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Mineralogy and geochemistry of the Late Cretaceous–Early Tertiary sediments in southwestern Egypt

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ABSTRACT

The Late Cretaceous–Early Tertiary sediments exposed at Bir Murr, Bir Kiseiba and Gabal Bargat El Shab in the southern part of the Western Desert of Egypt have been studied. Algal lime wackestones and foraminiferal packstones are the dominant lithofacies encountered in the Kurkur and Dungal Formations, respectively. These shallow marine carbonates are composed almost entirely of low-Mg calcite. They are characterized by low Mg, Na and Sr contents and high Ca and Fe contents.

Montmorillonite, kaolinite, illite and illite-montmorillonite mixed layer are the major clay minerals detected in the shales of the Dakhla and Garra Formations. Chlorite, palygorskite and glauconite are rare. The non-clay minerals include quartz, potassium feldspar, calcite, gypsum and anhydrite. Most trace elements are associated with detrital material and their abundance is mainly controlled by the distribution of carbonates, clay minerals and iron oxides.

INTRODUCTION

In the last few years, several articles have been published on the general geology and stratigraphy of the southern part of the Western Desert (e.g. Klitzsch 1983, 1984 & 1987; Dominik 1985; Hendriks 1987). However, little is known about the mineralogical and geochemical composition of the exposed sediments. Heavy minerals in the Campanian–Early Tertiary sediments of the Dakhla Oasis were studied by Fay & Herrmann-Degen (1984), and clay mineral assemblages of the same interval were investigated in the Kharga Oasis (Hendriks 1985).

The study area lies on the southeastern part of the Dakhla Basin (Fig. 1), accessible along the ancient caravan route of the "Darb El-Arbain". In the absence of previous mineralogical and geochemical studies, the authors decided to investigate the distribution of the major and trace elements (Ba, Cr, Ni, Zn, Rb, Sr, Y, Zr & Nb) as well as the clay and non-clay minerals.

Two sections were measured and sampled in detail along Darb El-Arbain at Bir Kiseiba and Bir Murr. A third section was collected from Gabal Bargat El Shab, near the Sudanese border (Fig. 1). Thirty-six argillaceous and calcareous samples from Maastrichtian-Eocene rock units were included in the analyses. X-ray diffraction was used for bulk sample composition, while clay minerals were examined separately from oriented mounts containing the -2 μm fraction; these specimens

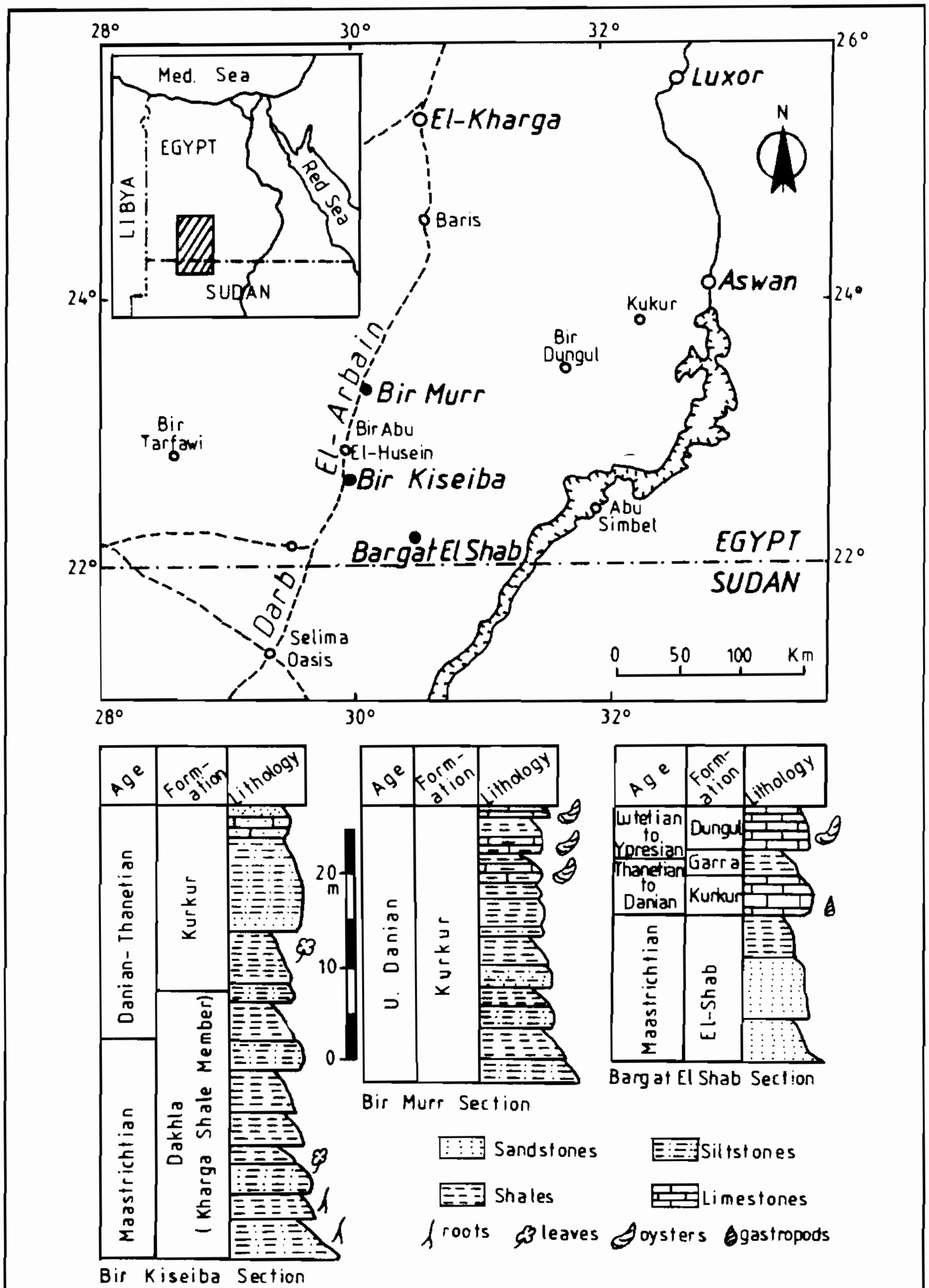

Fig. 1. Location and lithostratigraphy of the sections studied.

were air dried after glycolation and heating to 550°C. Pre-treatment was avoided. The relative proportions of the various minerals were estimated semiquantitatively according to a modified method of Thorez (1976). Major and trace elements were determined in twenty-five bulk samples using X-ray fluorescence. The average mineralogical and chemical composition of the studied sediments is given in Tables 1–3, and the stratigraphic distribution of some of their components is illustrated in Figs 2 and 3.

LITHOSTRATIGRAPHY

The study area was mapped by Issawi (1971) who classified its Maastrichtian-Eocene sedimentary succession into four rock units, namely: Dungul Formation (L. Eocene), Garra Formation (L. Eocene–U. Paleocene), Kurkur Formation (Paleocene) and Dakhla Formation (Maastrichtian–L. Paleocene). This shale-marl-limestone sequence (Fig. 1) overlies a sandstone-siltstone sequence of the Nubia Formation. Klitzsch & Lejal-Nicol (1984) introduced the name Kiseiba Formation instead of Issawi's Nubia Formation in this particular area, a usage subsequently followed by other German workers.

THE DAKHLA FORMATION

About 30 m of this rock unit is exposed along the measured section at Bir Kiseiba and is represented by shales alternating with siltstones. The shales are light to dark-gray, fissile and silty. The basal beds are rich in ferruginous root relics and angiosperm leaves. *Haplophragmoides* sp. and other arenaceous foraminifera have been identified from this unit (Kora *et al.* 1988).

THE KURKUR FORMATION

This unit overlies the Dakhla Formation and is characterized by a succession of silty shales interbedded with fossiliferous limestones. Its thickness is about 35 m to the north of Bir Murr but decreases southwards. It contains three different lithofacies. The oldest comprises carbonaceous silty shales, while the middle facies is a glauconitic coquinoid marl, partly phosphatic, and containing oysters and other bivalve shell debris. The youngest facies is an algal lime wackestone lithofacies which forms the plateau surface north and east of Bir Murr. It includes many reddish brown calcareous algae, recrystallized bivalve shell fragments, glauconite-replacing fossils, cavity-filling calcite and rare corroded quartz grains.

THE GARRA FORMATION

This unit comprises a single, 4 m thick bed of gray, fissile gypsiferous shale, which outcrops at Gabal Bargat El Shab. It underlies the Dungul Formation and contains few benthic and rare planktonic foraminifera.

THE DUNGUL FORMATION

This formation is represented by a white, hard limestone bed (5 m thick) exposed on top of Gabal Bargat El Shab. This part of the Dungul succession is characterized by a foraminiferal packstone lithofacies. Larger foraminifers including *Operculina* sp., *Discocyclina* sp., *Assilina* sp. and *Nummulites* sp. as well as some ostracod carapaces compose the main framework. Recrystallization has affected many of the fossils and parts of the microcrystalline calcite matrix.

LIMESTONES

Carbonate rocks are confined to the Kurkur and Dungul Formations in the sections of Darb El-Arbain area. Their HCl-insoluble residue is about 20% on average. X-ray examination showed these limestones to be composed almost entirely of low-Mg calcite. A shallow marine environment of deposition is suggested by the occurrence of algal biomicrosparite and foraminiferal biomicrite facies. The most common diagenetic features observed are recrystallization and internal filling. These rocks contain high calcium and low magnesium contents (Table 1). Consequently the Ca/Mg ratio of the analysed limestones is very high (about 179, compared with 6·43 for the average world limestone (Turekian & Wedepohl 1961)). These limestones are also characterized by low content of Si, Al, Mn, K and Ti, possibly due to a lower content of clayey and terrigenous materials compared with the world average.

The average Na content recorded by us (80 ppm) is much lower than the world average (400 ppm). This reflects the low salinity of the depositional environment, since Na distribution in carbonate rocks is mainly controlled by this factor (El Hinnawi & Loukina 1971). The percentage of iron is generally high in the limestones compared with world average and they contain higher contents of Ba, Cr, Zn,

Table 1. Average major and trace elements of the limestones studied compared with that for world limestone

	Darb El-Arbain (Present work)	World limestone (Turekian & Wedepohl 1961)
(%)		
SiO_2	1·48	5·14
Al_2O_3	0·54	0·79
Fe_2O_3	1·28	0·54
MgO	0·34	7·79
CaO	51·10	42·30
Na_2O	0·01	0·05
K_2O	0·09	0·65
MnO	0·12	0·14
TiO_2	0·05	0·07
P_2O_5	0·25	0·18
(ppm)		
Ba	21	10
Cr	18	11
Ni	8	20
Zn	53	20
Rb	10	3
Sr	270	610
Y	17	30
Zr	21	19
Nb	3	0·3

Rb, Zr and Nb, and lower contents of Ni, Sr and Y (Table 1). These differences are due to the fact that the abundance of minor elements in carbonate rocks depends particularly on the presence of non-carbonate materials (Graf 1962).

Sr content in the Early Tertiary limestones (Table 1 and Fig. 2) is in harmony with values for ancient carbonates, which are generally less than 500 ppm. However, the average Sr content reported here (270 ppm) is generally lower than that of the

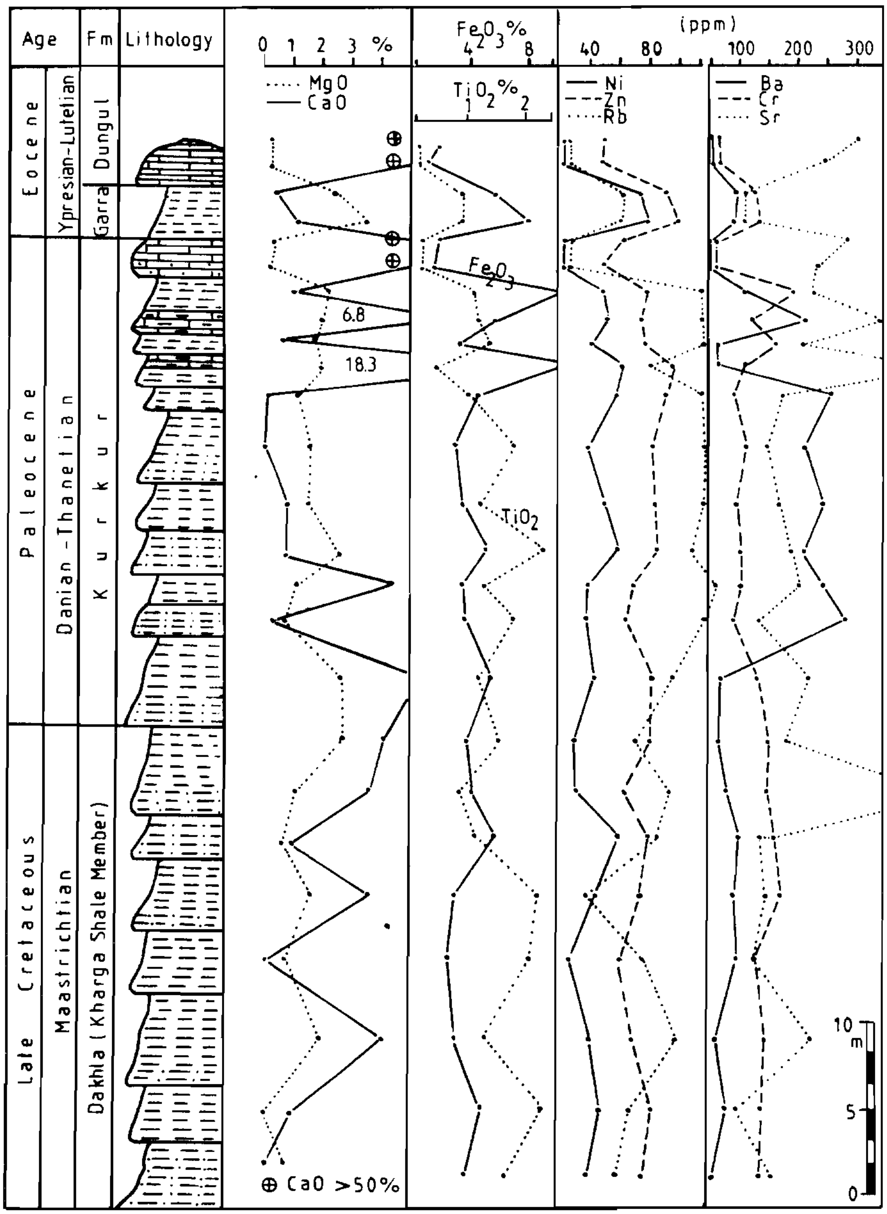

Fig. 2. Distribution of some elements in the succession.

Table 2. Average mineralogical composition of the shales studied

	(a) Clay minerals %				
	Montmoril.	Kaolin.	Illite	Illite-Mont.	Illite/Kaolin.
Garra Formation:	58	24	11	6	0·45
Kurkur Formation:	40	29	8	15	0·46
Dakhla Formation:	15	54	16	14	0·33
	(b) Non-clay minerals				
	Quartz	Feldspars	Calcite	Gypsum	Anhydrite
Garra Formation:	40	13	00	22	25
Kurkur Formation:	48	15	13	9	13
Dakhla Formation:	61	13	00	7	15

world average (610 ppm) given by Turekian & Wedepohl (1961) and lower than that of other Egyptian carbonates (1960 ppm) recorded by El Hinnawi & Loukina (1972). This is attributed not only to the complete absence of celestite, calciostrontianite and aragonite which are the main host minerals of Sr, but also to the diagenetic alteration of the studied limestones.

SHALES

Quartz, K-feldspar, gypsum and anhydrite are the main non-clay minerals encountered. Calcite, goethite and halite are found in some samples. Quartz is most common in the shales of the Dakhla Formation, whereas gypsum and anhydrite contents are relatively high in the Garra Formation and calcite is detected only from the Kurkur Formation (Table 2).

The clay minerals identified in the shales are predominantly montmorillonite and kaolinite, which together constitute about 70% of the clay fractions examined (Table 2). Stratigraphically, a general downward decrease in montmorillonite is compensated by an increase of kaolinite (Fig. 3). Illite and illite-montmorillonite mixed layer (IM) are found in small amounts and show a tendency to increase downwards. Chlorite, glauconite and palygorskite are relatively rare and restricted to the upper part of the Kurkur Formation. Similar clay mineral assemblage was recorded in the Late Cretaceous–Early Tertiary shales exposed in both the Kharga Oasis in southern Egypt (Hendriks 1985) and the Abyad Basin in northern Sudan (Barazi 1985).

The vertical distribution of major elements indicates enrichment of Si, Al, Na and Ti in the Dakhla Formation, of Ca, Mn and P in the Kutkur Formation, and of Fe, Mg and K in the Garra Formation (Fig. 2). This is a reflection of the vertical variations of carbonate, sand and mud contents as well as the mineralogical composition of the shales.

Compared with the world average (Table 3), the shales studied generally contain low Fe, Mg, Na, K and P values. This possibly points to the higher percentages of montmorillonite, illite and chlorite minerals in the world shales. Mn is mainly associated with both iron and carbonate contents, as indicated by their significant positive correlation ($r = +0{\cdot}85$ and $+0{\cdot}67$, respectively). Ti content in the shales is

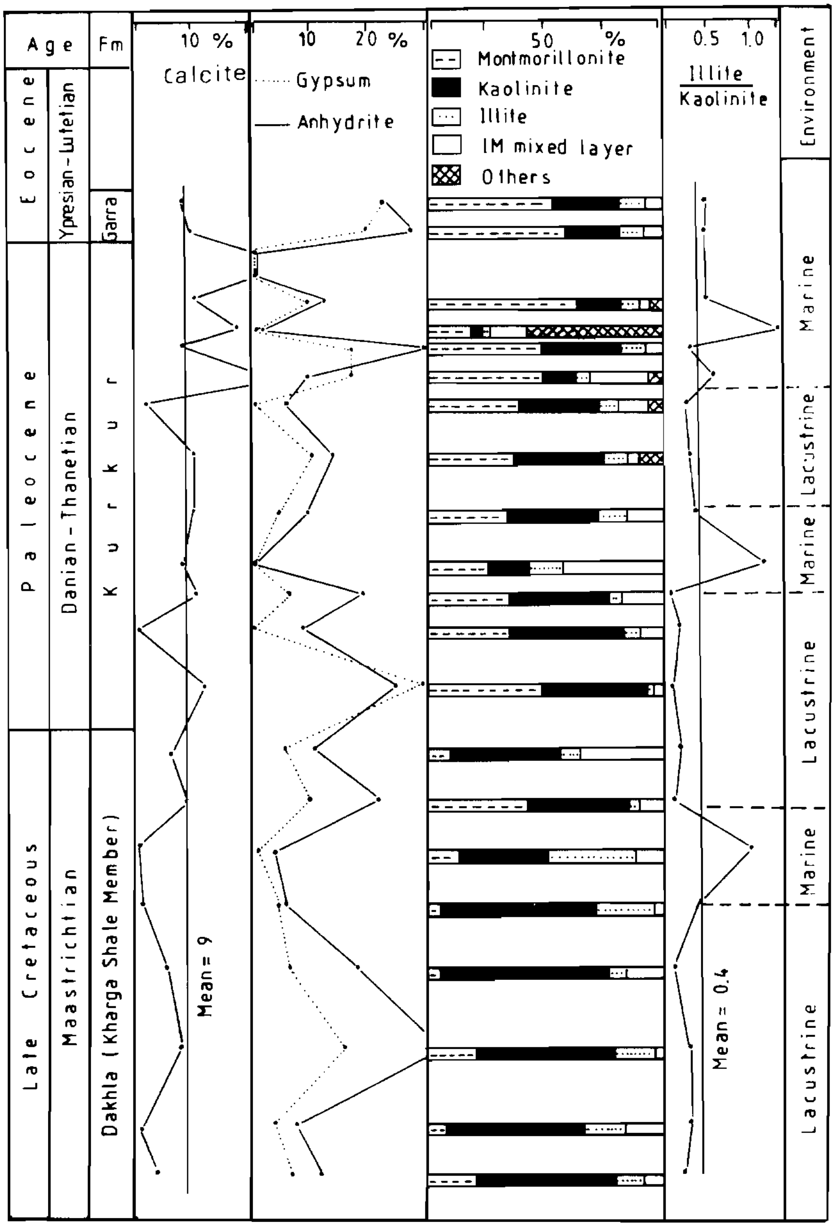

Fig. 3. Vertical distribution of some minerals in the shales.

higher than the world average. The strong positive correlation between Ti and quartz ($r = +0{\cdot}76$) points to the partial occurrence of Ti as a separate mineral phase. Ti is probably also associated with kaolinite as indicated by their significant correlation ($r = +0{\cdot}57$).

The stratigraphic distribution of trace elements (Fig. 2) demonstrates that shales of the Dakhla and Kurkur Formations contain higher amounts of Cr, Zr, Ba, Nb,

Table 3. Average content of major and trace elements in the shales studied compared with that for world shale

	Darb El-Arbain (Present work)	World shale (Turekian & Wedepohl 1961)
(%)		
SiO_2	56·90	15·60
Al_2O_3	16·80	15·05
Fe_2O_3	4·90	6·71
MgO	1·82	2·48
CaO	3·03	3·11
Na_2O	0·77	1·20
K_2O	1·31	3·13
MnO	0·12	0·11
TiO_2	1·36	0·77
P_2O_5	0·19	0·32
(ppm)		
Ba	129	580
Cr	136	90
Ni	49	68
Zn	81	95
Rb	99	140
Sr	213	300
Y	35	26
Zr	413	160
Nb	26	11

Rb, Sr and Y. The Garra Formation seems to be enriched in Ni and Zn. The strong element-mineral correlations indicate that most trace elements entered the depositional basin in close association with the detrital minerals. Therefore, vertical variation in trace elements along the studied section is mainly due to differences in source materials. Our comparisons with the average for world shale (Table 3) point to the high contents of Cr, Y, Zr and Nb in the shales examined. Ba, Ni, Zn, Rb and Sr show relatively lower concentrations than the average for world shale, due in part to differences in clay mineral constituents, since each clay mineral has a characteristic adsorption pattern (Cody 1971).

DISCUSSION

The occurrence of montmorillonite and kaolinite as the predominant clay constituents in most samples indicates diverse origins for the shales. The dominance of kaolinite in clays of the Dakhla Formation and lower part of the Kurkur Formation suggests that these sediments were derived largely from the acidic igneous rocks of the Red Sea Hills. On the other hand, the high frequency of montmorillonite in the upper part of Kurkur and Garra Formations suggests contribution from basic, ultrabasic and metamorphic rocks.

Correlations between clay minerals and environment of deposition have been made by several authors. Millot (1970) reported that kaolinite dominates in fluviolacustrine deposits where acid leaching is active. Weaver & Pollard (1973) pointed to the formation of illite and montmorillonite in river muds, whereas in marine mud the relative amount of illite increases and montmorillonite decreases. They further added that montmorillonite could alter to illite in a marine environment. It may be concluded that most sediments of the Dakhla Formation and lower part of the Kurkur Formation were deposited in fluviolacustrine environment, in which kaolinite exceeds montmorillonite. The argillaceous horizons of the Garra Formation and the upper part of the Kurkur Formation were deposited under more marine conditions, since montmorillonite exceeds kaolinite. This is also supported by the occurrence of chlorite and glauconite in the shales of the upper part of the Kurkur Formation.

Correlation between the mineralogical and chemical data shows that the distribution of trace elements in the argillaceous sediments is mainly controlled by the abundance of carbonates, quartz, clay minerals and iron oxides. Sr has a strong correlation with carbonate content ($r = +0{\cdot}75$), suggesting that the carbonate fraction is the main host in the shales. This is also evidenced by strong negative correlations between Sr and clay fractions ($r = -0{\cdot}69$) and between clay and quartz ($r = -0{\cdot}62$).

Ni and Zn show a significant positive correlation ($r = +0{\cdot}59$) with iron oxides. Such behaviour points to the detrital association of both elements in the shales. Ni and Zn also have a sympathetic relation with montmorillonite. Ba, Rb, Cr and Y show no significant relationship with any detrital materials, suggesting a possible authigenic control for these elements, which therefore cannot reflect the character of the depositional environment.

Zr exhibits a strong positive correlation with quartz content ($r = +0{\cdot}77$), indicating its partial occurrence in the resistate phase as zircon within quartz. It is also positively correlated with kaolinite ($r = +0{\cdot}53$). Nb relates to both kaolinite and quartz, as indicated by their correlations ($r = +0{\cdot}68$ and $+0{\cdot}57$). This behaviour points to the detrital association of both elements, and their abundance reflects the acidic nature of the source rocks.

CONCLUSIONS

The Late Cretaceous–Early Tertiary succession we studied is composed of silty shales alternating with limestones. Carbonate rocks are represented by algal and foraminiferal biomicrite lithofacies of the Kurkur and Dungul Formations, respectively. These limestones belong to the calcitic type and consist mainly of low-Mg calcite. They are believed to have been deposited in a shallow marine environment and contain very low Na and Sr, but very high Fe compared with world average limestone. Recrystallization is the main diagenetic alteration observed.

Montmorillonite and kaolinite are the dominant minerals identified in the shales of the Dakhla, Kurkur and Garra Formations, followed by illite and illite-montmorillonite mixed layer. The stratigraphic distribution of these detrital minerals is controlled by variations in the source rocks as well as the depositional environment. The ultimate source varied from acidic igneous rocks in the Late Cretaceous to basic and metamorphic rocks in the Early Tertiary. The depositional environment of the argillaceous horizons, based on the illite/kaolinite ratio, oscillated between lacustrine and marine.

Most trace elements are detritally associated and entered the depositional basin in close association with quartz, clay minerals and iron oxides. Calcite is the main host of Sr while Ni and Zn are related to the iron content. Zr and Nb are associated with both quartz and kaolinite. Rb, Cr and Y seem to be authigenic in origin.

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التركيب المعدني والجيوكيميائي لرسوبيات العصر الطباشيري المتأخر ـ الثلاثي المبكر في جنوب غرب مصر

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خلاصة

تمت دراسة رسوبيات نهاية العصر الطباشيري وباكورة العصر الثلاثي المتواجدة عند بئر مر وبئر كسيبه وجبل برقة الشب ، في جنوب صحراء مصر الغربية ، والتي تتكون أساسا من الطفلة المتبادلة مع الحجر الجيري . وتبين الدراسة أن صخور الحجر الجيري تتميز بـزيادة في كميـات الكالسيوم والحديد وانخفاض في مقادير الماغنسيوم والصوديـوم والاسترنشيـوم . كما أوضحت الدراسة أن معادن المونتموريللونايت والكاولينايت والإلاّيت هي المكونات الـرئيسية لصخـور الطفلة المنتشرة في المنطقة . وبالرغم من أن معظم العناصر الشحيحة في هذه الطفلة قد دخلت إلى بيئة الترسيب مصاحبة لمعادن الطين والكوارتز وأكاسيد الحديد إلا أن بعضها تكون داخل حوض الترسيب . وقد تبين أن ظروف ترسيب هذا التتابع تراوحت بين بيئة البحيرات الهادئة والبيئة البحرية الضحلة .