy minerals identified in the very fine sand fraction, in a decreasing order of abundance are zircon, epidote, augite and tourmaline. While hornblende, rutile, staurolite and garnet are less common. The relative frequency of each individual mineral is represented in histograms (Fig. 8).

In general, the stable minerals of zircon, tourmaline and rutile represent more than 70% of the non-opaque heavy minerals, while the unstable components of epidote, augite and hornblende constitute less than 50%.

The study of heavy minerals in Post Miocene sand in the Gulf of Suez furnishes that the province supplying materials consists mainly of pre-existing sedimentary rocks. Otherwise, the high content of epidote and augite proves further derivation from metamorphic source rocks.

Clay Mineralogy

X-ray investigation has been carried out on the clay fraction separated from the Post-Miocene shale members in well BB-80. The data obtained are illustrated in bar

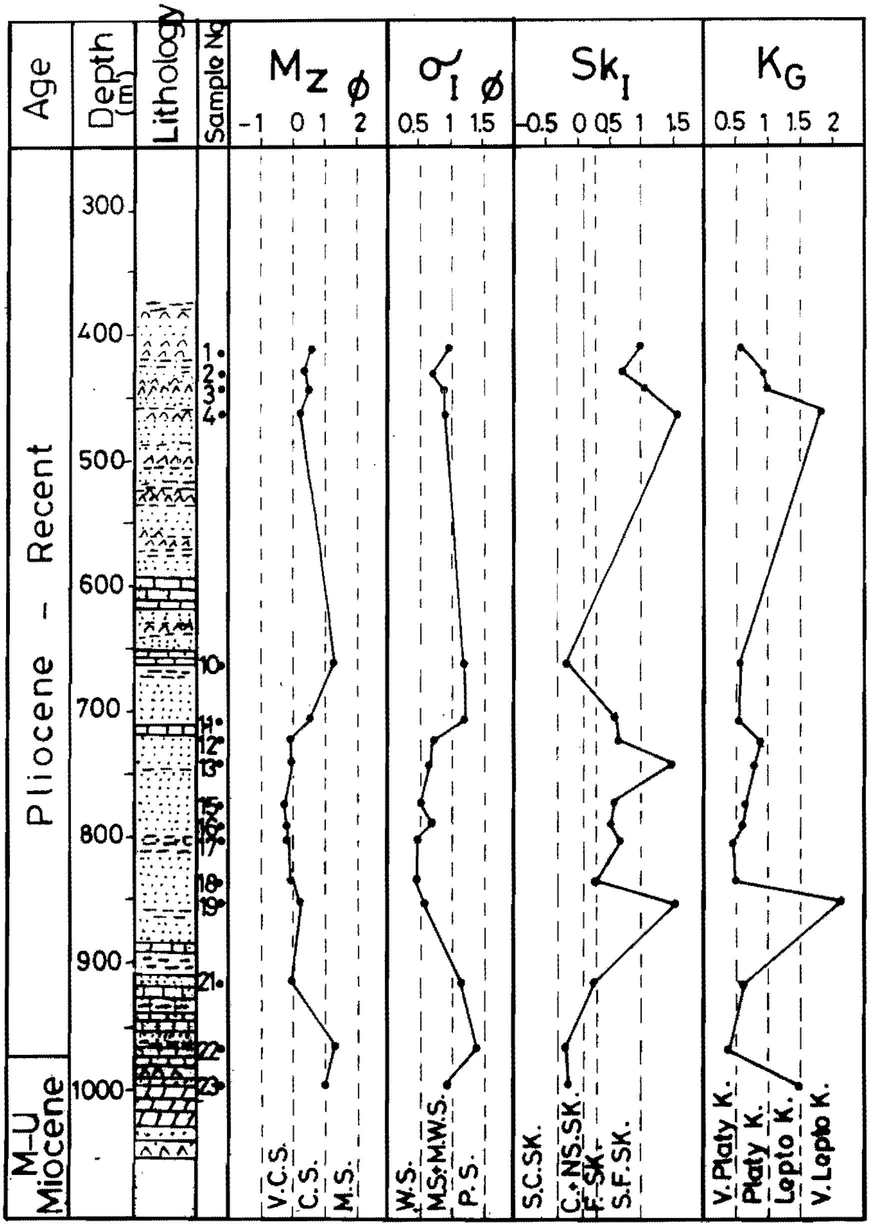


FIG. 5. Stratigraphic variation of graphic grain size parameters of Folk and Ward (1957) for Post-Miocene sand in Gulf of Suez (Well BB-80).

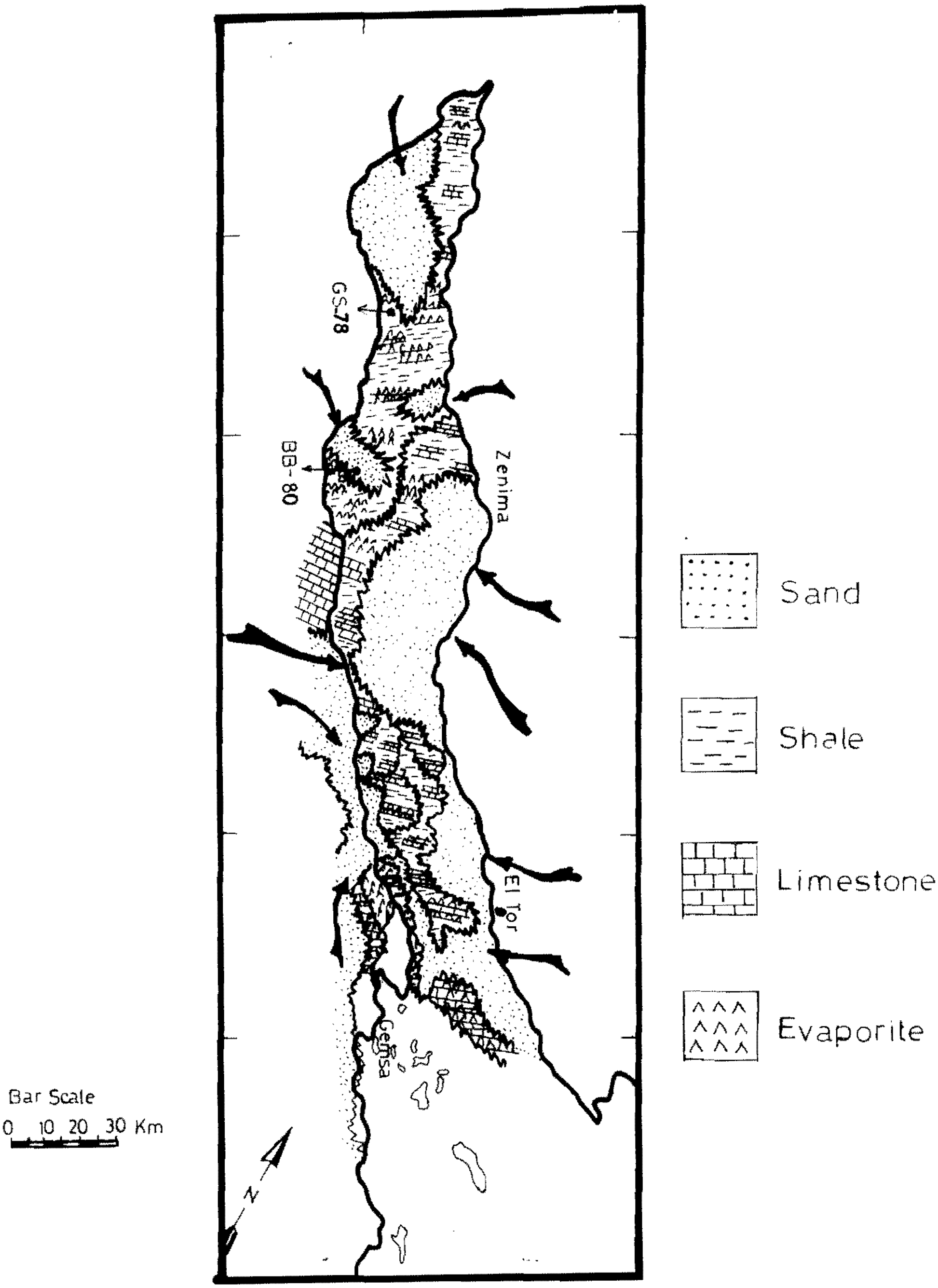


FIG. 6. Post-Miocene sediments facies map (after Fawzy and Abdel Aal 1984).

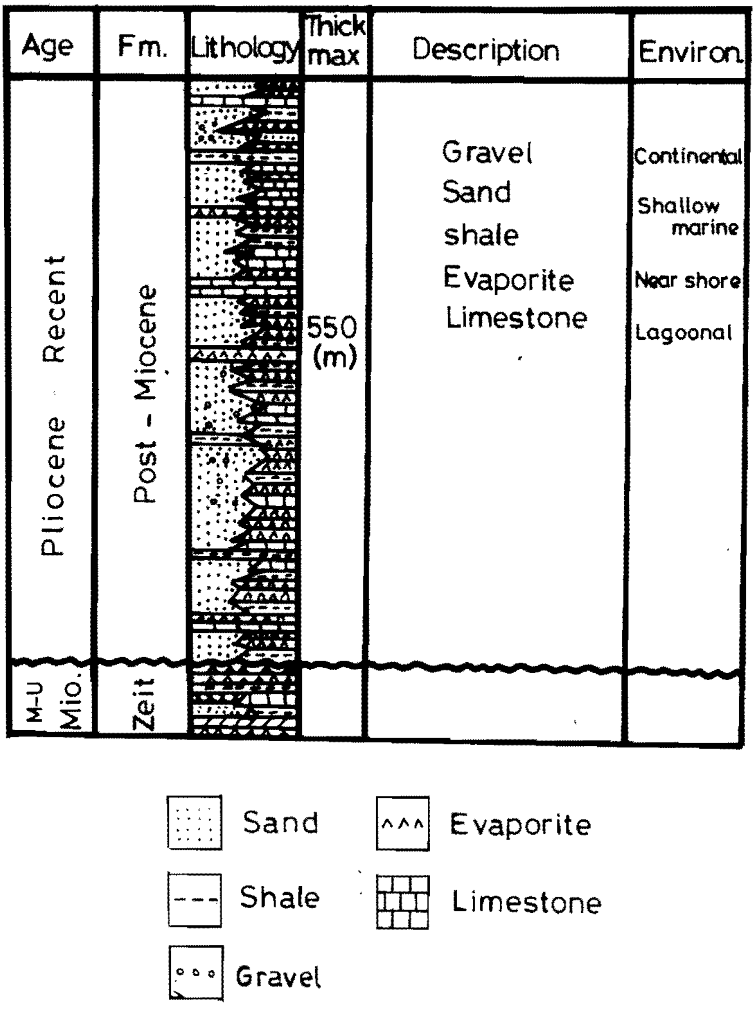


FIG. 7. Generalized litho-stratigraphy of Post-Miocene in the Gulf of Suez.

diagrams representing the clay mineral composition. These bars simply serve to give a visual aspects of the changes in the relative frequency of the identified clay minerals (Fig. 9).

In general kaolinite is the dominant constituent recorded in the top part of the Post Miocene sequence. Montmorillonite and illite occur in subordinate amount. With increasing depth, montmorillonite predominates on the expense of kaolinite in the bottom part of the sequence.

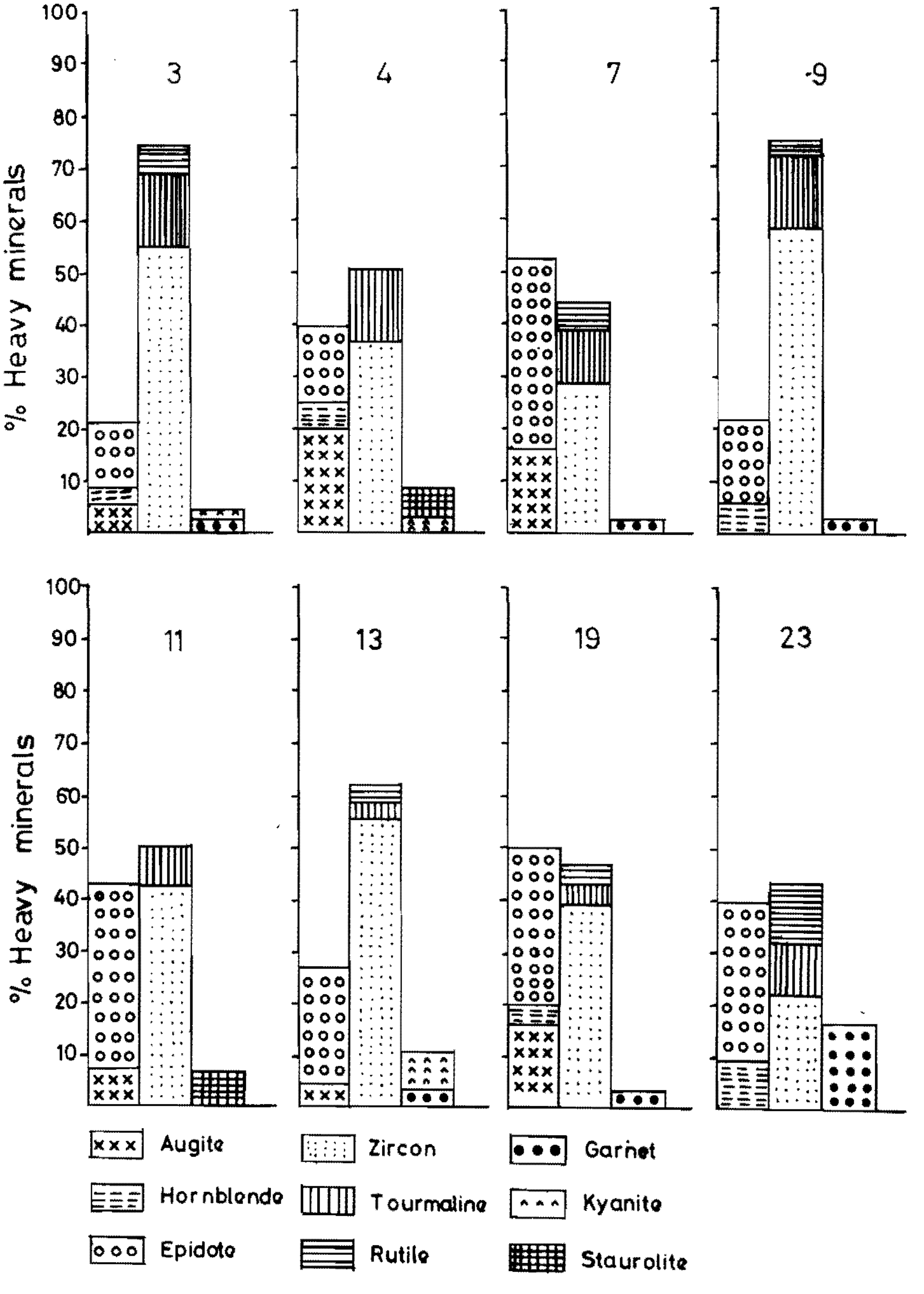


FIG. 8. Histograms showing the relative percentage of heavy minerals in Post-Miocene sand of Gulf of Suez (Well BB-80).

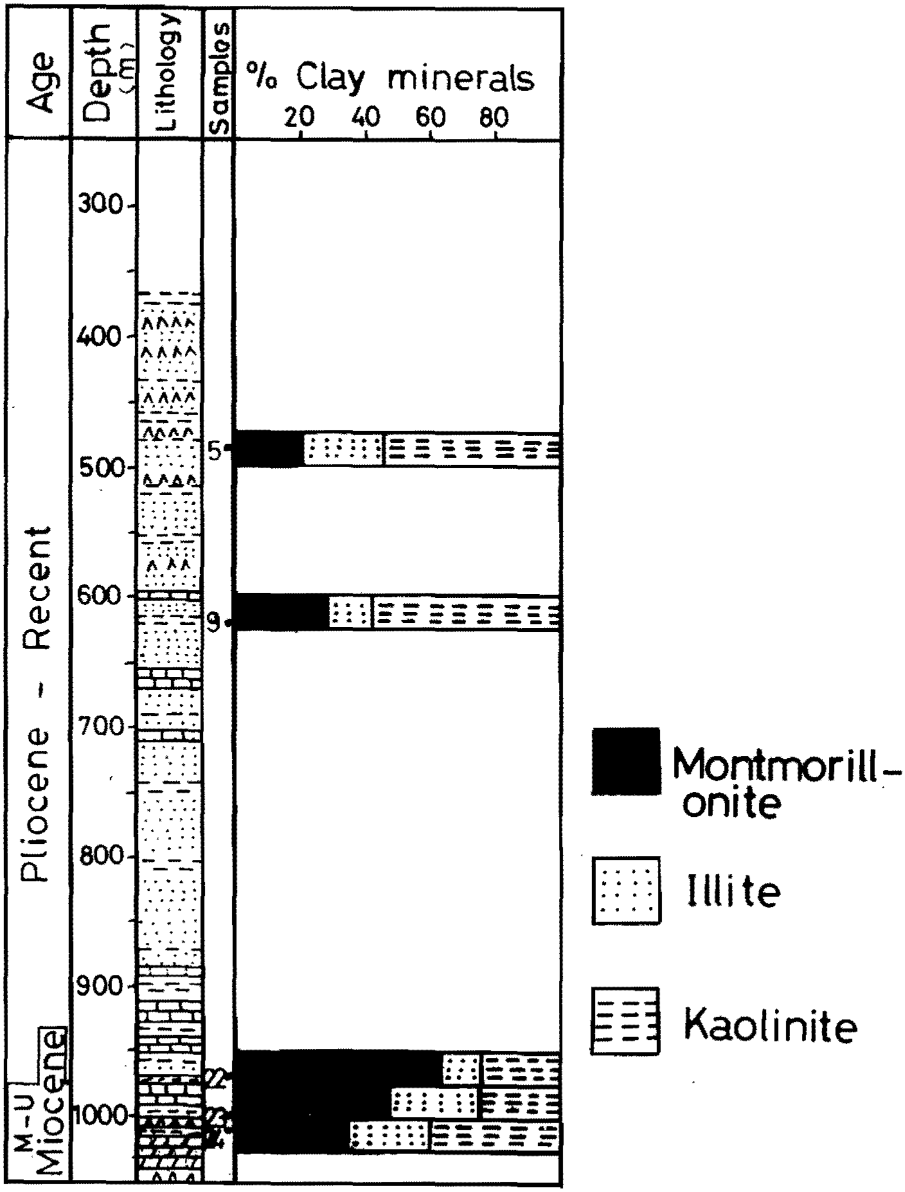


FIG. 9. Stratigraphic variation of clay minerals for Post-Miocene shale in Gulf of Suez (Well BB-80).

Kaolinite is produced by weathering during soil formation under strong leaching condition in continental and marsh environment (Millot 1962 and 1970), while montmorillonite is deposited under marine conditions.

Kaolinite is abundant in the Paleozoic to Pre-Cenomanian mudrocks favoured by the prevalence of humid and warm climate on a peneplained continental cratonic shelf (Gindy and Samuel 1978). Kaolinite is generally not affected by transportation so that when it enters the basin of deposition, its composition and amount remain the same (Perrin 1971).

Illite among the constituents in the Carboniferous to Cretaceous mudrocks in the Gulf of Suez area is due to the tectonic unstability (Gindy and Samuel 1978).

Bulk Mineralogy and Geochemistry

The detailed mineralogical data obtained from X-ray analysis of the rock powdered material are summarized in Table 1. The most common minerals documented in Post Miocene sediments are anhydrite, gypsum, calcite and dolomite occurring in different varying amounts. Among the less common minerals are feldspar and quartz.

Complete chemical analysis of major constituents *i.e.*, SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, MnO and P_2O_5 as well as of some important trace elements like Ba, Zr, Sr, Rb, Cr, Ni, and Zn were performed for 11 cutting samples of Post Miocene age. The present geochemical study shed light on the environmental conditions that prevailed during the deposition of the Post-Miocene sedimentary sequence and the distribution of mineral-forming elements.

The stratigraphic variation in mineralogical and chemical composition of Post-Miocene sediments in the Gulf of Suez is given in Fig. 10 and 11.

Evaporites (anhydrite and gypsum) are the main components encountered in the Post Miocene deposits. A peculiar variation of both minerals with depth was noticed. While gypsum increases upward, anhydrite seems to increase downward in the two studied wells (Table 1). Both gypsum and anhydrite may be precipitated subaqueously in shallow and deep water and subaerially in coastal sabkhas (Tucker 1986). It is concluded that on deep burial all $CaSO_4$ is present as anhydrite. The formation of anhydrite requires an arid climate with high temperature. When the climate is less arid gypsum may develops within the sediments. Moreover gypsum can be formed by the secondary hydration of primary anhydrite of evaporite sediment. Furthermore, a marked cyclic repetition of evaporite member can be noticed reflecting stages in the restriction of the sea.

Carbonates (calcite and dolomite) are the second dominant component in Post-Miocene deposits. Generally calcite seems to decrease while dolomite increases with increasing depth (Table 1). Dolomitization of carbonate is associated with gypsum precipitation as seen in well GS-78 where calcium ion releases for gypsum formation.

Detrial quartz and feldspar are common only in Post-Miocene sequence of well BB-80, while they are scarce in well GS-78. It is noticed that where evaporite decreases carbonate and detrital components increase (Fig. 10 and 11).

Regarding the chemical composition of Post-Miocene sediments in the Gulf of

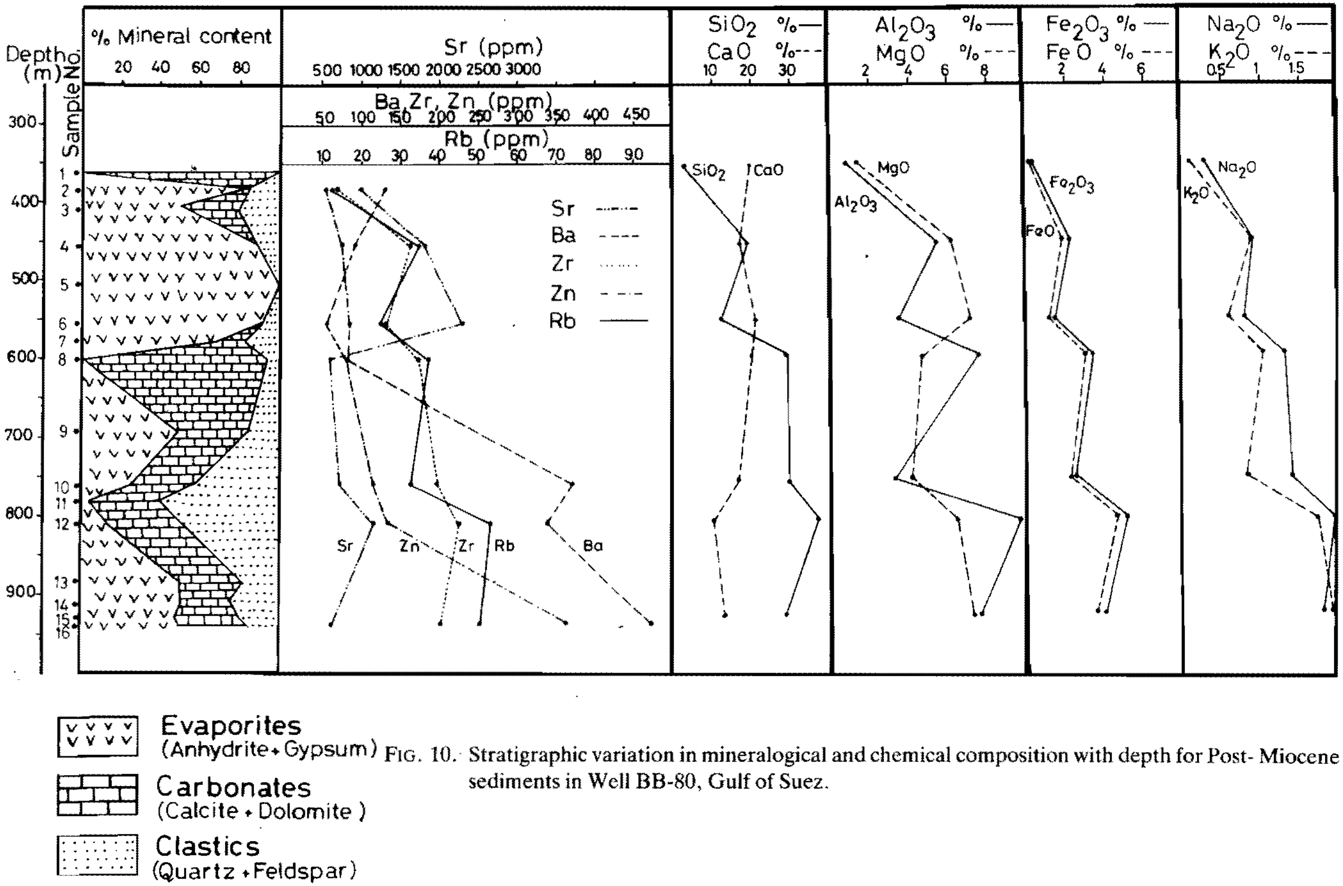


FIG. 10. Stratigraphic variation in mineralogical and chemical composition with depth for Post- Miocene sediments in Well BB-80, Gulf of Suez.

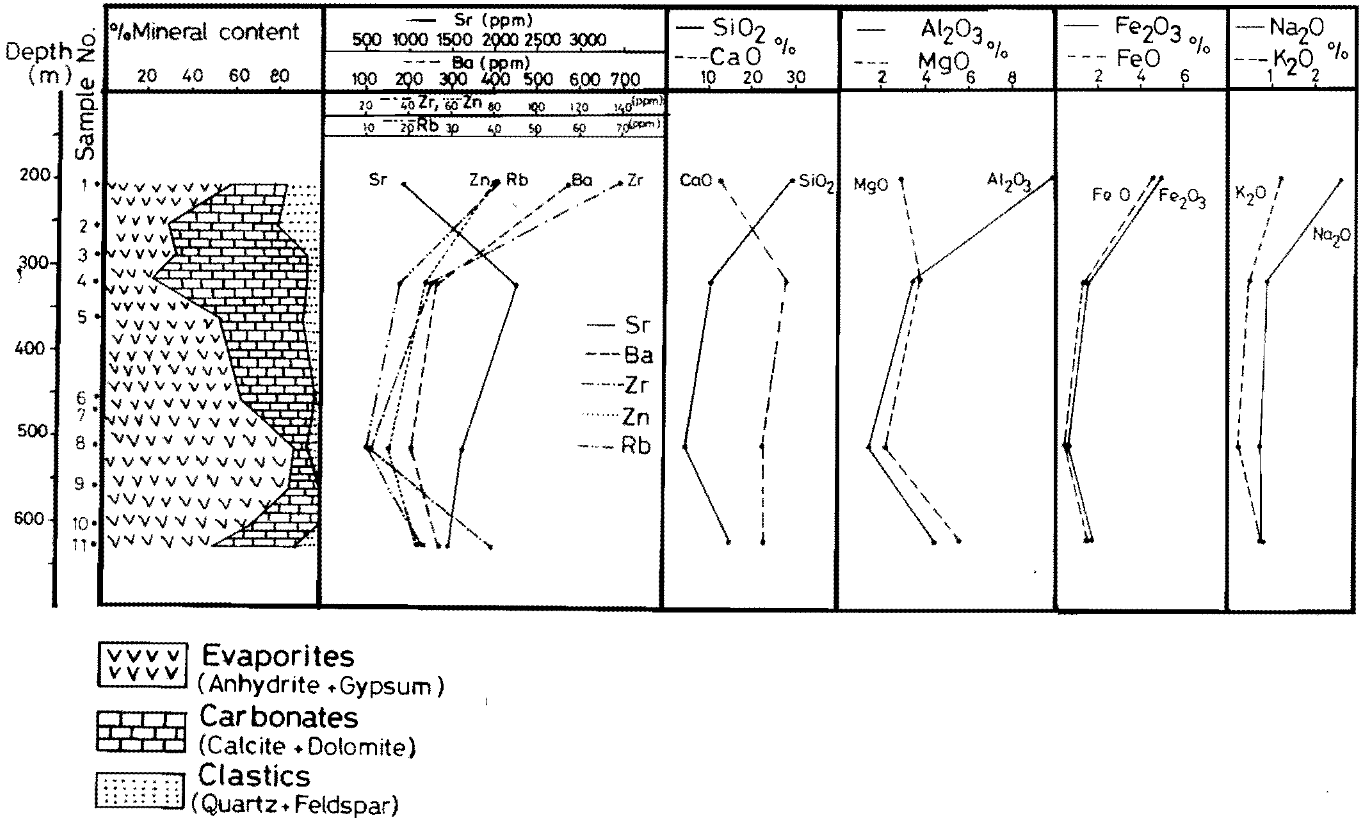


FIG. 11. Stratigraphic variation in mineralogical and chemical composition with depth for Post- Miocene sediments in Well GS-78, Gulf of Suez.

TABLE 1. Bulk mineralogy of the Post-Miocene subsurface sediments in the Gulf of Suez.

No.	Depth (m)	Anhydrite	Gypsum	Calcite	Dolomite	Quartz	Feldspar
Well	BB-80						
1	360	–	–	100	–	–	–
2	384	–	85	–	–	15	–
3	408	–	50	30	–	20	–
4	456	61	28	–	–	11	tr.
5	504	90	10	–	–	–	–
6	552	59	32	–	–	9	–
7	576	46	22	14	–	18	–
8	600	–	–	53	40	7	–
9	690	43	5	13	23	16	–
10	762	26	–	10	21	43	–
11	786	3	–	3	34	55	5
12	810	13	–	4	34	34	15
13	882	50	–	–	31	19	–
14	912	50	–	–	25	25	tr.
15	927	47	–	–	32	21	tr.
16	936	48	–	4	32	16	–
Well	GS-78						
1	207	–	58	16	10	8	8
2	255	–	30	12	37	6	15
3	291	–	33	40	20	7	–
4	321	–	22	52	19	7	–
5	366	–	53	11	27	9	–
6	459	33	30	12	22	3	–

TABLE 1. (continued)

7	471	54	15	6	22	3	–
8	513	76	12	6	6	–	–
9	561	86	–	–	14	–	–
10	606	59	10	8	23	–	–
11	630	41	10	6	32	11	–

Suez given in Table 2 and represented graphically in Fig. 10 and 11, the following observations are given :

1. In general, the Post-Miocene sediments are enriched with CaO and MgO indicating their enrichment in carbonates and evaporites. However, the antipathetic behaviour between CaO and MgO is attributed to dolomitization processes (Brand and Veizer 1980).
2. CaO and MgO content exhibits similar variation to Sr in well GS-78 (Fig. 11).

TABLE 2. Chemical composition of Post-Miocene sediments.

Well name	Well BB-80							Well GS-78			
Sample no.	2	4	6	8	10	12	16	1	4	8	11
Depth (m)	384	456	552	600	762	810	936	207	321	513	630
Oxides											
SiO_2	3.70	19.60	12.80	29.60	29.90	37.30	29.00	29.50	10.30	3.90	14.20
TiO_2	0.06	0.36	00.22	0.57	0.43	0.73	0.54	0.71	0.19	0.06	0.24
Al_2O_3	1.00	5.60	3.60	7.60	5.40	9.80	7.70	10.30	3.40	1.30	4.20
Fe_2O_3	041	2.32	1.46	3.38	2.72	5.09	4.04	4.96	1.45	0.46	1.55
MgO	1.40	6.20	7.20	4.70	4.20	6.50	7.30	2.80	3.70	1.90	5.50
CaO	20.74	18.64	21.12	20.37	17.12	10.54	14.06	13.31	27.99	22.35	21.99
Na_2O	0.30	0.90	0.80	1.30	1.40	2.20	1.80	2.60	0.90	0.70	0.80
K_2O	0.11	0.92	0.58	0.99	0.84	1.68	1.94	1.17	0.47	0.19	0.78
MnO	0.00	0.02	0.02	0.03	0.04	0.23	0.28	0.07	0.02	0.00	0.02
FeO	0.37	2.09	1.32	3.05	2.44	4.58	3.64	4.46	1.31	0.42	1.40
P_2O_5	0.02	0.10	0.09	0.10	0.07	0.19	0.21	0.16	0.08	0.03	0.12
Element											
Ba ppm	107	66	30	57	350	266	450	575	262	210	218
Sr	741	1567	2089	387	488	914	390	939	2281	1654	1470
Zr	44	144	105	150	171	229	177	139	51	23	79
Rb	8	30	20	32	28	49	46	40	18	110	24
Cr	25	54	40	71	63	90	73	91	57	43	82
Ni	44	62	22	77	208	99	40	57	11	15	34
Zn	32	51	59	58	90	113	342	80	50	32	49

Note: CO_3, SO_4 and H_2O are not determined.

3. Al_2O_3 content shows general opposite variation with MgO, while it exhibits similar variation with Rb. It is known that Al_2O_3 is encountered in feldspar and the matrix, while MgO is encountered in dolomite.

4. Sr exhibits similar variation with evaporite mineral components. The entrance of strontium into the minerals of marine salt sediments seem to be regulated by the calcium content of the evaporite minerals. During crystallization from these aqueous solution Sr replaces exclusively the calcium ions. The high concentrations of Sr in some samples (samples no. 4 and 6 in well BB-80 and samples no. 4, 8 and 11 in well GS-78) may be due to the formation of secondary anhydrous strontium sulphate (celestite). It may be released due to formation of gypsum by the secondary hydration of the primary anhydrite of evaporite sediments which was unable to retain the full strontium content of anhydrite (Goldschmidt 1954).

5. Ba, Rb, Zr and Zn show weak variation with the detritus material (quartz and feldspar, Fig. 10).

6. Fe_2O_3 and FeO exhibit similar variation like K_2O and Na_2O and all of them increase with increasing depth reflecting association with the detrital influx. However, iron oxides may be precipitated by evaporation or oxidation. While Na_2O may be encountered in the form of soluble salts and/or constituents in the clay minerals as well as feldspar. Furthermore, Na_2O and K_2O show nearly parallel trend and comparable results.

In the light of the above mentioned general discussion it could be stated that during the Post-Miocene sedimentation in the Gulf of Suez repeated subsidence took place for some blocks (at the site of well BB-80 and the Pliocene-Recent movements must have been strong enough to produce temporary flooding providing the basin of deposition with the detrital influx. However, a restricted lagoonal or high evaporitic condition prevailed in other localities (at the site of well GS-78).

The configuration of the basin of deposition is greatly affected by tectonism. The study of the sediments enables the construction of depositional environments and paleogeographical condition of the Gulf of Suez basin during the Pliocene and Recent times.

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العمليات الترسيبية لرواسب مافوق الميوسين في خليج السويس بمصر

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و قسم الجيولوجيا ، كلية العلوم ، جامعة المنصورة ، مصــر

المستخلص . يهدف البحث إلى دراسة مقارنة الرواسب التي تقع فوق الميوسين (البليوسين والبليستوسين) لبئرين عميقين حفرا في الجزء الشمالي من خليج السويس . وقد لوحظ تغير التركيب الصخري والسمك من مكان لآخر .

تم تحليل بعض العينات الفتاتية المختارة من القطاعين فوق الميوسين حيث تم تحليلهم معدنيًا (٢٧ عينة) وكيميائيًا (١١ عينة) باستخدام جهازي الأشعة السينية وأشعة الفلورسنت كما فحصت المعادن تحت الميكروسكوب .

تميزت رواسب فوق الميوسين في شمال الخليج بسحنتين مختلفتين إحداهما فتاتية والأخرى كيميائية . السحنة الفتاتية عبارة عن طبقات متبادلة من الرمل والحصى والطين دفعت إلى الخليج على شكل أنهار مروحية حيث كان الترسيب سريع في أحواض الفوالق الصغيرة النشطة ، أما السحنة الكيميائية فهي تتكون من المتبخرات ممثلة في معدني الانهيدريت والجبس والحجر الجيري الذي يشمل معدني الكالسيت والدولوميت .

ودلت الدراسة الكيميائية على أن السحنة الكيميائية تتميز بأنها غنية في أكسيد الكالسيوم وأكسيد الماغنسيوم وعنصر الاسترانشيوم ، حيث لوحظ أن تركيز عنصر الاسترانشيوم يصاحب تركيز معادن الكبريتات مما يدل على ترسيب بحري وأحيانًا سبخات شاطئية ، حيث لا توجد حفريات تقاوم درجة الملوحة العالية ، بينما تركزت عناصر الباريوم ، الزيركونيوم ، الروبيديوم ، الكروم ، النيكل والزنك في المكونات الفتاتية المنقولة .