

Sedimentological and Mineralogical Fingerprint of the Beach Sediments, Western Mediterranean Coast, Egypt

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Abstract

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The composition and texture of beach sediments along continental coastlines vary considerably. Beach sands made completely of carbonate sediments are prevalent along Egypt's Western Mediterranean Coast. Forty-five sediment samples were collected from various locations (El-Dekhela, Kilo-21, Abu Talat, and Sidi Krir) along the Western Mediterranean Coast of Egypt. The sedimentological and mineralogical attributes of the collected sediments were investigated using collaborative techniques. The beach sediments in the coastal region between El-Dekhela and Sidi Krir consist mainly of carbonate sands that are mineralogically composed of dolomite, calcite, and aragonite with smaller amounts of quartz, sylvite, anhydrite, gypsum, and trace amounts of microcline. They contain ooids with bioclasts and very few heavy minerals, except for notable amounts of these minerals in the El-Dekhela region. These heavy minerals primarily consist of opaque minerals, amphiboles, and pyroxenes, with smaller amounts of epidote, zircon, tourmaline, rutile, garnet, kyanite, monazite, sphene, staurolite, and biotite. The combination of heavy minerals in these deposits indicates a wide variety of igneous, metamorphic, and sedimentary rock types as potential source rocks. Heavy mineral concentrations decrease westward from the Nile River's mouth near Rosetta to Egypt's Western Mediterranean Coast. Most of the studied ooids are white colored and usually have a pearly luster; these characteristics indicate that these sediments were formed in agitated water. The current study reveals that the ooids in the study area originated from a variety of sources, including autochthonous and allochthonous ooids that eroded and broke, implying that they may have originated from coastal plain carbonate ridges.

Keywords: Beach sediment; Carbonate sand; Ooid; Mineralogy; Provenance; Mediterranean coast

1. Introduction

Beach sediments typically constitute a significant part of the world's coastal areas. Many researchers have investigated beaches in all their diverse aspects (Badapalli et al., 2022; Yalcin et al., 2022). Since the 1960s, coastal scientists have universally recognized beaches as dynamic sedimentary systems that require a variety of external inputs to form sediments, waves, and accommodation space (Mahmoud, 1995; Soloy et al., 2022). Beach sands are formed from parent materials of three principal sources transported and then deposited along the shorelines. They could naturally derive from

terrigenous sources (continental), volcanic activities, and marine carbonate organisms (coral reef detritus and shells) (Malick and Ishiga, 2016; Al-Humaidan et al., 2021; Pera et al., 2021; Lapietra et al., 2022; Farhat et al. 2022). In comparison to the uniform, rounded quartz sands that make up terrigenous beach sediments, the morphologies of carbonate sand grains are markedly varied, so it is more beneficial to determine the contribution from different marine and terrigenous sources by examining the texture and nature of carbonate grains than quartz or terrigenous grains (Gómez-Pujol et al., 2013). Many studies on beach sediments have focused on siliciclastic sand (Guillén and Hoekstra, 1996; Anthony and Héquette, 2007; Nabhan and Yang, 2018; Sandaruwan et al., 2022), but fewer studies have focused on calcareous beach sand (Falls and Textoris, 1972; Kasper-Zubillaga et al., 2017; Mattheus et al., 2020).

Systemic analysis and presentation of the textural and mineralogical composition of sediment data can provide sufficient evidence of the transport history, weathering processes, and the source rock composition (Alharbi et al., 2019; Venu and Velmayil, 2021; Al-Amery et al., 2022; Al-Mosawi et al., 2022). Grain size distribution is influenced by contributing factors such as source material, distance from the source, distance from the shoreline, topography, and transportation processes. Sedimentologists frequently employ analyses of grain size distribution to categorize sedimentary environments and clarify transport mechanisms (Ramadan et al. 2019; Rahman et al., 2022). The mineralogical composition of the consolidated and unconsolidated detrital sediments, particularly the characteristics of the heavy minerals' assemblage have long been recognized as sensitive indicators of the sources of sediments and allow their extensive usage in provenance tracing (Ramadan et al., 2019; Lahijani and Tavakoli, 2012; Shalini et al., 2020; Ali, 2021; Al-Mur and Gad, 2022; Ali et al., 2022). The main factors that control heavy mineral assemblages in the detrital sediments are the mineralogical composition of the source rock, shape and size of the mineral, specific gravity and stability during transport, weathering, and diagenesis (Savage and Potter, 1991; Garzanti et al., 2018; Al-Ankaz et al., 2022).

Based on general topographic and lithological variations, the Egyptian Mediterranean coast can be divided into three sections: the eastern (east of Damietta), the medial (between Rosetta and Damietta), and the western (west of Rosetta). There are only a few extensive studies that adequately address the Egyptian Mediterranean coast's sedimentological history and mineralogical composition. Elshazly et al. (2019) revealed that along the Mediterranean coast of Egypt, the marine deposits are primarily composed of ooids and bioclastic grains. The early diagenetic alteration of these deposits occurred in marine subaqueous conditions. Eren et al. (2016) used signatures to prove the unreality of the myth that Marcus Antonius carried ooid-rich beach sediments from Alexandria in Egypt to Cleopatra beach in Turkey for his lover Cleopatra and found that the ooids in the sediments from the Mediterranean coast of Alexandria range in shape from spherical to ellipsoidal with a milky white colour. The nuclei of these ooids may be quartz or bioclast grains. Most of the bioclasts are preserved gastropods found with broken echinoid spines, spherical red algae, and a few foraminiferal tests. El-Anwar et al. (2018) concluded that mineralogically, the carbonate deposits of El-Hamam and El-Omayid quarries in the north-western Mediterranean coastal area of Egypt are primarily composed of aragonite and calcite, with smaller amounts of dolomite, quartz, halite, and anhydrite. El-Wakeel and El-Sayed (1978) noted that the distinctive characteristics of the heavy minerals' assemblage of the beach sands along Egypt's north-western Mediterranean coast are similar to those of the Nile deposits. From the Rosetta Nile mouth, a marked decrease in the concentration of heavy minerals is detected. The beach sands have a considerable carbonate content that gradually decreases eastwards. The current study intends to analyze the textural and mineralogical fingerprint of the beach sediments along Egypt's western Mediterranean coast in order to verify the source rock status of the nearby sedimentary successions and delineate the sedimentation history of these sediments.

2. Materials and Methods

2.1. Study Area

The study area is located in the western Mediterranean coast of Egypt. It extends for about 35 Km from Alexandria's western borders to the Sidi Krir area. It is bounded by longitudes $29^{\circ} 30' - 29^{\circ} 50' E$ and latitudes $30^{\circ} 55' - 31^{\circ} 10' N$ (Fig.1). This area is located in the semiarid belt south of the Mediterranean Sea; it has a hot stable summer and a rainy unstable winter.

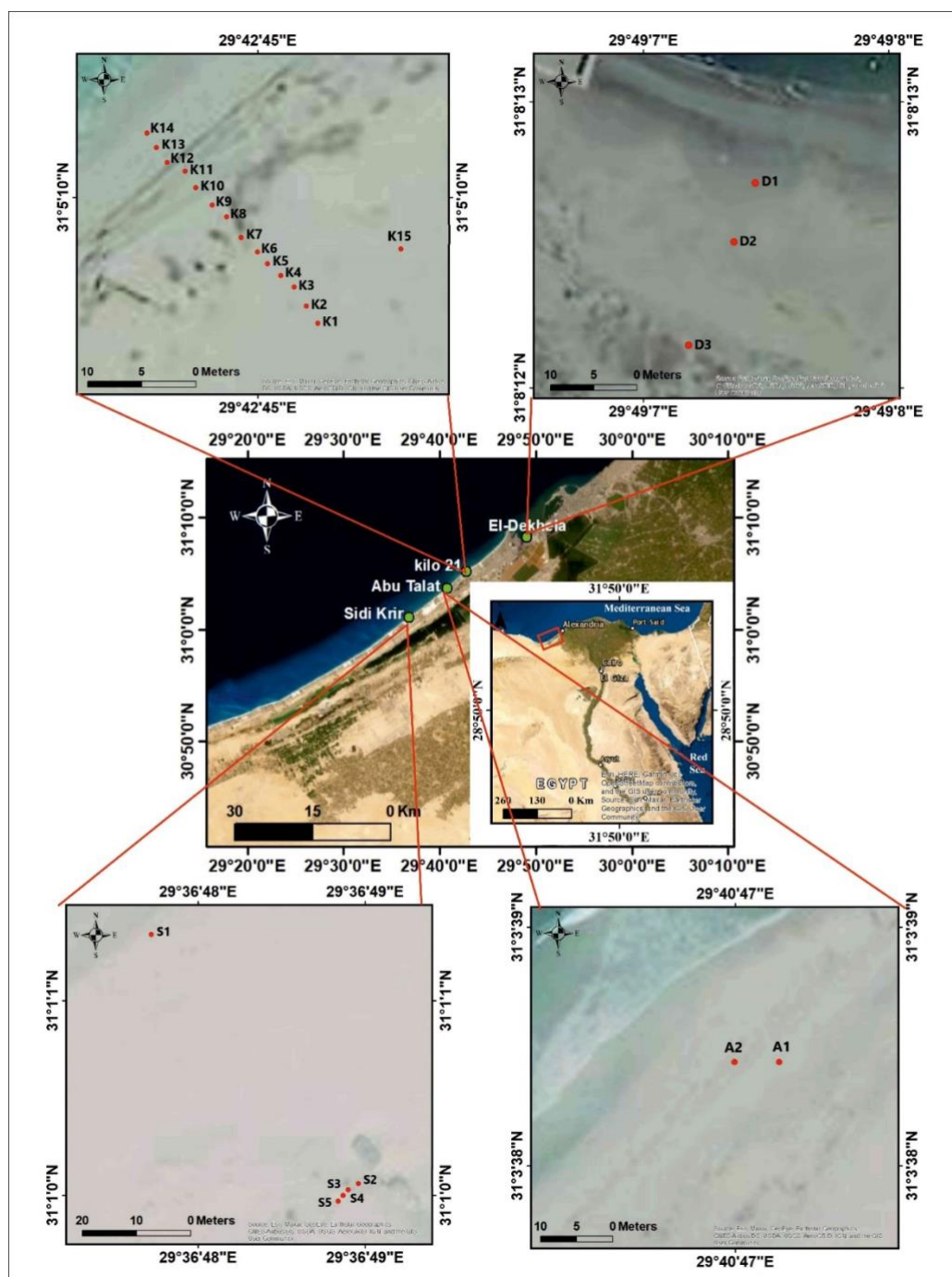


Fig.1. Location of the study area

Two particular provinces make up the western Mediterranean coastal area of Egypt. These are the coastal region to the north and the elevated plateau in the south (Yousif et al., 2013). The geology of the studied area is dominated by sedimentary rocks from the Tertiary and Quaternary periods. The Tertiary Miocene plateau, which is primarily composed of limestone and dolomite and frequently approaches the shoreline, distinguishes the geology of the area. The Pliocene and Middle Miocene deposits of the Tertiary period form the principal part of the plateau. Extended beaches, wadis, and coastal plains expose Quaternary deposits (Hegazi et al., 2009; Yousif, 2015). The geomorphologic features of this area typically include the coastal plain, coastal dunes, coastal ridges, lagoons, coastal depressions, and beaches. The coastal plain in the area is marked by at least eight extended parallel carbonate ridges. These ridges are divided by interdunal longitudinal depressions and run parallel to the shore. These carbonate ridges consist of biogenic and oolitic white grainstones (Eren et al. 2016; Assal et al., 2020).

2.2. Samples Collection and Preparation

Forty-five sediment samples were collected from different locations in El-Dekhela, Kilo-21, Abu Talat, and Sidi Krir areas along the western Mediterranean coast of Egypt. As profiles, three profiles (fourteen samples) from El-Dekhela, one profile (two samples) from Kilo-21, two profiles (six samples) from Abu Talat and one profile (five samples) from Sidi Krir, and surface samples, fourteen surface samples from Kilo-21 and four surface samples from Sidi Krir to cover the whole studied area (Fig.1). The collected sediment samples were allowed to dry in the air before using the coning and quartering method to provide representative samples for the examination.

2.3. Samples Analyses

The dry sieving technique was used for grain-size distribution analysis. 100 grams of each sediment sample were sieved for 20 minutes in a Ro-Tap shaking machine using sets of -1, 0, 1, 2, 3, and 4 Ø standard mesh sieves. Phi (Ø) values 5, 16, 25, 50, 75, 84, and 95 were determined using the cumulative curves to calculate the textural parameters according to Folk and Ward (1957). The total carbonate content (%) was determined using the gravimetric technique depending on measuring weight loss in sediment samples after adding dilute hydrochloric acid (HCl 10%) according to Gross (1971). The X-ray diffraction (XRD) analysis was performed on the bulk representative samples with a PANalytical X-Ray Diffraction instrument model X'Pert PRO with monochromator, Cu-radiation ($\lambda = 1.542 \text{ \AA}$) at 40 Kv, 40 mA, and a scanning speed of $0.03^\circ/\text{sec}$ to define the total mineral composition.

Heavy minerals were separated from fine and very fine sand-size fractions of representative sediment samples from El-Dekhela area using bromoform (specific gravity of 2.85 g/cm^3) as the heavy liquid as recommended by Galehouse (1971) and Mange and Maurer (1992). Ethyl alcohol was used to wash the separated heavy fraction and then the heavy minerals were mounted on slides with Canada balsam. In each heavy mineral mount, more than 300 grains per sample were counted then the heavy minerals percentages in each sample were calculated. The heavy minerals were identified and counted under Olympus polarized microscope using the "ribbon counting" technique of Mange and Maurer (1992). ZTR maturity index which represents the percentage of (Zircon- Tourmaline- Rutile / Non-Opaques Non-Micaceous), was calculated according to Hubert (1962). Thin sections of representative samples were prepared according to the procedure adopted by Miller's (1988) as the unconsolidated sediments firstly were imbedded in resin then cut into thin sections with a nominal thickness of $30 \mu\text{m}$ and then glued to glass slides. The prepared thin sections were examined using the polarized microscope (Olympus) then the various components (carbonate and non-carbonate) in each sample were counted and the average percentages of these components' abundance were calculated. Representative samples were examined using Philips XL 30 environmental scanning electron microscope (ESEM) with EDX

analyzer to identify the chemical composition of the ooids in each region of the studied area and to determine the surface features of these ooids.

3. Results and Discussions

3.1. Grain-Size Distribution

The textural nomenclature of the studied sediments was determined using the results of the grain size analyses (Table 1), and the calculated grain-size parameters are shown in Table 2. This revealed that the studied sediments are classified as sand, with the exception of two samples in the Kilo-21 area, which were classified as sandy gravel and gravelly sand.

Table 1. Percentages of the studied sediments size fractions and their textural nomenclature.

Location	Sample code	Gravel %	V. Coarse	Sand %				Total	Mud %	Nomenclature	CaCO ₃ %	Insoluble Residue%
				Coarse	Medium	Fine	V. Fine					
El-Dekhela	D1/1	0.33	1.85	7.94	35.35	52.29	2.24	99.67	0.00	Sand	73.60	26.40
	D1/2	0.25	1.50	7.43	31.93	55.76	3.13	99.75	0.00	Sand	74.20	25.80
	D1/3	0.16	1.40	6.92	32.48	56.67	2.37	99.84	0.00	Sand	75.20	24.80
	D1/4	0.00	0.28	2.54	37.56	57.35	2.27	100	0.00	Sand	73.10	26.90
	D1/5	0.16	0.69	3.74	37.17	56.39	1.85	99.84	0.00	Sand	73.80	26.20
	D1/6	0.35	1.12	5.53	42.14	49.39	1.47	99.65	0.00	Sand	73.50	26.50
	D1/7	0.09	0.10	1.33	41.74	54.55	2.19	99.91	0.00	Sand	73.90	26.10
	D1/8	0.00	0.00	0.27	14.69	81.31	3.73	100	0.00	Sand	76.70	23.30
	D2/1	0.00	0.38	1.66	18.21	73.95	5.41	99.61	0.38	Sand	73.20	26.80
	D2/2	0.00	0.10	0.80	17.38	76.10	5.42	99.80	0.2	Sand	75.00	25.00
	D2/3	0.00	0.00	0.21	15.82	78.22	5.70	99.95	0.05	Sand	76.30	23.70
	D2/4	0.00	0.00	0.23	13.02	81.21	5.43	99.89	0.12	Sand	78.50	21.50
	D3/1	0.53	0.99	3.26	25.07	64.64	5.24	99.20	0.26	Sand	93.70	6.30
	D3/2	0.20	0.22	0.52	20.20	73.57	5.16	99.67	0.12	Sand	79.00	21.00
Kilo-21	K1	0.00	1.25	44.28	43.83	10.40	0.24	100	0.00	Sand	99.77	0.23
	K2	0.31	1.32	39.29	47.11	11.90	0.07	99.69	0.00	Sand	99.73	0.27
	K3	0.10	1.80	45.20	42.48	9.71	0.70	99.89	0.00	Sand	99.73	0.27
	K4	0.00	1.54	39.60	45.67	12.88	0.31	100	0.00	Sand	99.78	0.22
	K5	0.32	1.41	42.91	43.52	11.63	0.21	99.68	0.00	Sand	99.79	0.21
	K6	0.14	1.12	36.00	43.77	18.35	0.62	99.86	0.00	Sand	99.66	0.34
	K7	0.45	1.80	38.28	42.05	16.74	0.67	99.54	0.00	Sand	99.82	0.18
	K8	0.11	1.56	32.24	43.99	21.54	0.56	99.89	0.00	Sand	99.76	0.24
	K9	0.28	3.15	24.63	46.43	24.90	0.60	99.71	0.00	Sand	99.66	0.34
	K10	0.18	3.58	27.04	45.27	23.70	0.22	99.81	0.00	Sand	99.73	0.27
	K11	0.30	7.07	54.23	31.02	7.11	0.27	99.70	0.00	Sand	99.72	0.28
	K12	0.40	3.70	59.42	31.20	5.13	0.14	99.59	0.00	Sand	99.75	0.25
	K13	0.37	6.58	56.49	30.50	5.82	0.24	99.63	0.00	Sand	99.24	0.76
	K14	1.93	8.88	54.75	26.36	7.66	0.42	98.07	0.00	Sand	99.69	0.31
	K15/1	9.20	4.61	21.42	49.67	14.81	0.29	90.80	0.00	Gravelly Sand	98.29	1.71
	K15/2	53.23	0.60	20.25	22.20	3.57	0.15	46.77	0.00	Sandy Gravel	99.58	0.42
Abu Talat	A1/1	0.44	16.11	37.52	21.03	24.40	0.50	99.56	0.00	Sand	99.78	0.22
	A1/2	0.00	0.01	2.88	40.02	55.88	1.21	100	0.00	Sand	99.77	0.23
	A1/3	0.00	0.92	7.13	29.47	59.36	3.12	100	0.00	Sand	99.79	0.21
	A2/1	0.00	0.00	3.82	28.91	63.58	3.69	100	0.00	Sand	99.83	0.17
	A2/2	0.00	0.01	3.30	17.89	75.12	3.68	100	0.00	Sand	99.86	0.14
	A2/3	0.00	0.01	3.25	27.09	66.80	2.85	100	0.00	Sand	99.79	0.21
Sidi Knir	S1/1	0.01	0.19	9.94	46.54	43.02	0.30	99.99	0.00	Sand	99.76	0.24
	S1/2	0.00	0.11	8.43	49.49	41.55	0.42	100	0.00	Sand	99.76	0.24
	S1/3	0.00	0.04	3.46	47.57	48.52	0.41	100	0.00	Sand	99.80	0.20
	S1/4	0.00	0.22	9.82	38.12	51.42	0.42	100	0.00	Sand	99.64	0.36
	S1/5	0.10	0.60	23.30	43.19	32.40	0.40	99.89	0.00	Sand	99.32	0.68
	S2	0.00	0.01	6.98	74.49	18.18	0.34	100	0.00	Sand	98.99	1.01
	S3	0.00	0.04	13.62	63.74	22.56	0.04	100	0.00	Sand	99.60	0.40
	S4	0.00	0.01	6.47	68.48	24.89	0.15	100	0.00	Sand	97.62	2.38
	S5	0.00	0.01	4.35	67.63	27.83	0.18	100	0.00	Sand	99.62	0.38

Table 2. Grain size parameters of the studied sediments.

Location	Sample code	Mean size (Mz)		Standard deviation (σ)		Skewness (SK)		Kurtosis (KG)	
El-Dekhela	D1/1	1.95	Medium sand	0.68	Moderately well sorted	-0.30	Coarse skewed	1.13	Leptokurtic
	D1/2	2.01	Fine sand	0.67	Moderately well sorted	-0.29	Coarse skewed	1.14	Leptokurtic
	D1/3	2.01	Fine sand	0.64	Moderately well sorted	-0.30	Coarse skewed	1.10	Mesokurtic
	D1/4	2.08	Fine sand	0.51	Moderately well sorted	-0.11	Coarse skewed	1.03	Mesokurtic
	D1/5	2.04	Fine sand	0.53	Moderately well sorted	-0.19	Coarse skewed	1.04	Mesokurtic
	D1/6	1.95	Medium sand	0.59	Moderately well sorted	-0.21	Coarse skewed	1.06	Mesokurtic
	D1/7	2.07	Fine sand	0.48	Well sorted	-0.05	Nearly symmetrical	1.00	Mesokurtic
	D1/8	2.39	Fine sand	0.37	Well sorted	-0.06	Nearly symmetrical	1.11	Mesokurtic
	D2/1	2.43	Fine sand	0.39	Well sorted	-0.02	Nearly symmetrical	1.10	Mesokurtic
	D2/2	2.37	Fine sand	0.44	Well sorted	-0.07	Nearly symmetrical	1.18	Leptokurtic
	D2/3	2.41	Fine sand	0.40	Well sorted	-0.04	Nearly symmetrical	1.10	Mesokurtic
	D2/4	2.42	Fine sand	0.39	Well sorted	-0.02	Nearly symmetrical	1.11	Mesokurtic
	D3/1	2.21	Fine sand	0.59	Moderately well sorted	-0.19	Coarse skewed	1.20	Leptokurtic
	D3/2	2.33	Fine sand	0.45	Well sorted	-0.09	Nearly symmetrical	1.14	Leptokurtic
Kilo-21	K1	1.18	Medium sand	0.61	Moderately well sorted	0.19	Fine skewed	0.96	Mesokurtic
	K2	1.23	Medium sand	0.62	Moderately well sorted	0.10	Fine skewed	0.92	Mesokurtic
	K3	1.15	Medium sand	0.63	Moderately well sorted	0.18	Fine skewed	0.99	Mesokurtic
	K4	1.24	Medium sand	0.64	Moderately well sorted	0.12	Fine skewed	0.94	Mesokurtic
	K5	1.20	Medium sand	0.63	Moderately well sorted	0.15	Fine skewed	0.93	Mesokurtic
	K6	1.35	Medium sand	0.68	Moderately well sorted	0.12	Fine skewed	0.88	Platykurtic
	K7	1.29	Medium sand	0.71	Moderately well sorted	0.13	Fine skewed	0.90	Platykurtic
	K8	1.41	Medium sand	0.70	Moderately well sorted	0.04	Nearly symmetrical	0.85	Platykurtic
	K9	1.46	Medium sand	0.74	Moderately sorted	-0.09	Nearly symmetrical	0.90	Platykurtic
	K10	1.41	Medium sand	0.73	Moderately sorted	-0.10	Nearly symmetrical	0.87	Platykurtic
	K11	0.92	Coarse sand	0.69	Moderately well sorted	0.15	Fine skewed	1.06	Mesokurtic
	K12	0.92	Coarse sand	0.59	Moderately well sorted	0.19	Fine skewed	1.08	Mesokurtic
	K13	0.89	Coarse sand	0.65	Moderately well sorted	0.14	Fine skewed	1.07	Mesokurtic
	K14	0.85	Coarse sand	0.77	Moderately sorted	0.12	Fine skewed	1.17	Leptokurtic
	K15/1	1.14	Medium sand	1.17	Poorly sorted	-0.39	Strongly coarse skewed	1.64	Very leptokurtic
K15/2	-1.23	Gravel	1.60	Poorly sorted	1.00	Strongly fine skewed	0.49	Very platykurtic	
Abu Talat	A1/1	1.04	Medium sand	0.99	Moderately sorted	0.13	Fine skewed	0.69	Platykurtic
	A1/2	2.05	Fine sand	0.48	Well sorted	-0.16	Coarse skewed	1.01	Mesokurtic
	A1/3	2.06	Fine sand	0.63	Moderately sorted	-0.27	Coarse skewed	1.14	Leptokurtic
	A2/1	2.16	Fine sand	0.54	Moderately sorted	-0.17	Coarse skewed	1.13	Leptokurtic
	A2/2	2.29	Fine sand	0.49	Well sorted	-0.21	Coarse skewed	1.39	Leptokurtic
	A2/3	2.18	Fine sand	0.51	Moderately well sorted	-0.19	Coarse skewed	1.17	Leptokurtic
Sidi Krir	S1/1	1.82	Medium sand	0.56	Moderately well sorted	-0.23	Coarse skewed	0.96	Mesokurtic
	S1/2	1.84	Medium sand	0.54	Moderately well sorted	-0.18	Coarse skewed	0.96	Mesokurtic
	S1/3	1.95	Medium sand	0.46	Well sorted	-0.19	Coarse skewed	1.01	Mesokurtic
	S1/4	1.90	Medium sand	0.57	Moderately well sorted	-0.36	Strongly coarse skewed	0.98	Mesokurtic
	S1/5	1.58	Medium sand	0.67	Moderately well sorted	-0.10	Nearly symmetrical	0.79	Platykurtic
	S2	1.63	Medium sand	0.45	Well sorted	0.00	Nearly symmetrical	1.07	Mesokurtic
	S3	1.60	Medium sand	0.50	Well sorted	-0.04	Nearly symmetrical	0.88	Platykurtic
	S4	1.71	Medium sand	0.45	Well sorted	-0.01	Nearly symmetrical	0.98	Mesokurtic
	S5	1.76	Medium sand	0.43	Well sorted	0.00	Nearly symmetrical	0.99	Mesokurtic

Interestingly, the mud fraction is recorded only in some samples of El-Dekhela with very low content. This can be attributed to the dynamic water conditions (active waves and moderately strong currents) in this area, which cause sediments to be cleaned from very fine-size due to the absence of coral reef and rock structures (Al-Rousan et al., 2006). From the data shown in the boxplots of mean size (M_z), sorting coefficient (σ_1), skewness (SK_1), and kurtosis (KG) of the studied sediments (Fig.2), it is found that the beach sediments which cover the study area that extends from El-Dekhela to Sidi Krir are fine to medium sands with a few coarse sand samples and rarely gravel samples only in Kilo-

21 site. The standard deviation (σ_1) in the studied sediments ranges from poorly sorted to well-sorted and the majority of the area is covered by moderately and well-sorted sediments. The studied sediments exhibit remarkable variations in skewness (SK_1) which ranges from strongly coarse skewed to strongly fine skewed. The skewness of the majority of sediments in the study area is nearly symmetrical and fine skewed but it is remarkable that most of the sediment samples from Abu Talat area and one profile (D1) from El-Dekhela are coarsely skewed which indicates that these areas were more affected by erosion (Duane, 1964; Symphonia and Nathan, 2018). The kurtosis (KG) ranged from very platykurtic to very leptokurtic.

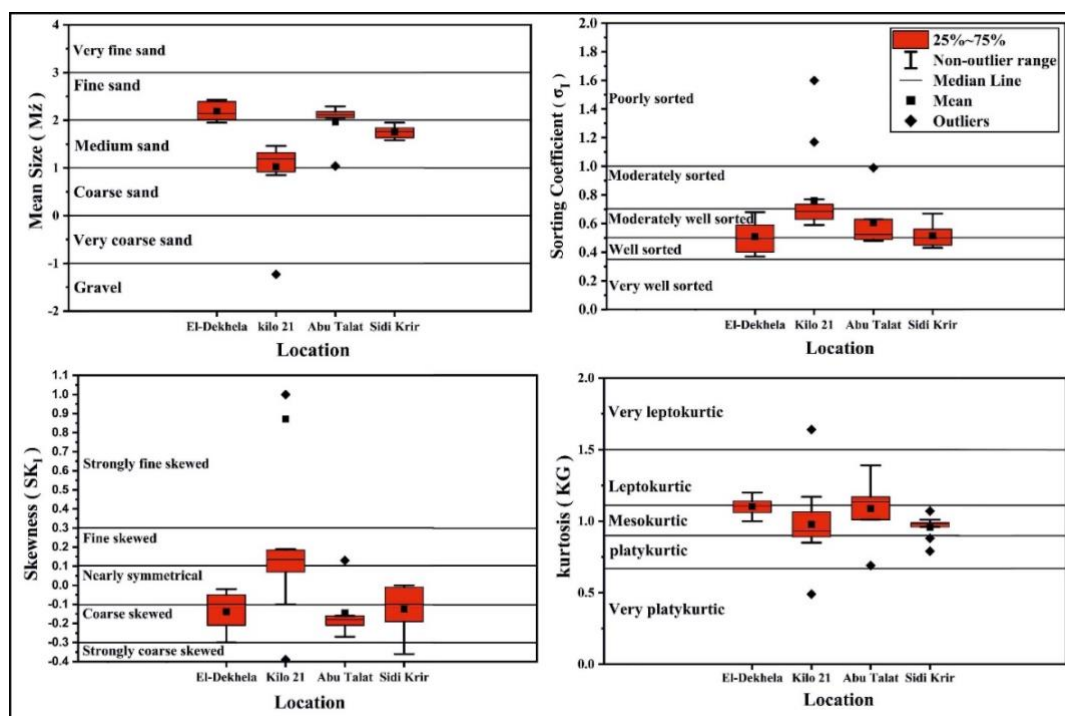


Fig.2. Boxplots of the calculated grain size parameters of the studied sediments.

3.2. Carbonate Content

The percentages of the carbonate content (Table 1) show that the beach sands in the El-Dekhela area are significantly less than the percentages of the carbonate content that reach more than 99 % in the other studied areas as they increase westward along the Mediterranean coast. In the study area's beaches, the carbonate content is primarily due to the carbonate sands which contain shell fragments (biogenic).

3.3. Mineralogy

On the western Mediterranean coast of Egypt, examined samples typically have calcareous sand mineralogy. (e.g., Tucker and Wright, 1990). The results of XRD analysis show that the dominant minerals are carbonate minerals (dolomite, calcite, and aragonite) with smaller amounts of quartz, sylvite, anhydrite, and gypsum, and trace amounts of microcline (Fig.3).

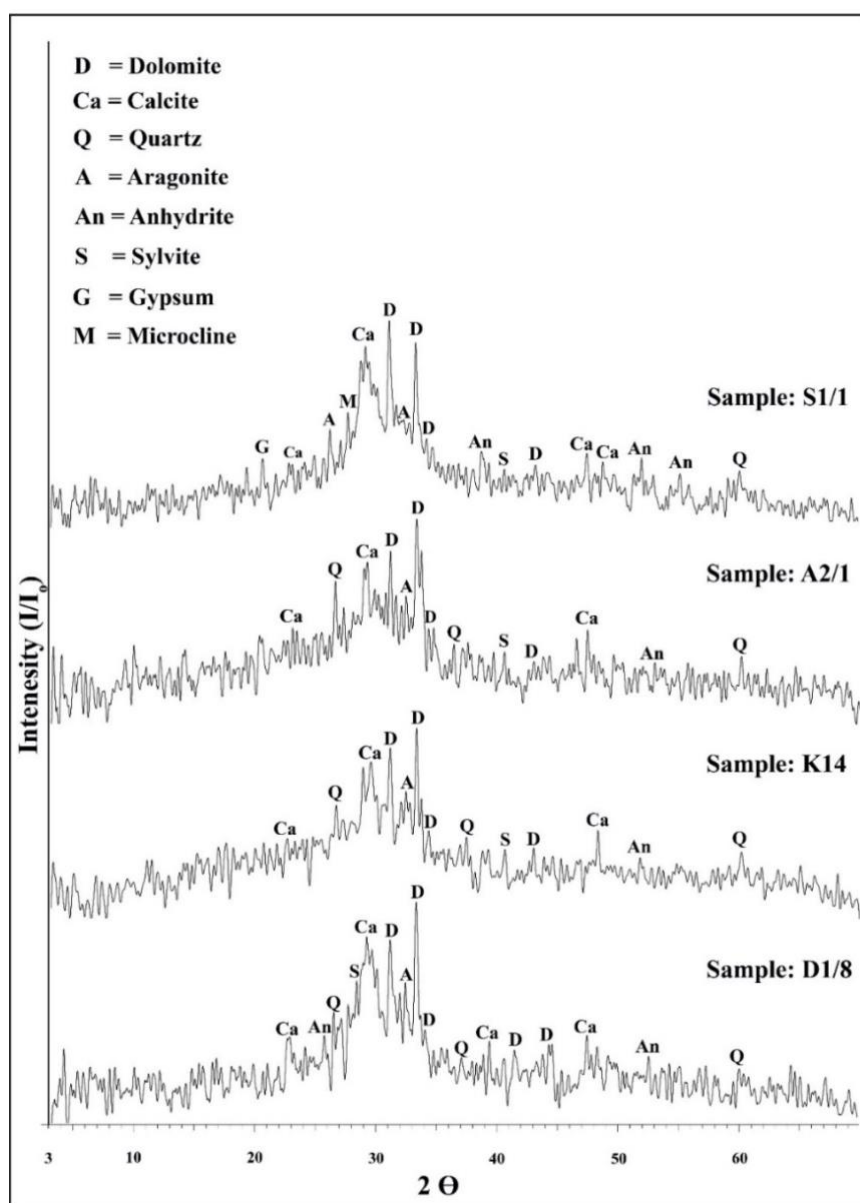


Fig.3. X-ray diffractograms of representative bulk sediments samples from the study area.

Heavy mineral separation technique was carried out on El-Dekhela sediments samples, which contain the highest insoluble residue percent. Generally, the sediments of El-Dekhela area are poor in heavy mineral concentrations. As shown in Table (3) the studied samples' heavy minerals index percentages range between 0.15 % to 1.36 % (average 0.61 %). The light fraction is composed mostly of quartz and feldspars. The heavy mineral assemblage of the investigated sediment samples contains both opaque and non-opaque heavy minerals. The percentages of both opaques and non-opaques abundances in the studied samples are shown in Table 3. The opaque minerals form the major portion of the total heavy minerals in the studied samples. The opaques values range between 30.73 % and 52.86 % (average 42.98 %). The dominant opaque minerals in sediments of the study area are iron ores including ilmenite and magnetite (Hilmy, 1951). The non-opaque heavy minerals were identified as pyroxenes, amphiboles, epidote, zircon, garnet, tourmaline, rutile, sphene, staurolite, kyanite, monazite, and biotite in various amounts. In the present study, the non-opaque minerals are classified as ultra-stable, metastable, and unstable (Mange and Maurer, 1992).

Table 3. Relative abundances of heavy minerals from the studied sediments.

Location	Sample Code	Heavy index	Op	Py	Am	Ept	Zrn	Tou	Rut	Gar	Sph	Sta	Ky	Mon	Bio	ZTR
El-Dekhela	D1/1	0.50	51.64	13.11	10.38	7.65	4.37	0.00	3.55	1.09	2.73	1.91	2.73	0.55	0.27	16.48
	D1/2	0.51	40.12	20.94	13.27	10.32	1.18	0.00	2.65	2.65	2.65	1.77	2.95	0.59	0.88	6.50
	D1/3	0.59	45.54	15.18	11.88	9.90	3.30	0.99	5.94	0.66	0.99	2.31	2.31	0.00	0.99	19.14
	D1/4	0.35	41.56	16.56	13.64	10.39	1.30	0.97	4.22	0.65	2.27	4.55	2.92	0.32	0.65	11.24
	D1/5	0.22	36.98	18.82	21.44	10.50	0.88	0.66	2.41	1.31	0.88	2.41	2.19	0.44	1.09	6.36
	D1/6	0.36	41.16	15.47	18.23	14.64	1.66	0.00	1.38	1.93	1.38	1.10	3.04	0.00	0.00	5.16
	D1/7	0.49	34.35	8.71	25.88	16.00	4.24	0.47	1.88	0.94	1.18	2.35	2.59	0.24	1.18	10.22
	D1/8	1.36	37.09	13.01	16.50	15.53	5.44	0.39	2.91	2.72	0.58	1.17	2.72	0.00	1.94	14.33
	D2/1	0.22	30.73	15.37	25.30	16.08	1.65	0.47	3.78	0.47	0.47	2.84	2.36	0.24	0.24	8.56
	D2/2	0.59	45.23	14.91	13.94	13.69	5.13	0.49	3.18	0.49	0.73	1.71	0.49	0.00	0.00	16.07
	D2/3	1.01	46.79	14.74	14.53	12.61	4.49	0.00	3.42	1.50	0.64	0.64	0.21	0.43	0.00	14.86
	D2/4	1.02	45.53	19.09	9.94	14.71	3.38	0.20	1.79	2.58	0.40	0.99	1.19	0.00	0.20	9.89
	D3/1	0.15	52.09	14.34	12.89	13.06	2.90	0.18	2.18	0.54	0.00	1.09	0.73	0.00	0.00	10.98
	D3/2	1.15	52.86	12.83	9.21	11.85	6.00	0.14	2.37	2.23	0.56	0.84	0.98	0.00	0.14	18.10
	Ave.	0.61	42.98	15.22	15.50	12.64	3.28	0.35	2.98	1.41	1.10	1.83	1.96	0.20	0.54	11.99

Op= Opaque, Py= Pyroxenes, Am= Amphiboles, Ept= Epidote, Zrn= Zircon, Tou= Tourmaline, Rut= Rutile, Gar= Garnet, Sph= Sphene, Sta= Staurolite, Ky= Kyanite, Mon= Monazite, Bio= Biotite.

The ultrastable group contains zircon, tourmaline, and rutile (Fig.4). Zircon is the most abundant mineral in this group. It is existed as colourless grains with prismatic, bipyramidal, subrounded and rounded shapes. Some of these grains are fractured and contain inclusions. Tourmaline grains of the studied samples show strong pleochroism and have prismatic and subrounded shapes with brown and green colours. Rutile grains have deep red, brownish red, and amber colours. They are characterized by distinct pleochroism and thick borders. The metastable group contains epidote, kyanite, staurolite, garnet and monazite. Epidote grains are sub-angular grains featuring yellowish green and lemon yellow colours. Kyanite grains are colourless cleavable elongated prismatic grains. Staurolite grains are sub-angular grains with golden yellow and bright yellow colours. Some of these grains contain inclusions. Garnet grains are colourless and light pale pink grains with sub-angular and rhombohedral shapes. Some of these grains' surfaces are pitted. Monazite grains are oval and spherical grains that are almost colourless or have a pale yellow colour. They are characterized by surface pitting and some grains have yellowish brown stains on their surfaces. The unstable group contains amphiboles, pyroxenes, sphene and biotite. The amphiboles grains in the studied samples are elongated, short prismatic, irregular and rectangular grains with green, bluish green and brown colours. They are characterized by distinct cleavages and strong pleochroism. The dominant amphibole mineral in the study area is dark green hornblende (Hilmy, 1951). The pyroxenes grains in the studied samples are colourless, brown and green grains with short and elongated prismatic, irregular and subrounded shapes. These grains vary between altered and rarely fresh grains and show inclusions and fractures. The dominant pyroxene mineral in the studied area is augite with brown and yellowish green colours (Hilmy, 1951). The observed sphene grains are irregular, almost rounded, and sub-angular grains with light brown and honey yellow colours. Biotite grains are platy irregular grains with reddish brown colour, characterized by inclusions and irregular outlines.



Fig.4. Photomicrographs of ultrastable, metastable and unstable heavy minerals in El-Dekhela area.

ZTR index quantitatively defines the mineralogical maturity of the heavy mineral assemblages (Hubert, 1962). When the ZTR maturity index increases, the concentrations of zircon, tourmaline, and rutile occur with a decrease in other non-opaque heavy minerals numbers. The ZTR index increases noticeably in mineralogically mature sediments. The ZTR index in the studied samples (Table 3) ranges between 5.16 % and 19.14 % (average 11.99 %). The low percentage of ZTR index and the high percentage of unstable minerals (amphiboles and pyroxenes) in the studied sediments suggest a mineralogically immature nature (Ali et al., 2022). El-Gamal and Saleh (2012) found that the highest value of the ZTR index in the beach sediments west of Rosetta estuary in the Nile Delta region in Egypt was 20.16 %, which indicates mineralogically immature sediments.

3.4. Petrological Components of the Beach Sediments

Petrographically, the selected beach sediment samples from the studied areas were examined and described texturally, morphologically, and compositionally. The beach sands in the study area are mainly composed of loose carbonate sands, which contain an abundance of ooids, peloids, and bioclasts with a few concentrations of quartz and glauconite in some places (Fig.5). Interestingly, the lowest amount of ooids and highest amount of quartz were recorded in El-Dekhela.

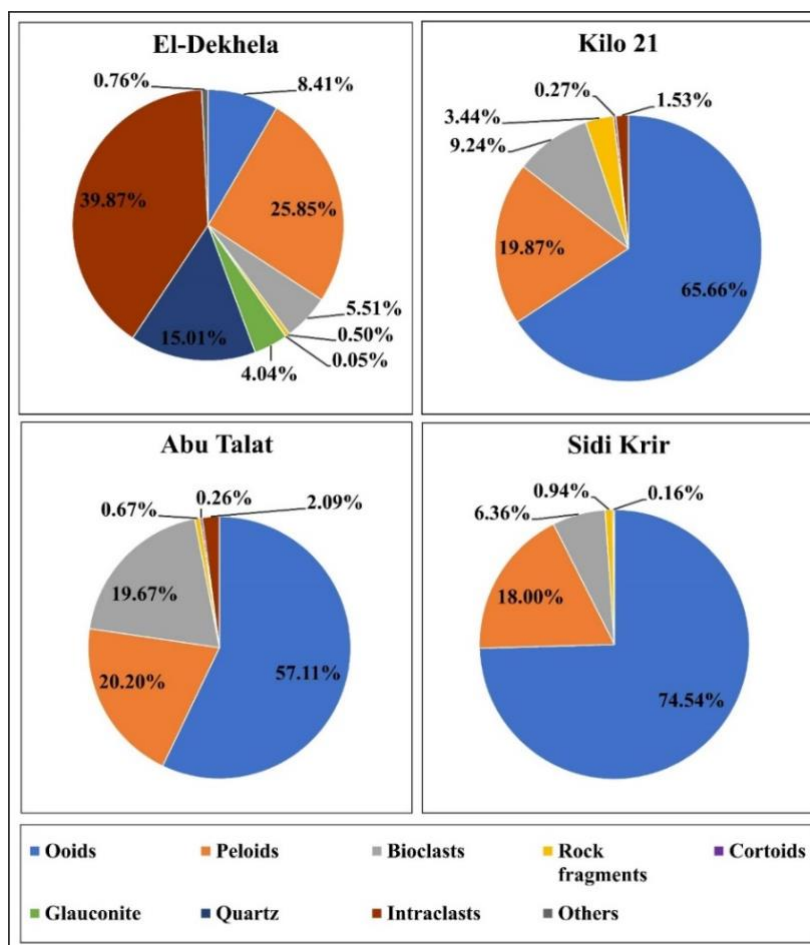


Fig.5. Pie diagrams showing the average percentages of the beach sediments components abundance in the study area.

The beach sediments in El-Dekhela area predominantly consist of intraclasts and peloids with average percentages of 39.87 % and 25.85 %, respectively (Fig.5). These sediments contain significant amounts of quartz grains (Fig.6A, E) with an average percentage of 15.01 %, smaller amounts of ooids (Fig.6A), bioclasts (Fig.6E, H), and glauconite (Fig.6G) with average percentages of 8.41 %, 5.51 %, and 4.04 %, respectively. The internal fabric of most intraclasts in the area is composed of anhedral and subhedral calcite crystals of varying sizes (Fig.6C). The most frequent way that intraclasts are formed is by the erosion of fragments from a thick layer of semi-consolidated carbonate sediment, with erosion occurring in the sediment at depths of a few inches to a few feet. Intraclasts can be made of any form of limestone or dolomite. Some consists of homogeneous microcrystalline calcite (Folk, 1959). Most of the micritic peloids in the area are oval and subrounded (Fig.6E, G). The absence of radial or concentric internal structures distinguishes peloids from ooids (Flügel, 2010). Most of ooids are normal ooids with concentric structures around peloidal nuclei. The sizes of these ooids range between 0.06 and 0.26 mm, while the thickness of surrounding light-coloured laminae ranges between 0.01 and 0.05 mm. Their colour is creamy white. Most of them are ellipsoidal, also the spherical shape is detected and some of them are eroded. The surface of these ooids is slightly rugged and has no special features (Fig.7A). Superficial ooids were detected in minute amounts (Fig.6C, H). The bioclasts are varied, including foraminifera (Fig.6E), echinoderms (Fig.6E), and coralline red algae (Fig.6H). In addition, these sediments contain small amounts of heavy minerals and feldspars, sedimentary rock fragments (Fig.6H)

and cortoids with average percentages of 0.76 %, 0.5 %, and 0.05 %, respectively. Cortoids are rounded skeletal grains encased in a thin micrite envelope, with an indistinct boundary between the grain and the envelope (Flügel, 2010; Deng et al., 2015; Pomoni and Karakitsios, 2016).

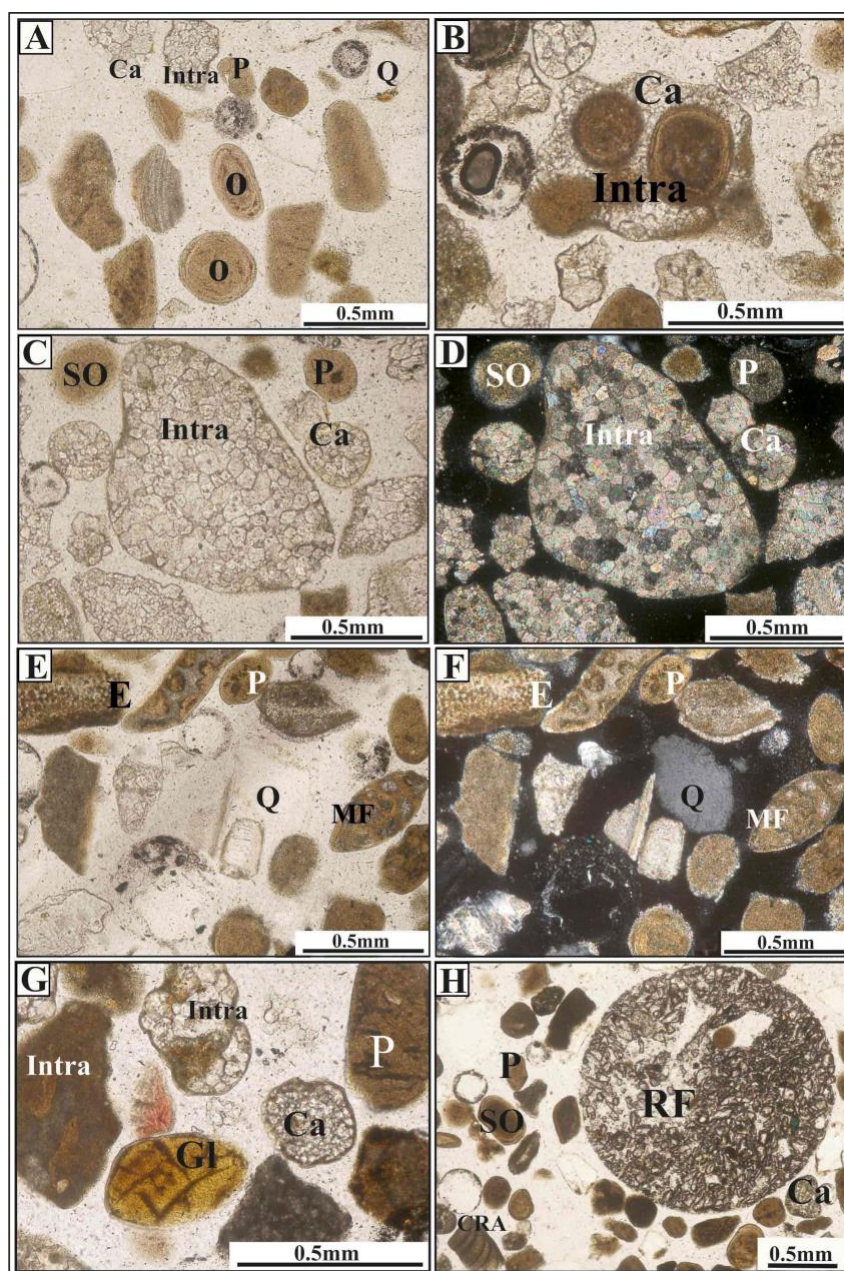


Fig.6. Photomicrographs of the carbonate and non-carbonate components of the beach sediments in El-Dekhela area (Plane polarized light except D and F in crossed Nicols): (A) Spherical and ellipsoidal ooids associated with intraclasts and quartz grains; (B) Intraclasts contain ooids bound by calcite crystals; (C) and (D) Intraclasts contain calcite crystals associated with peloids and superficial ooid; (E) and (F) Different types of bioclasts associated with peloids and quartz grains; (G) Different types of intraclasts with peloidal grains and glauconite; (H) Sedimentary rock fragment trapping a peloidal grain. (O: Normal ooids, SO: Superficial ooids, P: Peloids, Ca: Calcite crystals, Q: Quartz, Gl: Glauconite, Intra: Intraclasts, E: Echinoderms, MF: Miliolid foraminifera, CRA: Coralline red algae, RF: Sedimentary rock fragment).

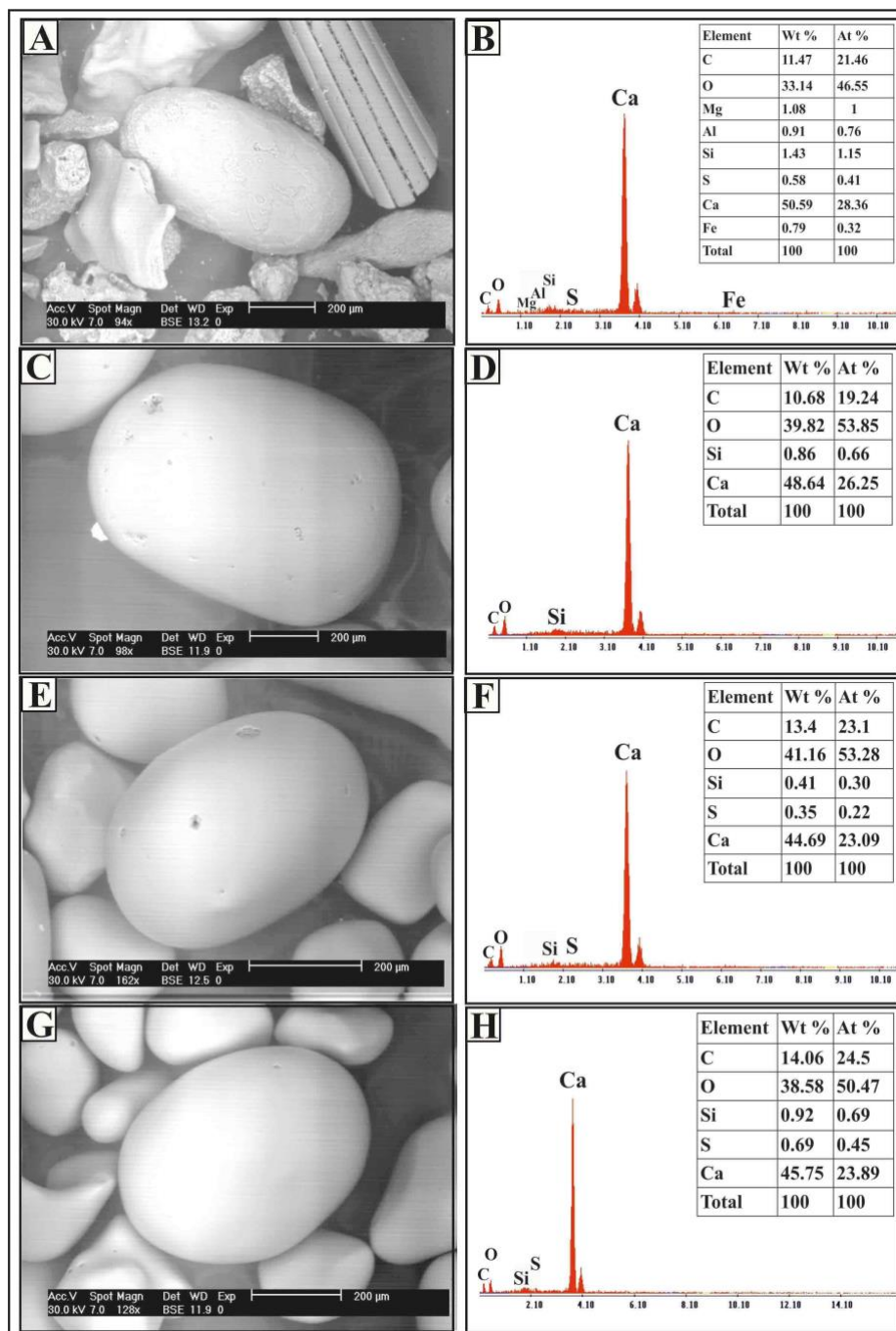


Fig.7. SEM micrographs and EDX analysis results of ooids from the studied areas: (A) Ellipsoidal ooid from El-Dekhela area with slightly rough surface; (B) Showing the chemical composition of the ooid from El-Dekhela area; (C) Ellipsoidal ooid from Kilo-21 area showing microborings on its surface; (D) Showing the chemical composition of the ooid from Kilo-21 area; (E) Ellipsoidal ooid from Abu Talat area with smooth surface and few microborings; (F) Showing the chemical composition of the ooid from Abu Talat area; (G) Ellipsoidal ooid from Sidi Krir area with smooth well-polished surface and microboring; (H) Showing the chemical composition of the ooid from Sidi Krir area.

The beach sediments in Kilo-21 area consist mainly of ooids with an average of 65.66 % (Fig.5). Most of these ooids are single tangential ooids having spherical and ellipsoidal shapes and peloidal nuclei with numerous concentric coatings and some of them contain nuclei of skeletal grains, quartz,

and calcite (Fig.8A, C). Microbial borings, the narrow dark-brown patches that may be seen in many grains, are related to organic matter (Scholle and Ulmer-Scholle, 2003; Trower et al., 2018). Some cerebroid ooids, superficial ooids, compound ooids, and eroded ooids (Fig.8F) were detected. Cerebroid ooids are ooids that have a mottled appearance of the cortex with radial micritic sectors which start often at the former nucleus surface depressions and cut the tangentially arranged laminae (Fig.8E) (Carozzi, 1962; Flügel, 2010; Xiao et al., 2021). The nuclei of superficial ooids are coated with a few numbers of micrite calcite envelopes (Fig.8G) (Zeng et al., 1983; Boggs, 2009; Riaz et al., 2021). Composite ooids are made up of two or three ooids that have a cortex surrounding them (Fig.8G) (Tucker, 1985; Khaing et al., 2022). The ooids in this area are well-polished white grains and their sizes range between 0.15 mm to 1.11 mm while the thickness of the surrounding light-coloured laminae range between 0.04 mm to 0.7 mm. Some ooids have micropores on their surface (Fig.7C). Peloids and bioclasts were detected in significant amounts in these sediments with average percentages of 19.87 % and 9.24 % respectively. Peloid shapes vary between spherical and ellipsoidal (Fig.8A, E, H). The bioclasts contain gastropods (Fig.8G), brachiopods (Fig.8G), bivalves (Fig.8H), echinoderms (Fig.8H), coralline red algae (Fig.8F), and calcareous green algae (Fig.8G). In addition, these sediments contain little amounts of sedimentary rock fragments (Fig.8H), intraclasts (Fig.8G), and cortoids (Fig.8E) with average percentages of 3.44 %, 1.53 %, and 0.27 %, respectively. The intraclasts consist of multiple allochems.

The beach sediments in Abu Talat area consist principally of white normal single ooids with peloidal nuclei and well-defined concentric lamination (Fig.9A, B). Occasionally, nuclei of these ooids are calcite grains or skeletal fragments and rarely quartz nuclei have been detected. Also, various forms of ooids appear in this area such as superficial ooids (Fig.9F, H), compound ooids (Fig.9B), and eroded or broken ooids (Fig.9E). Two shapes of ooids were observed: spherical and ellipsoidal. Some of these ooids lost the concentric texture as a result of micritization (micritized ooids) (Fig.9G), despite the possibility that it was also lost throughout the conversion of an original aragonitic ooid to calcite (neomorphism) (Adams et al., 1987; Chatalov, 2005; Vulpius and Kiessling, 2018). Richter (1983) observed that micritic ooids are associated with oomolds and sparry relic/brickwork ooids, such as originally aragonite cortices, in the Lower Triassic of Hydra Island (Greece) and the Lower Muschelkalk of Germany. The presence of micritic ooids would appear to suggest slow sediment accumulation rates and/or low sediment mobility (Chatalov, 2005). Sizes of the ooids in this area range between 0.07 and 1.48 mm, while the thickness of surrounding light-coloured laminae ranges between 0.04 and 0.15 mm. Some ooids have microborings as a surface feature (Fig.7E). The average percentage of the ooid abundance in Abu Talat area is 57.11 %. These sediments also include spherical and oval peloids (Fig.9E–G) with an average of 20.20 %, a wide variety of bioclasts including gastropods (Fig.9E), echinoderms (Fig.9C), bivalves (Fig.9C), porostromate cyanobacteria (Fig.9D), calcareous green algae (Fig.9D), coralline red algae (Fig.9F), bryozoans (Fig.9A, E), and foraminifera (Fig.9C, E) with an average of 19.67 % and little amounts of intraclasts of multiple allochems (Fig.9A, B, D), sedimentary rock fragments (Fig.9F), and cortoids with average of 2.09 %, 0.67 %, and 0.26 %, respectively.

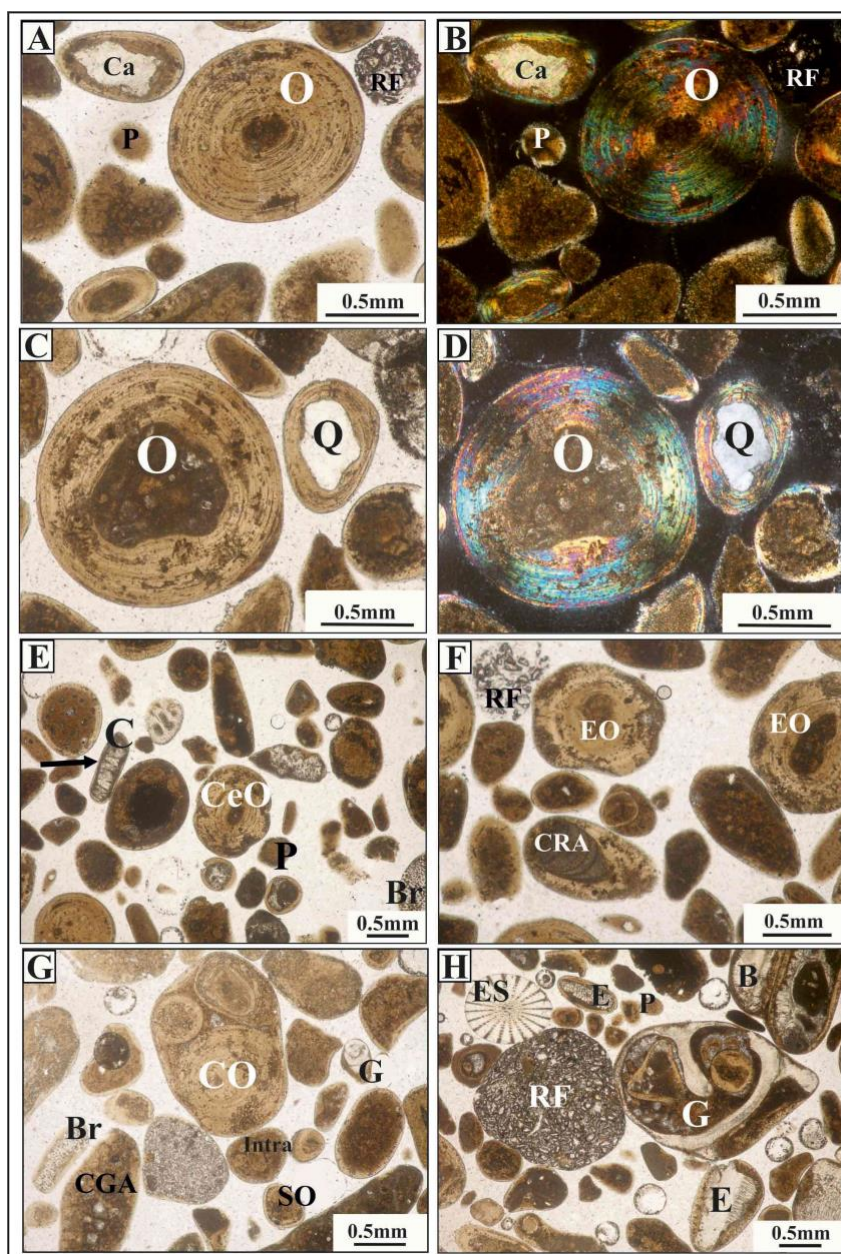


Fig.8. Photomicrographs of the beach sediments components in Kilo-21 area (Plane polarized light except B and D in crossed Nicols): (A) and (B) Normal tangential ooid with small peloidal nucleus interpreting the existence of thick laminae and ooid grain with large nucleus of calcite with thin laminae; (C) and (D) Detailed view of concentric ooid (the small, dark spots and lines are fungal and algal borings, some of which are filled with micritic cements) and ooid with quartz nucleus; (E) Different components of the sediments including cerebroid ooid, peloids, biocalsts and cortoid (black arrow refers to a micritic envelope surrounding the grain); (F) Eroded ooids reflecting reworked sediments; (G) In the center of the photo there is compound (composite) ooid consists of three ooid grains with cortex surrounding them, also the photo shows superficial ooid and distinct types of bioclasts; (H) Showing a gastropod shell filled with peloidal grains and calcite crystals and other types of bioclasts such as echinoderms and bivalves. (O: Normal ooids, CO: Compound ooids, CeO: Cerebroid ooids, SO: Superficial ooids, EO: Eroded ooids, P: Peloids, C: Cortoids, Ca: Calcite, Q: Quartz, Intra: Intraclasts, E: Echinoderms, ES: Echinoid spine, Br: Brachiopods, B: Bivalves, G: Gastropods, CGA: Calcareous green algae, CRA: Coralline red algae, RF: Sedimentary rock fragment).

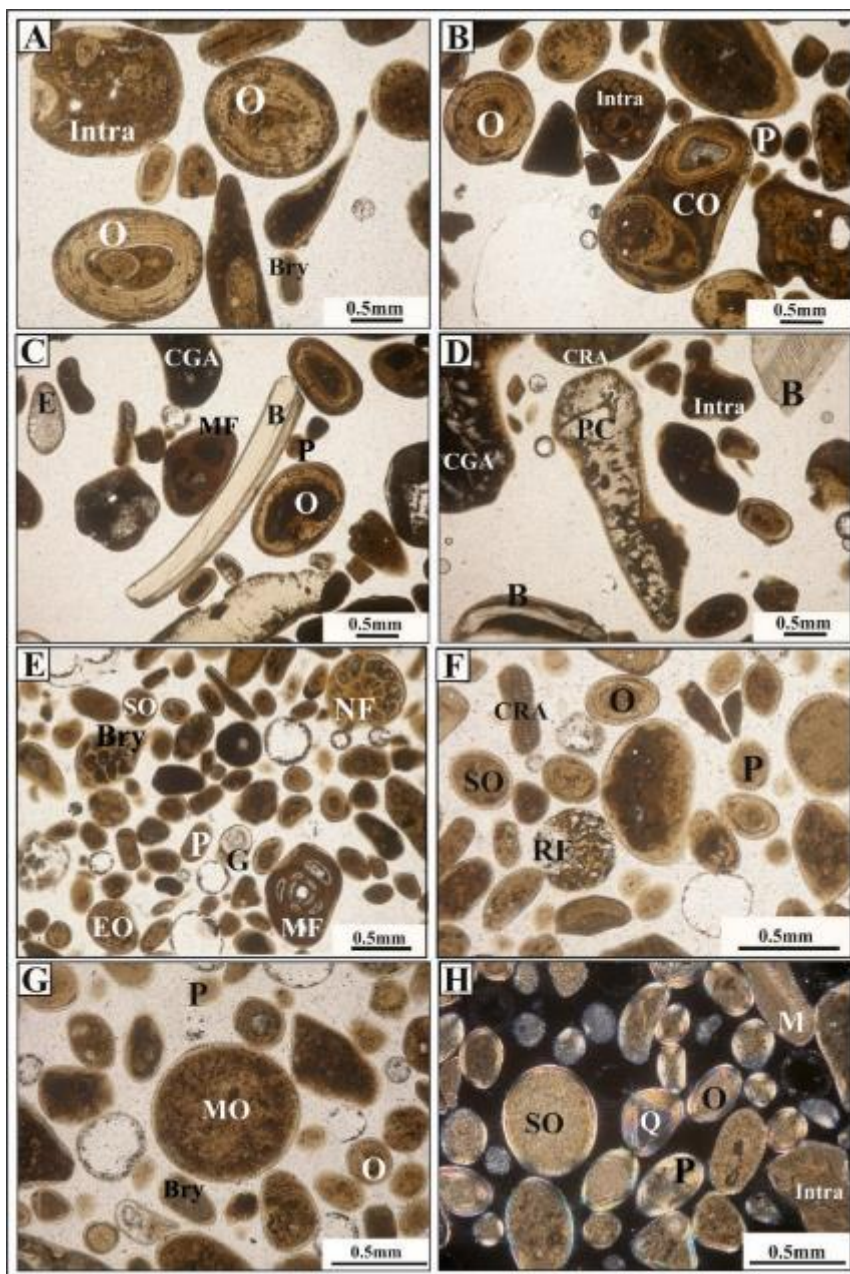


Fig.9. Photomicrographs of the beach sediments components in Abu Talat area (Plane polarized light except H in crossed Nicols): (A) and (B) Showing different shapes and forms of ooids (spherical, ellipsoidal, single and compound ooids); (C), (D), and (E) Showing diverse types of bioclasts including micritized bivalve shell (at the lower part of the photo (D)), foraminifera, algae, bryozoans and porostromate cyanobacteria; (F) Peloids associated with superficial ooids, sedimentary rock fragment and coralline red algae; (G) Almost completely micritized ooid appears in the center of the photo, micrite covers the concentric structure of the ooid leaving only thin laminae surrounded the grain; (H) Superficial ooids appear at the left half of the photo, concentric ooid with quartz nucleus appears in the center of the photo and molluscan fragment appears at the upper right side of the photo. (O: Normal ooids, CO: Compound ooids, SO: Superficial ooids, EO: Eroded ooids, MO: Micritized ooids, P: Peloids, Q: Quartz, Intra: Intraclasts, E: Echinoderms, B: Bivalves, G: Gastropods, M: Mollusca, Bry: Bryozoans, CGA: Calcareous green algae, CRA: Coralline red algae, NF: Nodosariid foraminifera (*Lenticulina*), MF: Miliolid foraminifera (*Triloculina*), PC: Porostromate cyanobacteria, RF: Sedimentary rock fragment).

Sidi Krir beach sediments consist mainly of normal single ooids with peloidal nuclei that also may be calcite grains, quartz grains, or skeletal fragments (Fig.10C, E, F). The dominant shape of these ooids is the ellipsoidal shape, and also spherical ooids were detected. Some eroded ooids (Fig.10H), micritized ooids (Fig.10E), geopetal ooids (Fig.10G), and superficial ooids (Fig.10C, G) were observed. Geopetal ooids are formed as a result of the selective dissolution of the cortex layers, leaving the less soluble nuclei unsupported. This caused the undissolved material to gravitationally collapse to the bottoms of the ooids' molds, creating a remarkable geopetal fabric. Later, spar filling of the moldic pores occurred after the collapse (Mazzullo, 1977; Scholle and Ulmer-Scholle, 2003; Varkouhi and Ribeiro, 2021). The existence of a thin cortex in superficial ooids is probably due to the large size of the nuclei, which restrict grain movement and inhibit ooid growth (Harris, 1979; Siahi et al., 2017). The average percentage of ooids abundance in Sidi Krir area is 74.54 % and their sizes range between 0.07 and 0.85 mm, while the thickness of the light-coloured laminae ranges between 0.04 and 0.3 mm and the concentrations of these laminae are well-defined. Most of the ooids are smooth and well-polished grains almost without special surface features except few microborings in some grains (Fig.7G). The sediments also contain peloids, bioclasts, sedimentary rock fragments (Fig.10H), and intraclasts with average percentages of 18.00 %, 6.36 %, 0.94 %, and 0.16 %, respectively. Most of the peloids have ellipsoidal shapes and some of them have spherical shapes (Fig.10A–C). The bioclasts include gastropods, calcareous green algae (Fig.10B), coralline red algae (Fig.10B), and foraminifera (Fig.10A). Intraclasts consist of different allochems (Fig.10B).

3.5. Provenance and Sedimentary History

The occurrence of rounded and prismatic shapes of the ultrastable heavy minerals in El-Dekhela region refers to the presence of different sources of heavy minerals in this area. One of these sources was mentioned by Hilmy (1951) as he concluded that the beach sands from El-Dekhela to Rosetta are thought to be water-borne sediments mechanically transported by the Nile River, derived primarily from the Ethiopian Plateau, and then mixed with shell fragments. As the mineral assortment has been carried by the Nile River for nearly 4000 Km, it has received modest additions from other rocks along the Nile's course, such as Precambrian gneisses, granites, schists, and syenites in the cataract areas of Upper Egypt and Sudan. The heavy mineral concentrations decrease westward from the mouth of the Nile River near Rosetta to the western portion of the coast at Marsa Matruh. The concentrations of the heavy minerals are almost the same in the whole area of the coast between Rosetta and Alexandria, while the beach sands west of El-Dekhela to Marsa Matruh are mainly composed of carbonate minerals forming oolites. The low amount of heavy minerals suggests that they were eroded from a carbonate ridge (Frihy et al., 2004). El Sayed et al. (2020) investigated the mineralogy of sediments near the Nile Delta and noticed prismatic and rounded zircon, tourmaline, and rutile grains, indicating two sources of these sediments. Because El-Dekhela is the closest area of the study areas to Rosetta, the Nile River added sediments containing heavy minerals to it. However, the relative distance of El-Dekhela from Rosetta caused the shortage of these minerals until they were almost absent to west. The direction of the marine currents from west to east caused the confinement of the presence of heavy minerals in El-Dekhela and prevented their transportation to the rest of the study areas to the west (Fig.11). The enrichment of amphiboles and pyroxenes in the examined samples from El-Dekhela site demonstrates the importance of the basement rocks (Red Sea Mountains) in the distribution of these minerals. The presence of amphiboles and pyroxenes in a higher percentage than the ultrastable heavy minerals is not due to the short distance of transportation, but rather to the weakness of the river currents responsible for the transportation of these sediments, that confirmed by the fine to medium size and the moderately well sorting of these sediments. The coexistence of epidote, kyanite, garnet, staurolite, and biotite indicates a metamorphic source (Milner, 1952).

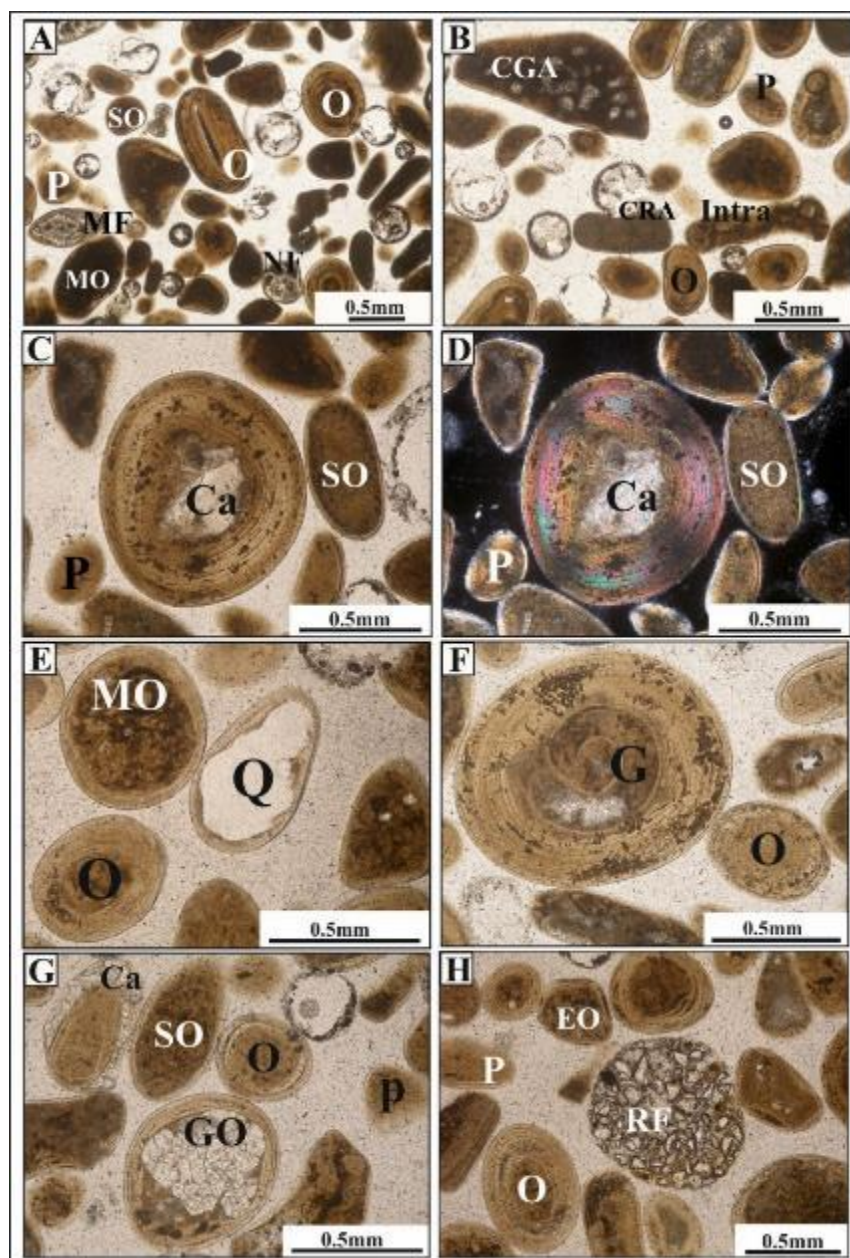


Fig.10. Photomicrographs of the beach sediments components in Sidi Krir area (Plane polarized light except D in crossed Nicols): (A) Spherical and ellipsoidal normal concentric ooids, superficial ooids with surrounding thin laminae and micritized ooid (The structure has been lost by micritization) associated with peloids and bioclasts. (B) The upper left part of the photo shows calcareous green algae has spherical, hollow segments (according to Scholle and Ulmer-Scholle (2003) the preservation was caused by the replacement of the original organism mineralized parts by synsedimentary infill). (C) and (D) Normal ooid with well-defined concentric laminae and calcite nucleus associated with peloids and superficial ooids. (E) Showing different forms of ooids including: ooid with quartz nucleus coated by relatively thin laminae, partially micritized ooid and normal concentric ooid. (F) Normal tangential ooid with shell fragment (gastropods) nucleus surrounded by well-defined concentric laminae rich in organic matter. (G) Showing geopetal ooid with collapsed nucleus and calcite filling the inner body of the ooid. (H) Sedimentary rock fragment, eroded ooid and peloidal grains. (O: Normal ooids, SO: Superficial ooids, EO: Eroded ooids, MO: Micritized ooids, GO: Geopetal ooids, P: Peloids, Ca: Calcite, Q: Quartz, Intra: Intraclasts, G: Gastropods, CGA: Calcareous green algae, CRA: Coralline red algae, NF: Nodosariid foraminifera, MF: Miliolid foraminifera, RF: Sedimentary rock fragment).

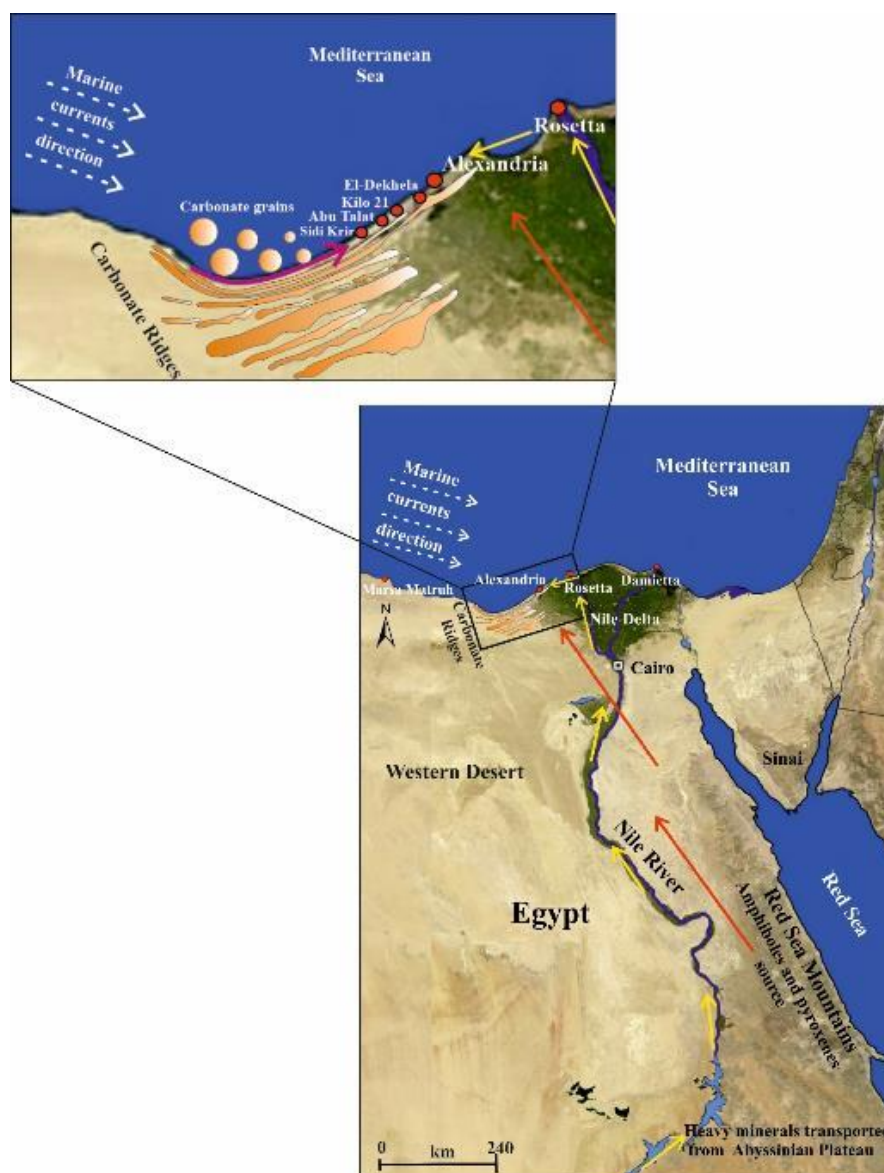


Fig.11. Sedimentary history in the study area.

Most of the ooids in the study area are cream to white in colour and generally have a pearly luster, these features indicate that these sediments were formed in highly energetically agitated water (Boggs, 2009). Water agitation appears to play a significant role in the growth of ooids, especially normal tangential ooids which generally have spherical forms with polished surfaces (Flügel, 2010). Jipa and Cehlarov (2017) studied the depositional environment of calcareous ooids from Dacian Basin in Romania and concluded that the concentric structure of ooids is a crucial feature that denotes the agitated water genetic condition. The small, dark spots which represent fungal and algal borings that have been detected in ooids of the study area reflect the effect of destructive and constructive forces in the ooid life. The construction occurs by precipitation through the motion of the grain at the surface, while the destruction is caused by endolithic organisms when the ooid is at rest (Scholle and Ulmer-Scholle, 2003). The micrite envelopes that are observed around some grains or around bioclasts (cortoids) may originate by many processes including destructive micritization associated with microboring organisms' activities, constructive development of the envelopes caused by epilithic organisms, and partial dissolution and recrystallization (Flügel, 2010). Vršič et al. (2021) studied marine carbonates in the Sirt Basin of Libya and found that some cortoids are a result of destructive micritization by the

microendolithic organisms. In addition, constructive micrite envelopes associated with epilithic organisms have been detected. The high abundance of ooids in Kilo-21, Abu Talat, and Sidi Krir areas can be a sign of autochthonous ooid deposits. The autochthonous ooids reveal a simple transport history, while the occurrence of compound ooids may indicate the redeposition of these sediments (Flügel, 2010). The occurrence of broken ooids in these areas reveals the reworking of high energy waves and currents (high energy level) (Tucker, 1984). Cerebroid ooids are observed in Kilo-21 area, the origin of this type of ooids may be related to the bacterial activity that dissolves parts of the surface of ooids (Kahle, 1974; Xiao et al., 2021). In Sidi Krir area, the presence of geopetal ooids is suggested to be related to the former existence of evaporites in the associated rocks (Carozzi, 1963). Chatalov (2005) studied types of the carbonate ooids in sediments from northwestern Bulgaria and mentioned that the former presence of the evaporites is one of the probable hypotheses that regard the dissolution of minerals in the shrunken (geopetal) ooids. The present study suggests that the ooids in the study area came from more than one source; autochthonous, especially in Kilo-21, Abu Talat, and Sidi Krir, and allochthonous ooids, maybe reworked from the carbonate ridges. Based on the ^{14}C dating, Fabricius et al. (1970) came to the conclusion that ooids in the modern marine sands of the Gulf of Gabesin Tunisia are not originating at the present time but rather are being reworked from older sediments. According to El-Shahat (1995), modern beach deposits in Alexandria are most likely autochthonous sediments. Stoffers et al. (1980) concluded that the recent pelletal carbonate sediments off Alexandria, are modern lithified fecal pellets. The low abundance of ooids and their rough surfaces in El-Dekhela area indicate that these ooids are reworked as they were transported probably from the carbonate ridges to the west, maybe from the Pleistocene ridges along the shoreline nearby Alexandria as a lot of these ridges have been entirely destroyed through urbanization (El-Sammak and Tucker, 2002).

4. Conclusions

The coastal region between El-Dekhela and Sidi Krir is covered with fine to medium carbonate sands, with carbonate content reaching more than 99 percent westward. These sediments are medium to fine sand size and moderately well sorted to well sorted, which indicates a medium- to high-energy depositional environment. The variations in sorting are probably caused by variations in water turbulence and the depositional current velocity. The results of XRD analysis show that the dominant minerals in the beach sediments of the study area are carbonate minerals (dolomite, calcite, and aragonite) with smaller amounts of quartz, sylvite, anhydrite, gypsum, and trace amounts of microcline. In El-Dekhela area, small amounts of heavy minerals were detected. Opaque minerals, amphiboles and pyroxenes form a major part of these heavy minerals with smaller amounts of epidote, zircon, tourmaline, rutile, garnet, kyanite, monazite, sphene, staurolite, and biotite. Low ZTR index values indicate that these sediments are mineralogically immature. The assemblage of heavy minerals in these deposits suggests a variety of possible source rock types including igneous, metamorphic, and sedimentary rocks.

The beach sediments in Kilo-21, Abu Talat and Sidi Krir areas are composed mainly of ooids which are the dominant component of these sediments with average percentages ranging between 57.11 % and 74.54 %, large amounts of peloids and bioclasts, small amounts of rock fragments, intraclasts, and very small amounts of cortoids except Sidi Krir samples which don't contain cortoids, while El-Dekhela area beach sediments consist mainly of intraclasts and peloids as dominant components with average percentages of 39.78 % and 25.85 %, respectively, significant amounts of quartz grains, smaller amounts of ooids, bioclasts and glauconite and very small amounts of heavy minerals and feldspars, rock fragments and cortoids. Ooids in the study area vary between autochthonous ooids mainly in Kilo-21, Abu Talat, and Sidi Krir area and allochthonous ooids mainly in El-Dekhela area and with a few amounts in other studied locations.

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