Mineralogy of the Upper Cretaceous–Lower Paleogene Successions at Esh El-Mellaha area, Gulf of Suez, Egypt

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Abstract

This study presents a comprehensive mineralogical analysis of the Upper Cretaceous–Lower Paleogene sedimentary successions in Esh El-Mellaha area, Gulf of Suez, Egypt. Utilizing X-ray diffraction (XRD), infrared spectroscopy (IR), and scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS), forty-two samples from the Sudr, Dib, Esna, and Thebes formations were examined to resolve previous inconsistencies in mineralogical interpretations. The results reveal that the Sudr and Dib formations are predominantly composed of calcite, suggesting deposition under stable, shallow marine conditions. The upper Sudr shows greater mineral variability, indicative of fluctuating environmental conditions. Esna Formation displays significant mineralogical heterogeneity, particularly in El-Dabbabyia Member near the Paleocene–Eocene boundary, reflecting complex depositional settings influenced by global climate shifts. Thebes Formation is marked by high calcite content with minor contributions from quartz, dolomite, gypsum, and phyllosilicates, pointing to a warm, carbonate-rich marine environment with limited terrigenous input. Infrared spectroscopy confirmed the presence of clay minerals such as smectite, kaolinite, and illite, supporting the XRD results and indicating varied sources and diagenetic alterations. These findings provide new insights into the mineralogical evolution, depositional environments, and diagenetic history of the region, contributing to a more refined stratigraphic and paleoenvironmental framework for northeastern Egypt.

Keywords: Esh El-Mellaha area; X-ray diffraction analysis; calcite; phyllosilicates.

Introduction

This study is part of the long-term, comprehensive program initiated by the Geology Department of the Faculty of Science at New Valley University, Egypt, which aims to achieve a detailed characterization of mineral compositions prevalent in various rock units distributed across different regions of Egypt. Specifically, this research focuses on identifying and quantifying these minerals found in the Upper Cretaceous-Lower Paleogene successions exposed in the Esh El-Mellaha area, Gulf of Suez, Egypt. The primary objective of this investigation is to address inconsistencies in the interpretation of the components of these rock units, as highlighted in previous studies **[1 - 7]**. Many of these earlier studies were conducted in the past decades when advanced techniques, now providing critical insights, were not yet available. Thus, this study is designed with the following aims: 1) to precisely characterize and quantify the bulk mineralogy of these sediments, 2) to identify the mineral phases present, 3) to determine the physico-chemical properties of these phases, and 4) to correlate these findings with the paleoenvironments, climatic conditions, and diagenetic processes under which these sediments were formed and subsequently altered.

Geological setting

The Upper Cretaceous-Lower Paleogene sequences in the Esh El-Mellaha area are situated to the west of the Gulf of Suez in the northern part of the Eastern Desert, forming a half-graben structure between two Precambrian (basement) fault blocks **(Fig.1).** The Esh El-Mellaha area is geographically located between latitudes 27° 24' and 27° 49' North, and longitudes 33° 11' and 33° 40' East. The Upper Cretaceous-Lower Paleogene rock formations extend as an elongated range in a northwest-southeast direction, spanning approximately 80 km in length. The surface geology of the region has been the subject of numerous studies since the early 20th century, with significant contributions from researchers such as References **(e.g. [8 - 25]**. These investigations have addressed a wide range of lithostratigraphical, biostratigraphical, palaeontological,

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mineralogical, and structural aspects of the area. Based on the recent stratigraphic analysis by El-Mohandes *et al* **[26],** the following stratigraphic units are identified in the Esh El-Mellaha area **(Figs. 2 and 3):** Thebes Formation (Lower Eocene), Esna Formation (Upper Paleocene-Lower Eocene), Dib Formation (Danian), and Sudr Formation (Upper Maastrichtian).

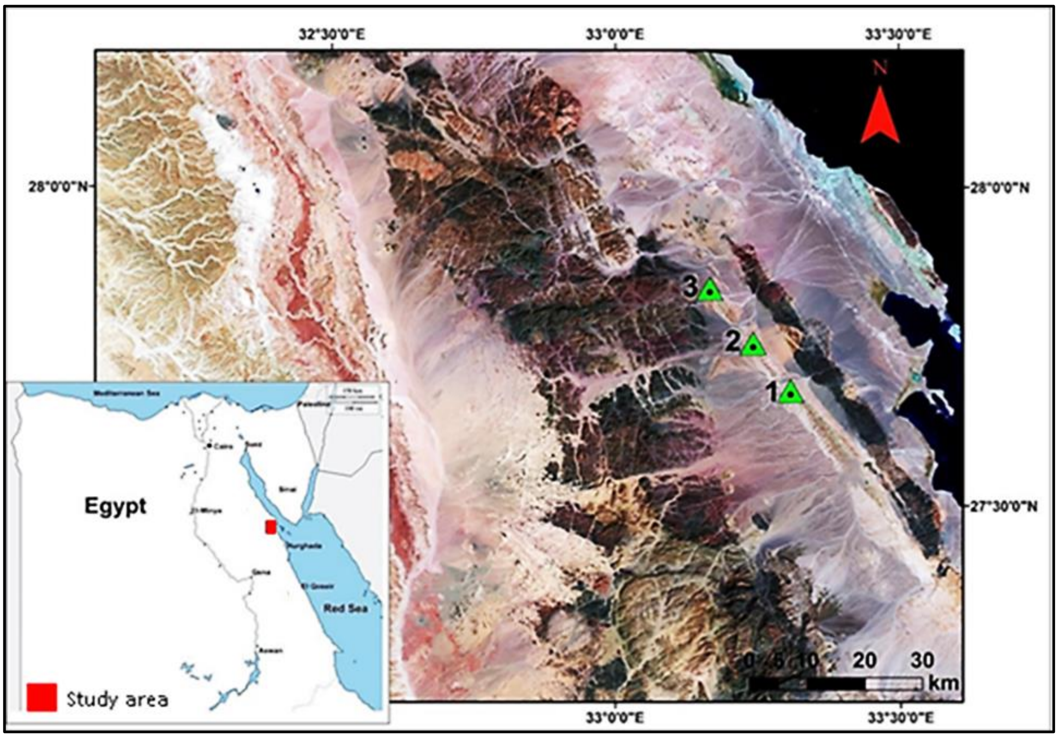

Fig.1: Location map of the studied sections.

Material and methods

Forty-two representative samples were collected from the exposed Thebes, Esna Shale, Dib, and Sudr formations in the studied area **(Figs. 2 and 3)**. These samples were selected based on their color and composition variation within the respective formations. X-ray diffraction (XRD) analysis of the bulk samples was performed after pulverization using an agate mortar, followed by mounting and orientation for analysis. The peak intensities of these samples were used for semi-quantitative evaluation. The mineralogical composition of the bulk rock samples was analyzed using a Philips X-ray diffraction system, model PW/1710, equipped with a monochromator and utilizing Cu K-α radiation ($\lambda = 1.54$ Å) at 40 kV and 35 mA, at the Department of Physics, Assiut University, Egypt. The identification and semi-quantitative estimation of the mineral percentages were carried out according to the procedures outlined by Moore and Reynolds **[27]**. Infrared (IR) spectral analysis was conducted on approximately 2 grams of dried samples homogenized with 1 gram of high-purity potassium bromide using an agate mortar. The analysis utilized prisms covering a wavelength range of 2.5 µm to 19 µm (corresponding to 4000–526 cm^{-1}). Scanning Electron Microscopy (SEM) investigations were performed using a JEOL scanning electron microscope. The combination of SEM with energy-dispersive X-ray spectroscopy (EDS) facilitated detailed visualization of crystal morphologies and enabled the identification of elemental compositions, as well as the examination of fossils and fossil fragments.

Results and interpretation

Bulk Mineralogy of Sudr Formation

Figure 4 illustrates the near-identical bulk rock mineralogy of the lowest unit of this formation, as indicated by their X-ray diffraction (XRD) patterns. In this unit, calcite constitutes 100% of the mineral composition, except for the upper three samples (7, 8, and 9), which contain varying amounts of phyllosilicates (11–17%), dolomite (3–5%), and quartz (1%) **(Table 1 and Fig.5).** In contrast, the XRD patterns of the upper unit exhibit considerable variation in bulk mineralogy **(Fig.4).** Specifically, the mineralogical composition of the upper unit differs significantly between samples, with calcite ranging from 31% to 96%, phyllosilicates from 0% to 30%, dolomite from 0% to 10%, quartz from 1% to 3%, gypsum from 0% to 35%, and feldspars from 0% to 6% **(Fig. 6)**. The predominance of calcite in the lower unit of the Sudr Formation suggests a relatively stable marine or shallow water environment characterized by minimal fluctuations in depositional conditions **[29]**. In contrast, the upper unit exhibits notable mineralogical variability, which reflects significant changes in the depositional environment. This includes varying degrees of evaporative conditions, as indicated by the presence of gypsum and dolomite, as well as fluctuating weathering or climatic conditions, as evidenced by the occurrence of phyllosilicates and feldspars **[30, 31]**. These mineralogical variations in the upper unit imply a shift towards a more dynamic environment, potentially marked by periods of increased evaporation, changes in water salinity, or climatic transitions, such as wet and dry cycles. The observed fluctuations in the relative abundances of calcite, gypsum, phyllosilicates, and other minerals further support the notion of a dynamic environment where multiple geological processes, including carbonate precipitation, evaporation, and weathering, were actively occurring **[32]**.

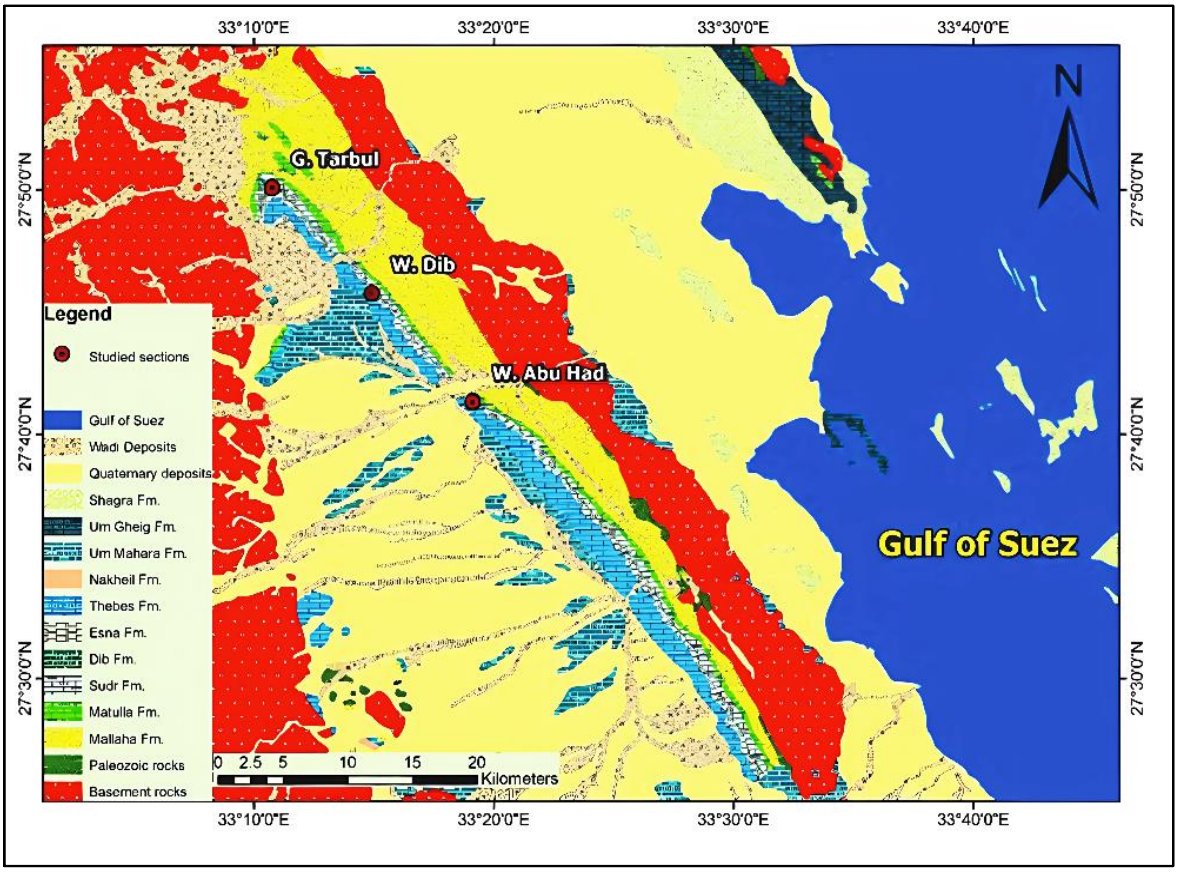

Fig. 2: Geological map of the study area (Esh El-Mellaha area) modified after **[28]**.

Bulk Mineralogy of Dib Formation

The bulk mineralogy of the samples from the Dib Formation exhibits a high degree of similarity, as demonstrated in **Figure 7**. Calcite constitutes the predominant mineral component, ranging from 54% to 80%. Phyllosilicates are present in significant proportions, ranging from 17% to 38%, while gypsum, quartz, and dolomite are found in smaller quantities, accounting for 3%, 3%, and 1%, respectively **(Table 2 and Fig. 8).** The bulk mineralogy of Dib Formation suggests a relatively stable and consistent depositional environment, with calcite being the dominant mineral component, comprising 54% to 80% of the samples. This high proportion of calcite indicates the prevalence of marine or shallow water conditions where carbonate precipitation was the primary process, possibly in a warm, shallow marine setting with limited terrestrial input **[33, 34]**. The significant presence of phyllosilicates (17% to 38%) suggests a degree of weathering or sedimentary recycling, possibly reflecting fluctuating environmental conditions, such as periods of freshwater influence or increased terrigenous input. The minor presence of gypsum (3%), quartz (3%), and dolomite (1%) further supports a relatively stable marine setting with localized variations, where evaporitic conditions (indicated by gypsum) may have occurred intermittently, and the presence of quartz suggests some input of siliciclastic material. Being present in low quantities, Dolomite may indicate a secondary diagenetic alteration of calcite under specific conditions, such as changes in salinity or water chemistry. Overall, the mineralogical composition reflects a depositional environment that was primarily dominated by carbonate production, with occasional shifts in conditions including evaporative processes and terrigenous influx .

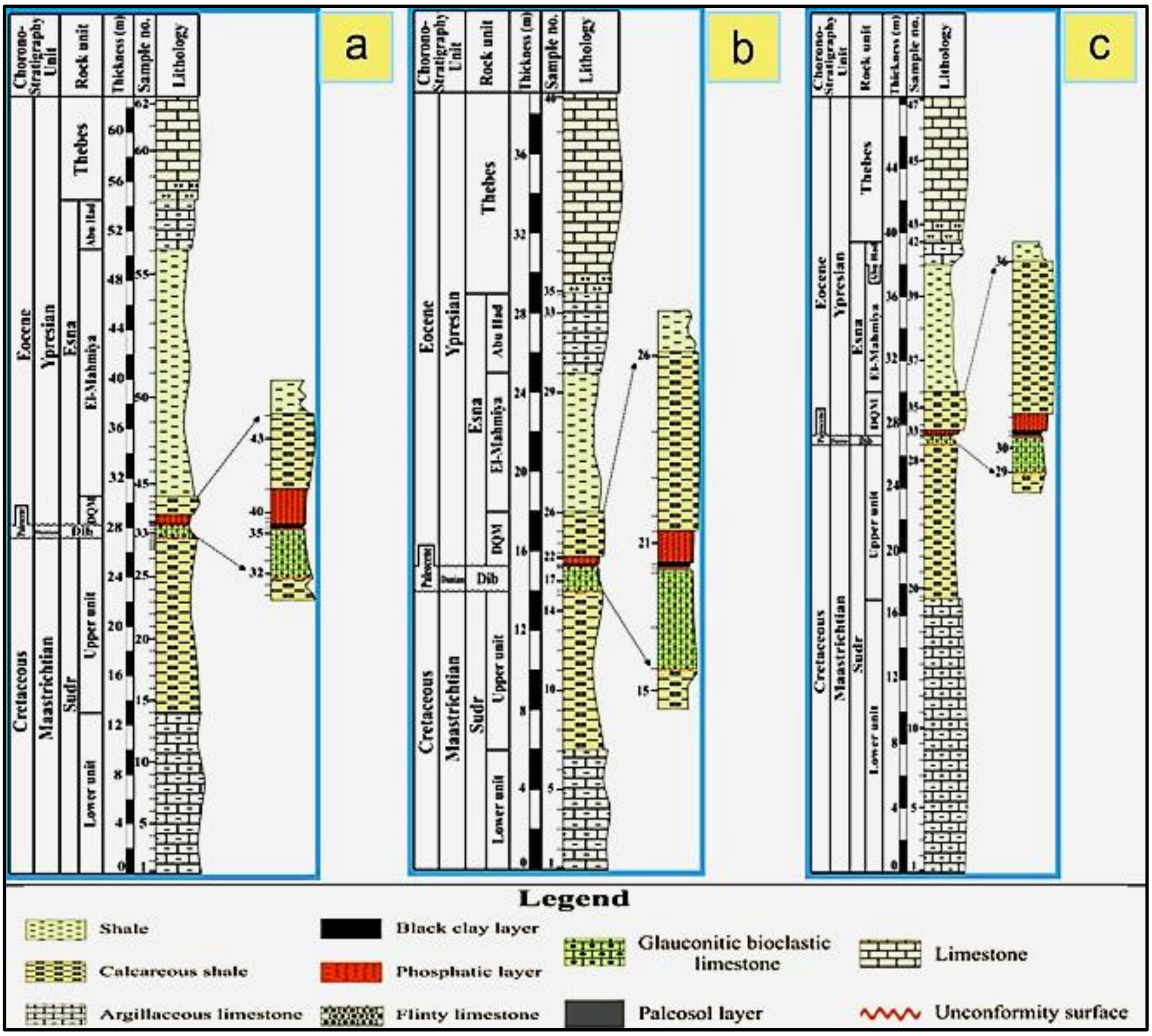

Fig.3: Lithostratigraphic columnar sections of the Upper Cretaceous- Lower Paleogene succession at Wadi Abu Had (**a**), Wadi Dib (**b**), and Gabal Tarbul (**c**).

Bulk mineralogy of Esna Formation:

The bulk mineralogy of Esna Formation exhibits considerable variation both among its different members and between individual samples, as indicated by the X-ray diffraction (XRD) patterns **(Fig. 9)** and mineral content histograms **(Fig. 10)**. In general, the two dominant minerals in the Esna Formation are calcite, with concentrations ranging from 0% to 96%, and phyllosilicates, which vary between 0% and 38%. Additionally, dolomite (0–50%), quartz (0–14%), gypsum (0–51%), and feldspar (0–15%) are present in subordinate amounts **(Table 3 and Fig. 10)**. Given the significance of the considerable variation observed in each member, as well as the presence of the P/E boundary in the Dabbabyia Member, a detailed analysis of these variations is provided in the following sections.

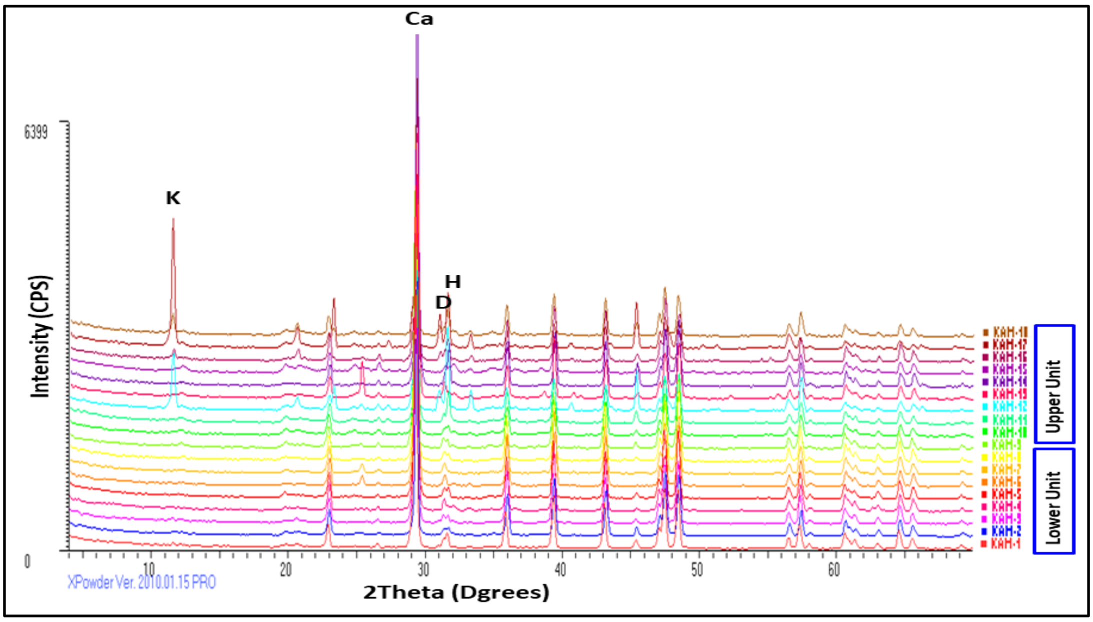

Fig. 4: XRD patterns of the Sudr Formation (lower and upper units) samples showing the similarity of their bulk mineralogy (K=kaolinite, Ca=calcite, D=dolomite, H=huntite).

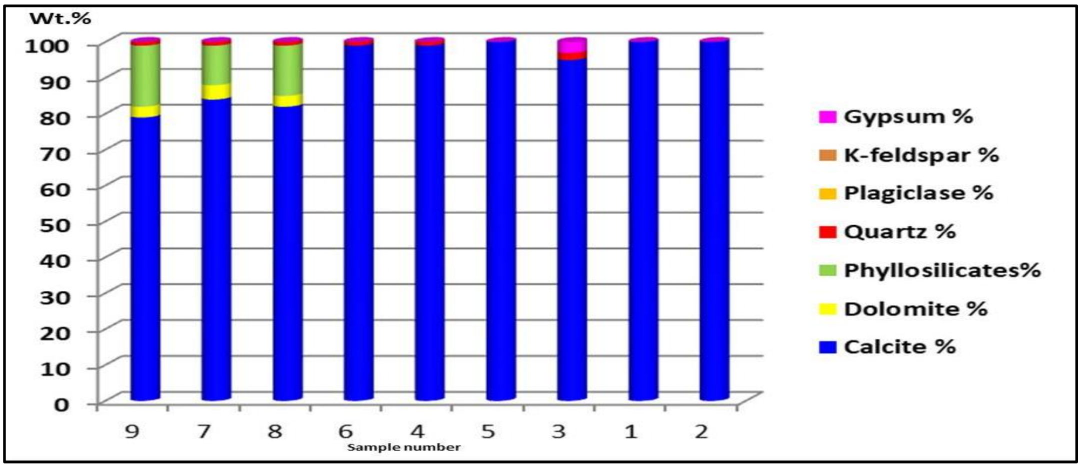

Fig.5: Bulk mineralogy contents of the Sudr Formation (lower unit) determined semi-quantitatively.

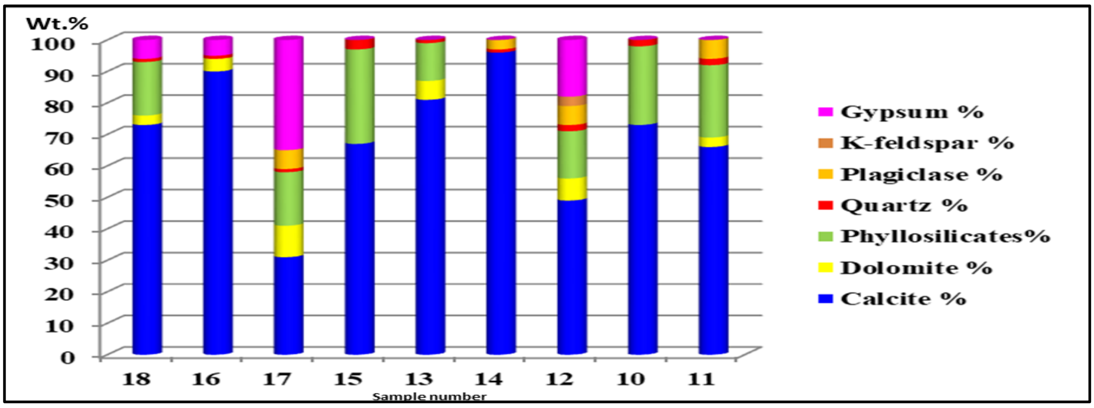

Fig.6: Bulk mineralogy contents of the Sudr Formation (upper unit) determined semi-quantitatively.

Table 1: Bulk mineralogy of Sudr Formation in the studied area.

Formation	Units	Site	Sample	Calcite %	Dolomite %	Phyllosilicates%	Quartz %	Plagiclase %	K-feldspar %	Gypsum %
Sudr Formation	Calcareous shale	**Gabel Trabul**	18	73	3	17	1	0	0	6
		Wadi Dib	16	90	4	0	1	0	0	5
		Wadi Abu Had	17	31	10	17	1	6	0	35
		Gabel Trabul	15	67	0	30	3	0	0	0
		Wadi Dib	13	81	6	12	1	0	0	0
		Wadi Abu Had	14	96	0	0	1	3	0	0
		Gabel Trabul	12	49	7	15	2	6	3	18
		Wadi Dib	10	73	0	25	2	0	0	0
		Wadi Abu Had	11	66	3	23	2	0	0	0
		Average		**70**	**4**	**15**	**2**	**2**	**0.3**	**7**
	Argillaceous limestone	**Gabel Trabul**	9	79	3	17	1	0	0	0
		Wadi Dib	7	84	4	11	1	0	0	0
		Wadi Abu Had	8	82	3	14	1	0	0	0
		Gabel Trabul	6	99	0	0	1	0	0	0
		Wadi Dib	4	99	0	0	1	0	0	0
		Wadi Abu Had	5	100	0	0	0	0	0	0
		Gabel Trabul	3	95	0	0	2	0	0	3
		Wadi Dib	1	100	0	0	0	0	0	0
		Wadi Abu Had	2	100	0	0	0	0	0	0
		Average		**93**	**1**	**5**	**1**	**0**	**0**	**0**
	Total Average			**81**	**2**	**10**	**1**	**1**	**0.2**	**4**

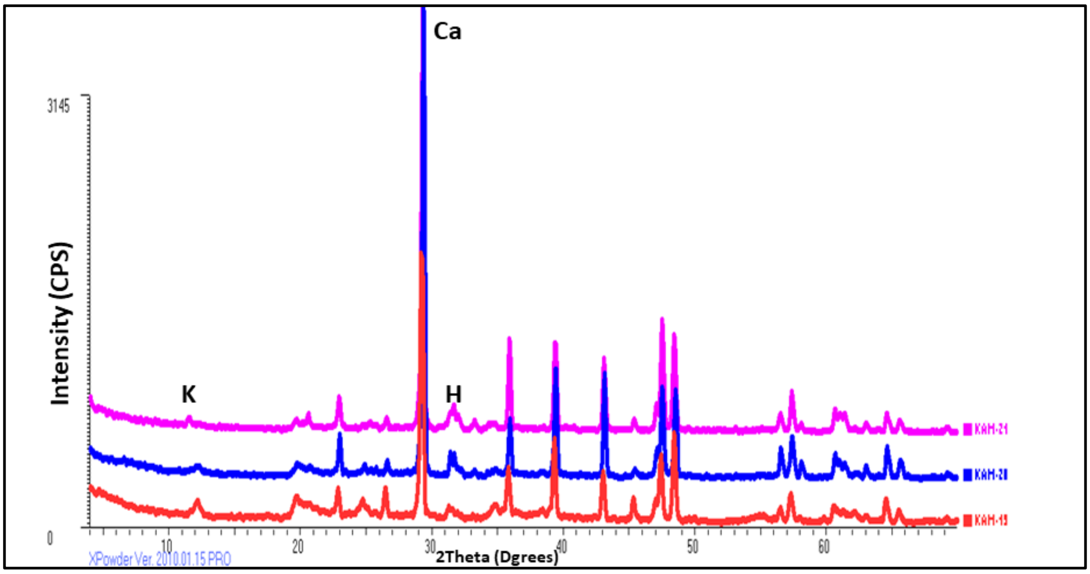

Fig. 7: XRD patterns of Dib Formation samples showing the rather similarity of their bulk mineralogy(**K**=kaolinite, **Ca**=calcite, **D**=dolomite, **H**=huntite).

Table 2: Bulk mineralogy of Dib Formation in the studied area.

Formation	Site	Sample	Calcite %	Dolomite %	Phyllosilicates%	Quartz %	Plagiclase %	K-feldspar %	Gypsum %
Dib	Gabel Trabul	21	74	4	17	2	0	0	3
	Wadi Dib	20	80	0	18	2	0	0	0
	Wadi Abu Had	19	54	4	38	4	0	0	0
	Average		**69**	**3**	**24**	**3**	**0**	**0**	**1**

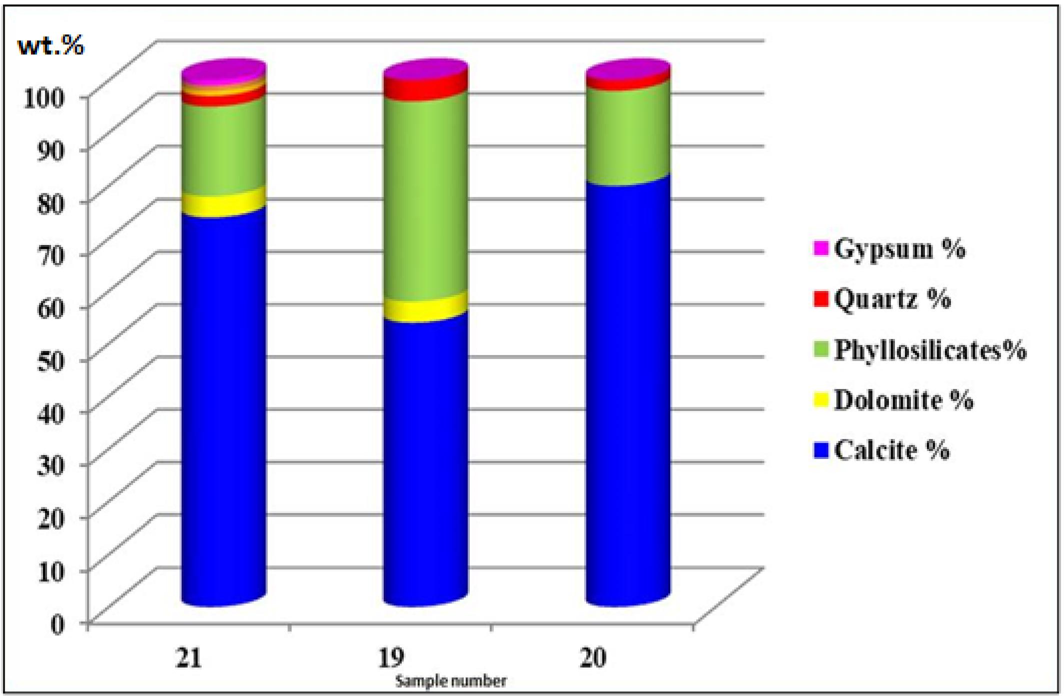

Fig.8: Bulk mineralogy contents of Dib Formation determined semi-quantitatively.

In the El-Hanadi Member, the bulk mineralogy is composed primarily of calcite (ranging from 0% to 66%, with an average of 42%), phyllosilicates (24% to 29%, with an average of 27%), gypsum (0% to 51%, with an average of 17%), plagioclase (0% to 15%, with an average of 9%), and quartz (3% to 5%, with an average of 4%) **(Fig. 10)**.

In El-Dabbabyia Member, Bed 1, the bulk mineralogy includes calcite (16% to 56%, with an average of 39%), phyllosilicates (11% to 32%, with an average of 25%), dolomite (2% to 50%, with an average of 18%), plagioclase (5% to 13%, with an average of 9%), K-feldspar (0% to 7%, with an average of 4%), quartz (5%), and gypsum (0% to 2%, with an average of 1%) **(Fig. 10)**. Notably, phyllosilicates and calcite show a slight decrease relative to the bulk mineralogy of the preceding member, while gypsum exhibits a sharp decline. In contrast, dolomite and K-feldspar appear in more substantial quantities in the El-Dabbabyia Member, Bed 1. The proportions of quartz and plagioclase in this member are nearly identical to those in the El-Hanadi Member.

The bulk mineralogy of El-Dabbabyia Member, Bed 2 and Bed 3, is characterized by calcite (16% to 55%, with an average of 37%), phyllosilicates (23% to 37%, with an average of 29%), dolomite (3% to 36%, with an average of 16%), plagioclase (0% to 12%, with an average of 4%), K-feldspar (0% to 11%, with an average of 4%), quartz (5% to 10%, with an average of 4%), and gypsum (0% to 4%, with an average of 3%) **(Fig. 10)**. In comparison to Bed 1, the mineralogical composition of Bed 2 and Bed 3 shows an increase in the proportions of phyllosilicates, quartz, and feldspars, alongside a decrease in calcite and dolomite.

The bulk mineralogy of El-Dabbabyia Member, Bed 4 and Bed 5, consists of calcite (11% to 66%, with an average of 47%), phyllosilicates (24% to 61%, with an average of 38%), quartz (3% to 14%, with an average of 7%), dolomite (3% to 7%, with an average of 4%), plagioclase (0% to 8%, with an average of 3%), and gypsum (0% to 3%, with an average of 1%) **(Table 3 and Fig. 10)**. In comparison to the El-Dabbabyia Member, Bed 2 and Bed 3, the mineralogical composition of Bed 4 and Bed 5 shows an increase in the relative abundance of calcite, phyllosilicates, and quartz, while feldspars, dolomite, and gypsum exhibit a decrease.

In El-Mahmyia Member, the two primary minerals are calcite (50% to 68%, with an average of 56%) and phyllosilicates (26% to 40%, with an average of 33%), with smaller amounts of plagioclase, dolomite, and quartz **(Fig. 10)**. Notably, calcite increases substantially in this member at the expense of detrital components when compared to the mineralogical composition of the Dabbabyia and El-Hanadi members.

In Abu Had Member, calcite becomes the dominant mineral, with an average content of 84%, accompanied by minor amounts of phyllosilicates, dolomite, and quartz **(Fig. 10)**.

The mineralogical data from the Esna Formation reveal significant variations in its composition across different members and beds, which can be interpreted in terms of depositional environments, diagenetic processes, and paleoenvironmental changes. Below is a detailed interpretation of the mineralogy for each member and its implications:

Esna Formation records a complex history of changing depositional environments, influenced by sea-level fluctuations, climate changes, and tectonic activity **[35]**. The lower members (El-Hanadi and El-Dabbabyia) reflect mixed carbonate-evaporite-terrigenous deposition, with periods of restricted marine conditions (gypsum) and increased detrital input (phyllosilicates, quartz, feldspars). The upper members (El-Mahmyia and Abu Had) indicate a shift to more stable marine conditions, dominated by carbonate deposition with reduced terrigenous influence **[36]**. The presence of the P/E boundary in the El-Dabbabyia Member suggests that these mineralogical changes may also reflect broader global events, such as climate shifts or biotic crises associated with the Palaeocene–Eocene transition **[37]**.

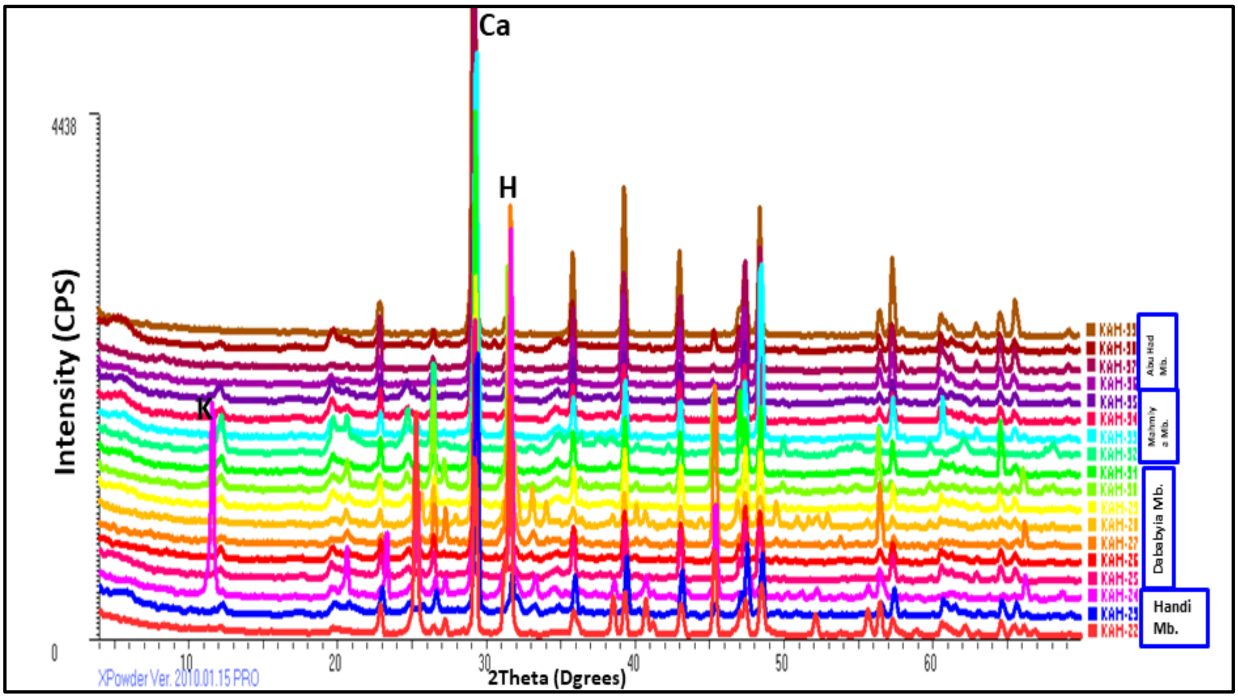

Fig.9: XRD patterns of Esna Formation samples showing the remarkable variations of their bulk mineralogy from one member to another.(**K**=kaolinite, **Ca**=calcite, **D**=dolomite, **H**=huntite)

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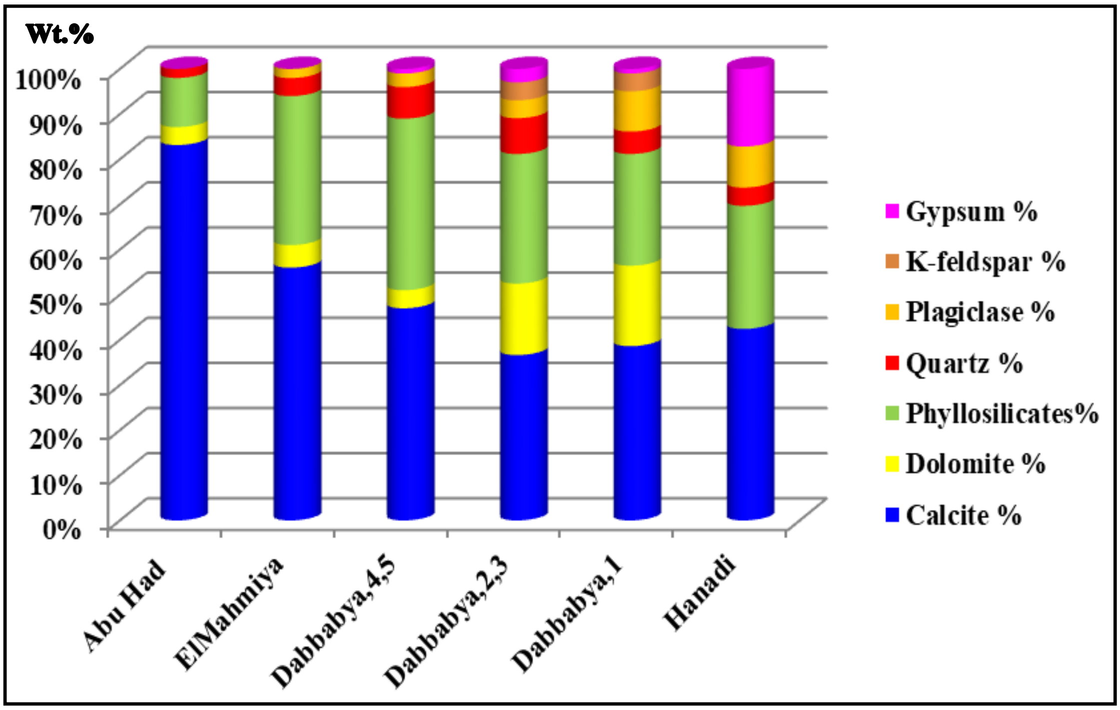

Fig. 10: Bulk mineralogy contents of Esna Formation determined semi-quantitatively.

Bulk mineralogy of Thebes Formation

The sediments of Thebes Formation exhibit nearly identical bulk rock mineralogy, as evidenced by their X-ray diffraction (XRD) patterns **(Fig.11)**. The XRD analysis of the bulk rock samples from this formation reveals that calcite is the predominant mineral component, comprising 71% to 84% of the total mineral content, with an average of 79%. Minor amounts of quartz (average of 2%) and gypsum (average of 1%) are present, alongside subordinate quantities of dolomite (ranging from 2% to 15%, with an average of 7%) and phyllosilicates (ranging from 8% to 15%, with an average of 12%) **(Table 4 and Fig.12)**.

In contrast to the findings of previous studies by Kehelia et al. **[38]** and Abd el Hafez et al**.** **[5]**, hematite, pyrite, and halite were not identified among the carbonate minerals in the studied samples of this formation.

The mineralogical data of this formation provide several important insights into the depositional environment, mineral composition, and potential diagenetic processes influencing the Thebes Formation. The following is a detailed analysis of these insights based on the data mentioned above.

Calcite is the predominant mineral in the Thebes Formation, comprising 71% to 84% of the total mineral content, with an average of 79%. The high proportion of calcite is a strong indicator of a carbonate-rich sedimentary environment. This is typically associated with marine environments, especially those characterized by warm, shallow waters with abundant biological activity (e.g., coral reefs, marine invertebrates, and algae) **(Fig.13)**. In such environments, biochemical processes lead to the precipitation of calcium carbonate, which forms the majority of the sediment. The presence of such a high percentage of calcite suggests that the formation may have been deposited in a shallow marine, lagoonal, or possibly reefal environment where calcite precipitation dominates **[39]**.

Quartz is present in small amounts (average of 2%), which indicates some terrestrial input into the sedimentary environment. This suggests that there may have been some contribution of detrital material (e.g., sand or silt) from nearby land sources. Quartz is chemically stable and resistant to weathering, which is why it is often found in small amounts in marine sediments. The low proportion of quartz implies that the depositional environment was not strongly influenced by large terrestrial input (e.g., river systems), but rather by more localized or restricted marine conditions **[34]**.

Gypsum is present in trace amounts (average of 1%). The presence of gypsum suggests that evaporitic conditions may have occurred locally in the depositional environment. Gypsum typically forms in environments where evaporation rates are high and water is relatively saline, such as in shallow marine settings, sabkhas (coastal flats), or evaporative lagoons. The

low abundance of gypsum implies that evaporitic conditions were not widespread, but may have been episodic or local in nature, such as in shallow areas where evaporation exceeded the rate of freshwater input [40].
Dolomite is present in minor to subordinate amounts (ranging from 2% to 15%, average of 7%). Dolomite commonly forms in evaporitic or marine settings where magnesium is present in seawater, and it often occurs as a result of the diagenetic alteration of calcite (dolomitization). The presence of dolomite suggests that some diagenetic processes have occurred, possibly dolomitization, where early calcite crystals in the sediments were replaced by dolomite over time, possibly due to the influence of magnesium-rich fluids. The relatively low abundance of dolomite suggests that dolomitization was not widespread but might have been locally significant [33, 41].
Phyllosilicates range from 8% to 15%, with an average of 12%. These minerals typically form from the weathering of silicate rocks and are commonly found in terrestrial or fluvial settings. Their presence in the Thebes Formation suggests that there was some degree of terrestrial input, possibly from rivers or floodplains that supplied clay-sized particles to the marine setting. The moderate abundance of phyllosilicates suggests that the formation was influenced by low-energy environments, where fine-grained clays could settle and accumulate, potentially in estuarine or lagoonal settings. It also suggests that the sediments may have undergone limited transportation before deposition, which would allow for the preservation of these fine-grained minerals [40, 41].
The Thebes Formation is primarily composed of carbonate-rich sediments (mainly calcite), suggesting a marine depositional environment, likely a shallow, warm marine setting. This could include environments like shallow seas, lagoons, or reefs with abundant biological activity. The presence of minor quartz suggests that there was some input of terrestrial material, likely from nearby landmasses or river systems. The trace amount of gypsum suggests episodic evaporitic conditions, which may have occurred in localized or shallow areas of the depositional basin, possibly influenced by changes in sea level or climate. The moderate presence of dolomite indicates that some diagenetic processes occurred, potentially linked to changes in pore water chemistry during burial, such as the conversion of calcite to dolomite. Phyllosilicates suggest some terrestrial or fluvial influence, possibly indicating a semi-restricted marine environment or a transition between marine and more continental conditions.
The mineralogy points to a shallow marine, possibly with periodic evaporation and restricted circulation. Calcareous sediments dominated by calcite suggest a warm, shallow marine environment with abundant biogenic carbonate production. The presence of gypsum and dolomite indicates localized evaporitic or diagenetic processes that could reflect fluctuating salinity levels or changes in water chemistry during the formation's deposition. The presence of phyllosilicates hints at some degree of terrestrial influence, which could imply proximity to a land source or fluvial input into the basin.

General remarks on the IR spectra of the studied sediments

The infrared (IR) spectra of all samples from the studied formations were recorded in transmittance mode over the range of 500 to 4000 cm-1 to investigate their structural composition. The following key features were identified from these spectra. This analysis largely corroborates the findings from X-ray diffraction (XRD) analysis, confirming the presence of both clay and non-clay minerals within the sediments. Moreover, it reveals the similarities and differences in the mineralogy of both the bulk mineralogy **(Fig.14)**. The clay minerals identified through IR analysis include smectite (montmorillonite), kaolinite, illite, and mixed layer smectite/illite, while the non-clay minerals are quartz, calcite, and feldspar. The splitting of certain spectral bands suggests the presence of multiple types of hydroxyl bonds, each characterized by distinct absorption frequencies. Specifically, bands between 3615 and 3622 cm-1 and 911 to 918 cm-1 are attributed to dioctahedral smectites [42, 43] and correspond to the stretching (ν) and deformation (δ) vibrations of hydroxyl groups in the [Al-Al-OH] configuration [44].

Table 3: The bulk mineralogy of Esna Formation exposed in the studied area.

Fm.	Mm.	Site	Beds	Sample	Calcite %	Dolomite %	Phyllosilicates%	Quartz %	Plagiclase %	K-feldspar %	Gypsum %
Esna Formation	Abu Had	Gabel Trabul		39	96	4	0	0	0	0	0
		Dib		37	94	4	0	2	0	0	0
		Abo Had		38	62	3	32	3	0	0	0
		Average			**84**	**4**	**11**	**2**	**0**	**0**	**0**
	ElMahmiya	Gabel Trabul		36	68	3	26	3	0	0	0
		Dib		34	50	7	34	4	5	0	0
		Abo Had		35	51	5	40	4	0	0	0
		Average			**56**	**5**	**33**	**4**	**2**	**0**	**0**
	Dabbabya	Gabel Trabul	4,5	33	66	7	24	3	0	0	0
		Dib	4,5	31	63	3	30	4	0	0	0
		Abo Had	4,5	32	11	3	61	14	8	0	3
		Average			**47**	**4**	**38**	**7**	**3**	**0**	**1**
	Dabbabya	Gabel Trabul	2,3	30	16	36	23	10	12	0	3
		Dib	2,3	28	41	9	27	8	0	11	4
		Abo Had	2,3	29	55	3	37	5	0	0	0
		Average			**37**	**16**	**29**	**8**	**4**	**4**	**3**
	Dabbabya	Gabel Trabul	1	27	16	50	11	4	13	4	2
		Dib	1	25	56	2	32	5	5	0	0
		Abo Had	1	26	45	3	32	5	8	7	0
		Average			**39**	**18**	**25**	**5**	**9**	**4**	**1**
	Hanadi	Gabel Trabul		24	0	0	29	5	15	0	51
		Dib		22	60	0	24	3	13	0	0
		Abo Had		23	66	0	29	5	0	0	0
		Average			**42**	**0**	**27**	**4**	**9**	**0**	**17**

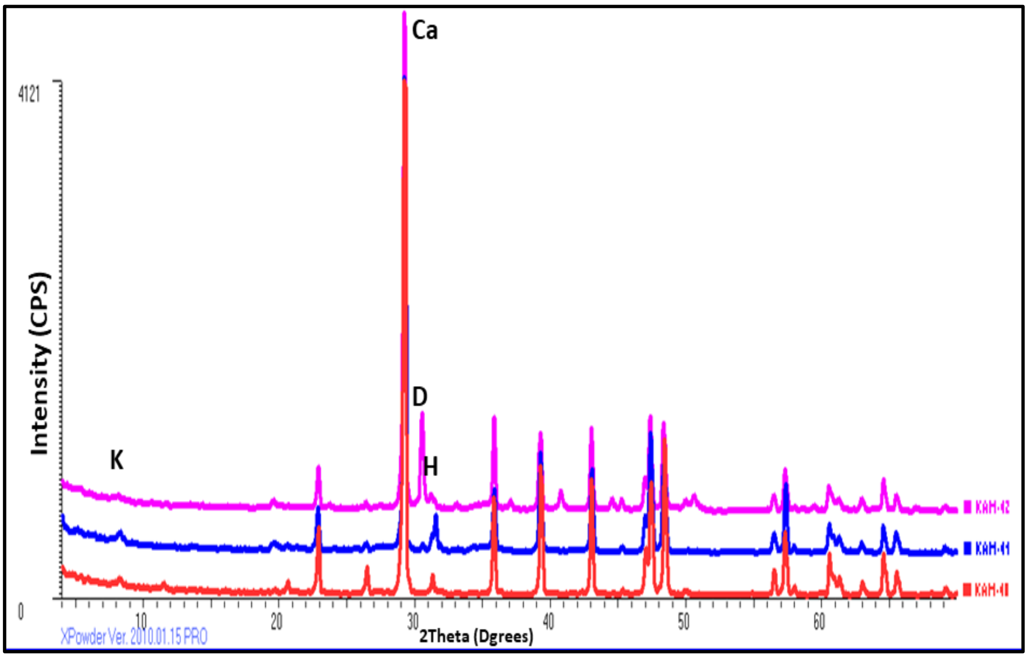

Fig. 11: XRD patterns of Thebes Formation samples showing the remarkable variations of their bulk mineralogy from one member to another. (**K**=kaolinite, **Ca**=calcite, **D**=dolomite, **H**=huntite)

Table 4: Bulk mineralogy of Thebes Formations in the studied area.

Formation	Site	Sample	Calcite %	Dolomite %	Phyllosilicates %	Quartz %	Plagiclase %	K-feldspar %	Gypsum %
Thebes	Gabel Trabul	42	71	15	13	1	0	0	0
	Wadi Dib	40	84	3	8	3	0	0	2
	Wadi Abu Had	41	82	2	15	1	0	0	0
	Average		**79**	**7**	**12**	**2**	**0**	**0**	**1**

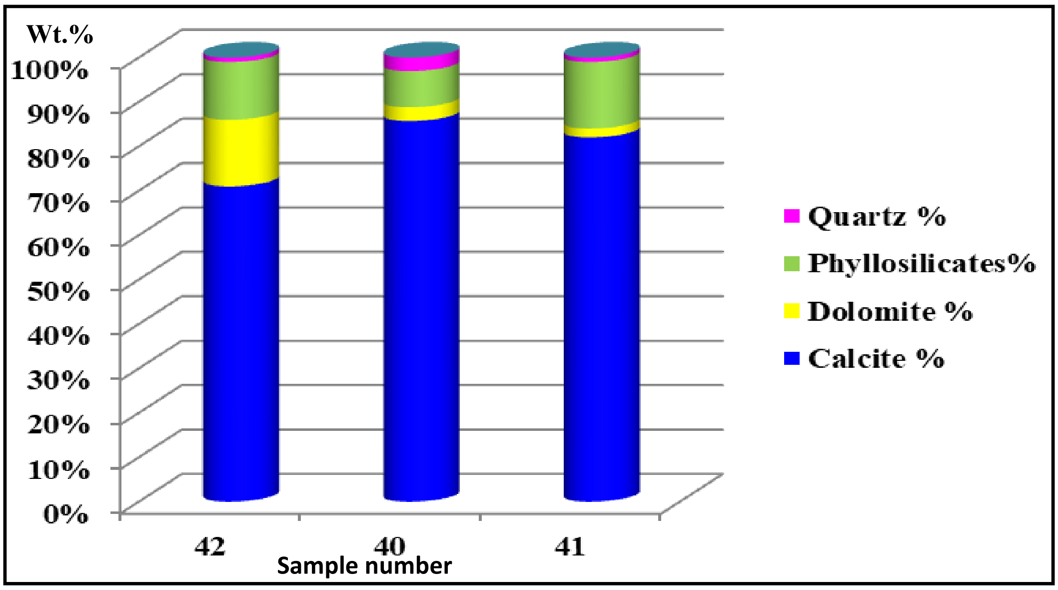

Fig.12: Bulk mineralogy contents of Thebes Formation determined semi-quantitatively.

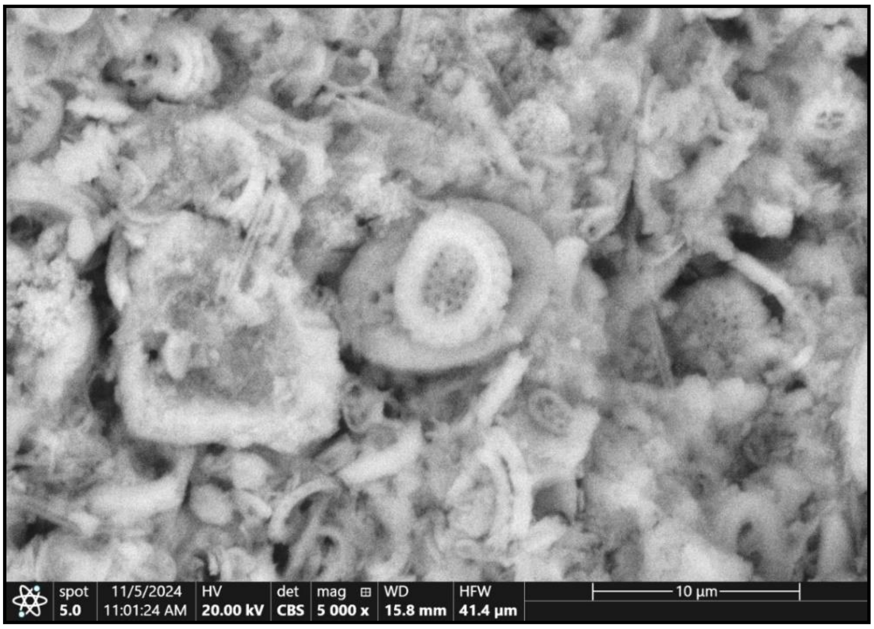

Fig. 13: A representative Scanning Electron Microscope microphotograph of the studied carbonate sediments.

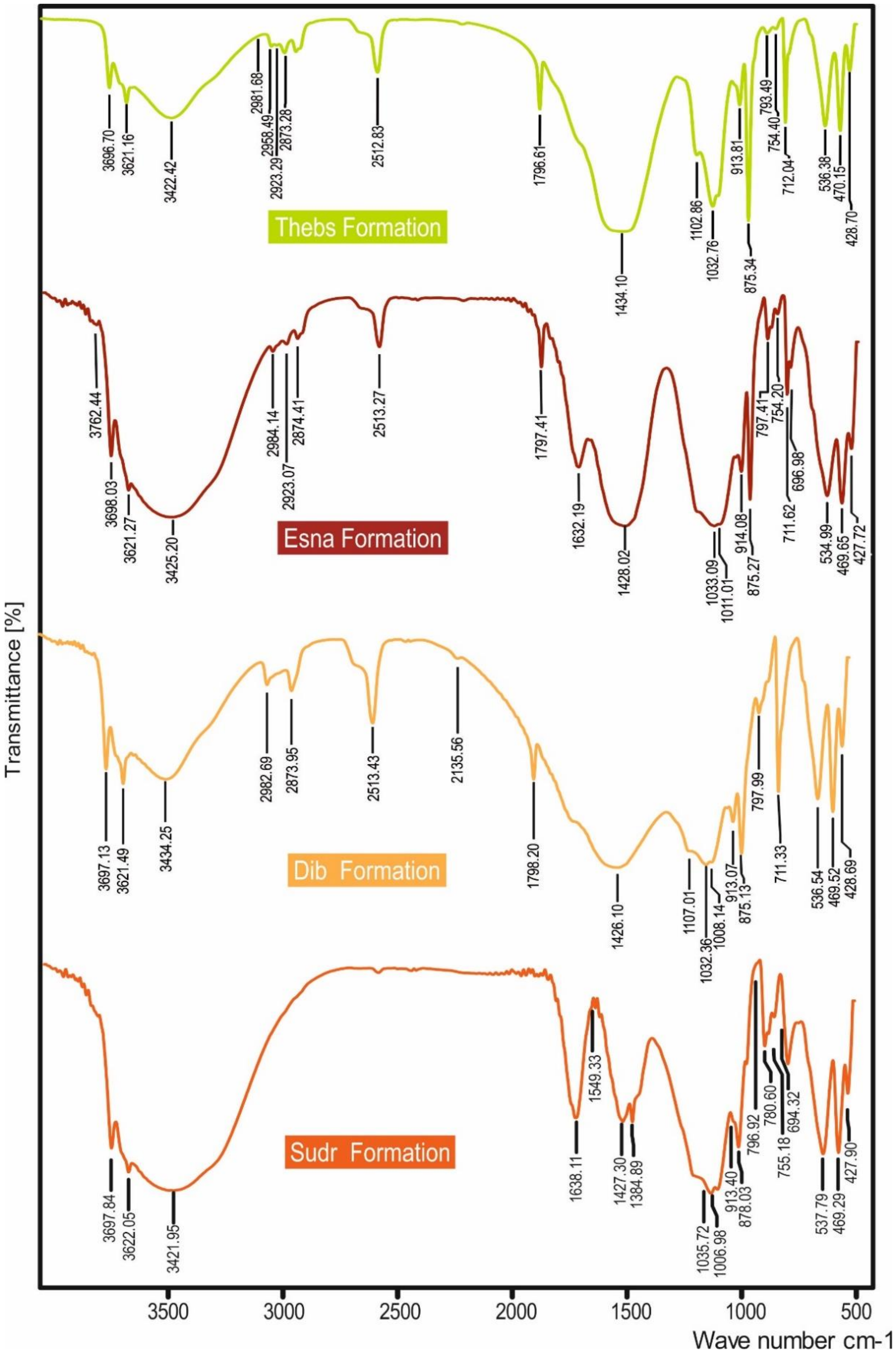

Fig. 14: Representative IR spectra of the bulk mineralogy of the studied formations.

Conclusions

This study provides a detailed mineralogical assessment of the Upper Cretaceous–Lower Paleogene successions in Esh El-Mellaha area, Gulf of Suez, Egypt. XRD, IR, and SEM-EDS analyses reveal significant mineralogical variations across the Sudr, Dib, Esna, and Thebes formations, reflecting shifts in depositional environments and diagenetic processes. Sudr and Dib formations are dominated by calcite, indicative of stable, shallow marine conditions, with Sudr's upper unit showing increased mineral diversity linked to evaporitic and climatic fluctuations. Esna Formation displays marked mineralogical heterogeneity, particularly around the P/E boundary, suggesting dynamic depositional settings influenced by global environmental changes. Thebes Formation is largely composed of calcite with minor terrigenous input, consistent with a warm, shallow marine environment. IR spectroscopy confirmed the presence of clay minerals such as smectite, illite, and kaolinite, aligning with XRD results and providing further insight into sediment origin and alteration. These findings refine previous interpretations and contribute to a more nuanced understanding of the region's paleoenvironmental history.

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