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Geomophological & geoarchaeological indicators of the Holocene sea-level changes on Ras El Hekma area, NW coast of Egypt

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ABSTRACT

Ras El Hekma area is a part of the NW coast of Egypt. It is located on the Egyptian Mediterranean Coast, approximately 220 km West of Alexandria City. It is shaped as a triangle with its headland extending into the Mediterranean sea for about 15 km, and is occupied by sedimentary rocks belonging to the Tertiary and Quaternary Eras. Its western coastline consists of Pleistocene Oolitic limestone ridges with separated steep scarps, while the eastern coastline consists of sandy beaches, coastal spits, coastal bars, tombolos and bays.

The objective of this paper is to define some geomorphological and geoarchaelological indicators of The Holocene sea-level changes in the study area, especially the geomorphic landforms such as: marine notches, cliffs, sea caves and benches. This is to add to some archaeological remains that have been discovered by the paper's author under the current sea level. These remains include: submerged ruins of Greek and Roman harbors, wells and fish tanks near the coastline (Leuke Akte, Hermaea, Phoinikous and Zygris), in addition to an ancient Roman harbor used during the World War II in Tell El Zaytun area (Site #6). Evaluations of the discovered archaeological remains help our understanding of the evolution of the sea level during the Holocene. This study is based on observation of the relative sea-level curves drawn of the Holocene, detailed geomorphological and Geoarchaelogical surveying, sampling, dating and mapping as well as satellite image interpretation and GIS techniques.

1. Introduction

1.1. Geological and geographical setting

Ras El Hekma area is a part of the NW coast of Egypt. It is located on the Mediterranean, 220 km West of Alexandria City. It is shaped as a triangle with its headland extending into the Mediterranean for about 15 km. It covers about 230 km^2 (Fig. 1).

The major geomorphic features of Ras El Hekma area are oriented towards E/W-direction, parallel to the present shoreline. Geologically speaking, the study area consists of parallel coastal ridges composed of aeolionites and paleosols along the recent coastline, which can be used as an indicator of former shorelines. The Miocene Marmarican homoclinal plateau may be seen as the Southern border of the study area with elevation between 100 and 135m above sea level. Extensive field investigations, measurement of selected geomorphic features above and under the current sea level, topographic maps, DEM, Landsat images and geomorphic mapping, have all participated in classifying the following geomorphic units from South to North:

A. The first unit is The Middle Miocene Carbonates Plateau: “El Daffah or Marmarica Plateau”. It is formed from Miocene limestone rock up to 150m thick. The plateau is affected by weathering processes and is developed into a hard pink crust with many solution-holes formed by chemical reactions as a result of rainfall and humidity.
B. The second unit is the sloppy surface piedmont plain between the Miocene plateau in the South and the coastal plain in the North. It is separated by some gullies and short V-shaped seasonal streams or wadies. Its surface is covered by mixed fluvial and aeolian sediments.
C. The third unit is a coastal plain. It covers the triangle's coastal plain to the north of the Miocene plateau. It is covered by Quaternary deposits which rest with conformable and or unconformable relation to the Tertiary deposits. These deposits

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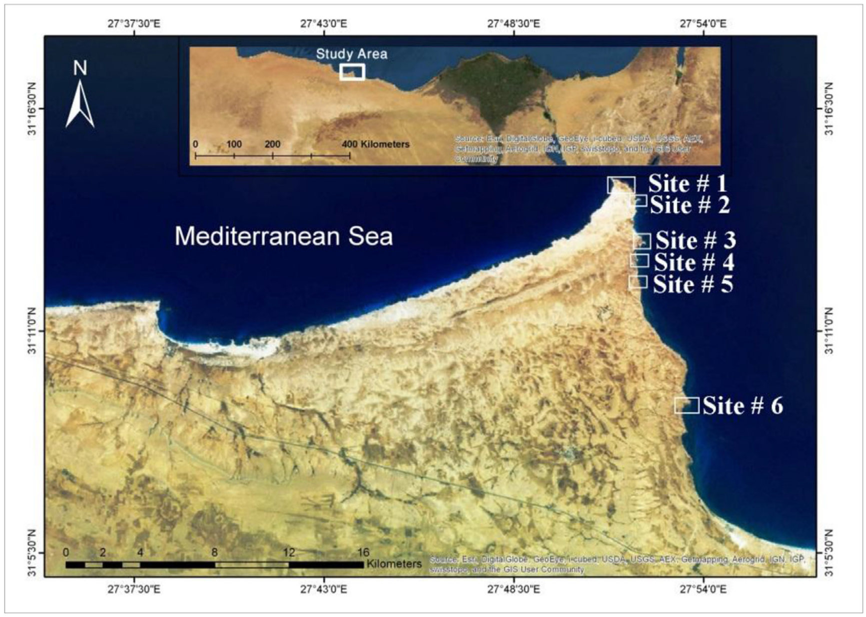

Fig. 1. Location map of the study area and selected field surveying sites.

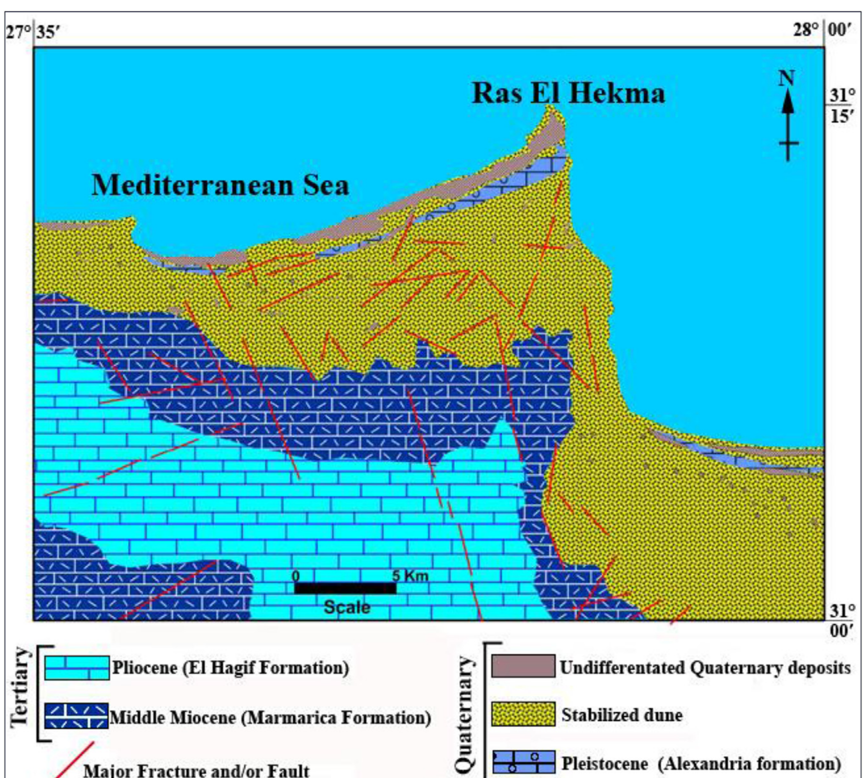

Fig. 2. Geological map of the study area. (After: Yousif and Bubenzer, 2011).

are mainly represented by the Holocene deposits of coastal sand dunes, lagoonal and alluvial deposits and Pleistocene Oolitic limestone ridges as well as old lagoonal deposits. This geomorphic unit is composed of a sequence of elongated limestone ridges. Its elevation varies between 10 and 60 m above sea level, and it slopes gently northward oriented parallel to the present coastline. It mainly consists of Ooltic limestone with darker color weathered crust, with shallow loamy paralleled elongated depressions (Fig. 2).

As part of the northwestern coast of Egypt, the study area's climate is typically a semi-desert one, with no real heavy rain throughout the year. It is generally characterized by warm dry summers with average annual temperatures of 20.7 °C, average annual rainfall of 141.32 mm, and average annual evaporation rate of 1578 mm (Fig. 3).

1.2. Objective

The objective of this study is to define some geomorphological and geoarchaelological indicators of The Holocene sea-level changes in the study area, especially the geomorphic landforms such as: marine notches, cliffs, sea caves and benches. This is to add to some archaeological remains that have been discovered by the author under the current sea level, and may be seen as indicators of rising sea-levels during the Holocene. These remains include submerged ruins of Greek and Roman harbors, wells and fish tanks discovered near the coastline (Leuke Akte, Hermaea, Phoinikous and Zygris), in addition to the remains of an old 2nd WW harbor.

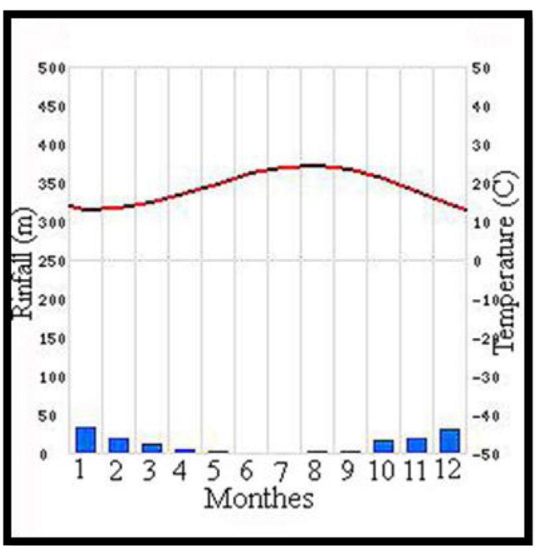

Fig. 3. Monthly temperature (C°) and rainfall (mm) data for Marsa Matruh area between 1998 and 2014.

1.3. Methods

Extensive geomorphological and geoarchaeological surveys along the beaches of Ras El Hekma area, have been performed during May & June 2015. Six selected sites (Fig. 1) have been surveyed and mapped in detail. Paleo sea-level shorelines have been mapped depending upon sea-level indicators, and some measurements were performed at each site for geomorphic eustatic features according to Pirazzoli (1986) & Evelpidou et al. (2012) such as positive and negative coastal notches, marine terraces, caves as well as geoarcheological evidence; such as ancient harbors, malls, fish tanks, wells, potteries and other remains, as well as dating it (Fig. 4).

2. Results

Some geomorphological and geoarchaeological indicators have also been used to define the Holocene shorelines as follows:

2.1. Geomorphological indicators

2.1.1. Notches

There are both emerged and submerged notches corresponding to former positive and negative shorelines, indicating rapid tectonic movements including uplift and subsidence activities. The detailed surveying along the selected sites in the coastal zone of Ras El Hekma area (Figs. 1 and 5 and Tables 1–3), show that some emerged eustatic-notches vertex height measure between ($\geq +250 \pm 37$ cm) from sea-level. The shape of most erosion notches on limestone rocks appear U-shaped, while some of them are also V-shaped. Some structural, solutional and composed notches are recognized in the studied sites on different elevations. This is to add to some well-marked U-shaped underwater notches, indicating a former shoreline of about −70–10 cm, developed on limestone coastal rocks specially at sites #3, 4 and 5 located at Rofa Bay and south of it.

2.1.2. Marine terraces

The Marine terraces of the study area are flat, horizontal, or gently slopped surfaces of marine origin, bounded by steeper slopes

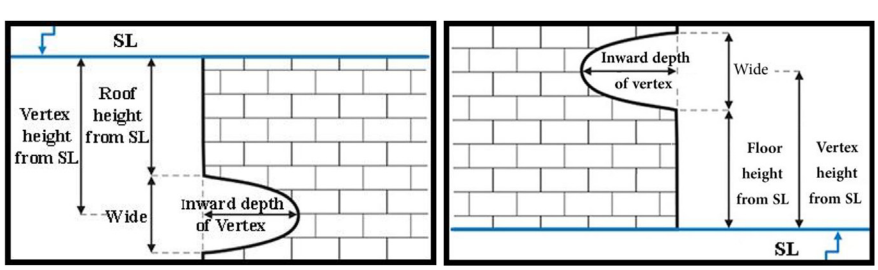

Fig. 4. Measurement of submerged & emerged notches dimensions. (After: Evelpidou et al., 2012)

Fig. 5. Some selected nothches in the study area (for locations see Figs. 6 and 7 and for dimensions see Tables 3–5).

Table 1
Dimensions of emerged notches in Site #1.

Notch #	Vertex height from SL (m)	Roof height from SL (m)	Wide (m)	Inward depth of vertex (m)	Remarks	Shape	Type
N1	4.5	3.50	2.00	1.50	Over MT 2.0 m	U Shape	Wind Erosion Sea
N2	2.30	1.70	1.00	0.50	Over MT 0.3 m		Sea level change
N3	4.90	3.70	2.40	0.40	Over MT 2.0 m		Structure
N4	3.40	2.40	2.00	0.60	Over MT 1.0 m		(Bedding plane)
N5	3.75	3.00	1.50	0.60	Over MT 2.0 m		Composed Erosion
N6	3.70	3.00	1.40	0.60			Solution
N7	0.75	0.50	0.50	0.40	Over MT 0.3 m	V Shape	Sea level change
N8a	5.20	4.30	1.80	1.00	Over MT 1.0 m	U Shape	Solution
N8b	2.80	2.00	1.90	0.60			Composed Erosion
N9	3.10	2.40	1.70	1.00			
N10	2.90	2.30	1.20	1.40			

Table 2
Dimensions of emerged notches in Site #2.

Notch #	Vertex height from SL (m)	Roof height from SL (m)	Wide (m)	Inward depth of vertex (m)	Remarks	Shape	Type
N11	2.05	1.50	1.10	0.45	Over MT 1.0 m	V Shape	Composed Erosion
N12	2.25	1.70	1.10	0.75			
N13	1.85	1.40	0.90	0.35			
N14	1.85	1.50	0.70	0.40			
N15a	0.75	0.40	0.70	0.20	Composed Over MSL	U shape	Sea level change
N15b	1.65	1.20	0.90	0.45		V shape	
N16a	0.80	0.40	0.80	0.40		U shape	
N16b	1.80	1.30	1.00	0.55		V shape	Structure
N17a	2.77	2.20	1.15	0.40	Over MT 0.4 m	U shape	Sea level change
N17b	3.80	3.10	1.40	0.50			
N18	2.10	1.20	1.80	0.70		V shape	
N19	2.10	1.20	1.80	0.50		U shape	
N20	2.05	1.20	1.75	0.50		V shape	
N21	2.15	1.20	1.90	0.50	Over MT 0.4 m with cave	U shape	
N22	2.10	1.20	1.80	0.60	Over MT 0.4 m		
N23	2.10	1.30	1.60	0.30			
N24	1.80	1.20	1.20	0.30	Over MT 0.4 m with cave		
N25	2.10	1.20	1.80	0.40	Over MT 0.4 m		
N26	2.10	1.20	1.80	0.40			
N27	2.15	1.20	1.90	0.60	Over MT 0.4 m with cave		
N28	2.40	1. 20	2.40	0.50	Over MT 0.4 m		
N29	1.55	1.15	0.80	0.25			

Table 3
Dimensions of notches in Site #3.

Notch #	Vertex height from SL (m)	Roof height from SL (m)	Wide (m)	Inward depth of vertex (m)	Remarks	Shape	Type
N30	0.37	0.20	0.35	0.20	Emerged	U Shape	Sea level change
N31	0.40	0.20	0.40	0.40			
N32	0.50	0.25	0.50	0.35	Submerged	V Shape	
N33	0.45	0.30	0.30	0.55		U Shape	
N34	0.60	0.25	0.70	0.60		V Shape	
N35	0.70	0.40	0.60	0.60		U Shape	
N36	0.65	0.40	0.50	0.60			

Table 4
Dimensions of the marine terraces in Site #1.

MT#	Height from SL (m)	Maximum wide (m)	Long (m)	Remarks	Type
MT1a	2.00	6.10	169.85	Emerged	Sea level change
MT1b	1.00	5.75	185		
MT2	2.00	6.45	83.26		
MT3	3.00	5.15	172.95		
MT4	0.40	5.45	92.75		
MT5	2.00	6.40	192		
MT6a	2.00	5.70	166.87		
MT6b	0.30	4.90	138		
MT7	1.00	3.50	65.63		
MT8	1.00	5.30	81.55		
MT9	1.50	5.85	105.77		

Table 5
Dimensions of the marine terraces in Site #2.

MT#	Height from SL (m)	Maximum wide (m)	Long (m)	Remarks	Type
MT18	− 0.10	2.50	88.97	Submerged	Sea level change
MT19	− 0.10	4.50	215.65		
MT20	0.80	2.50	115.83	Emerged	
MT21	0.20	1.30	111.32		
MT22	0.20	1.50	118.4		

Table 6
Dimensions of the marine terraces in Site #3.

MT#	Height from SL (m)	Maximum wide (m)	Long (m)	Remarks	Type
MT10	2.50	5.50	27.11	Emerged	Sea level change
MT11	2.30	6.30	50.18		
MT12	1.00	1.30	93.18		
MT13	2.20	5.70	22		
MT14	0.30	9.80	29.47		
MT15	0.30	5.70	47.82		
MT16	0.40	6.30	24.7		
MT17	0.40	5.70	45.94		

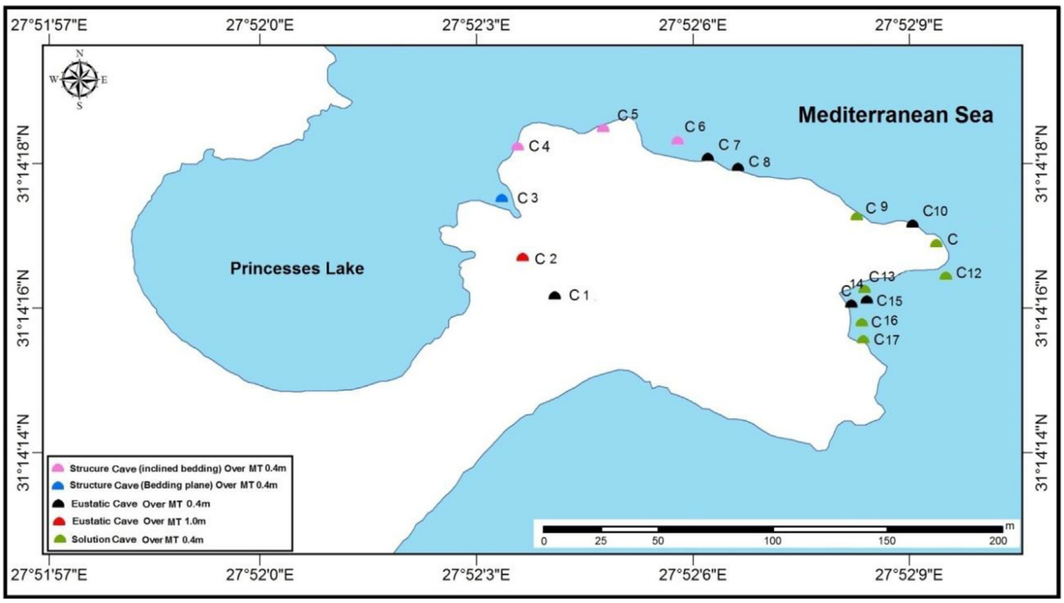

Fig. 6. Dimensions of caves in Site #2.

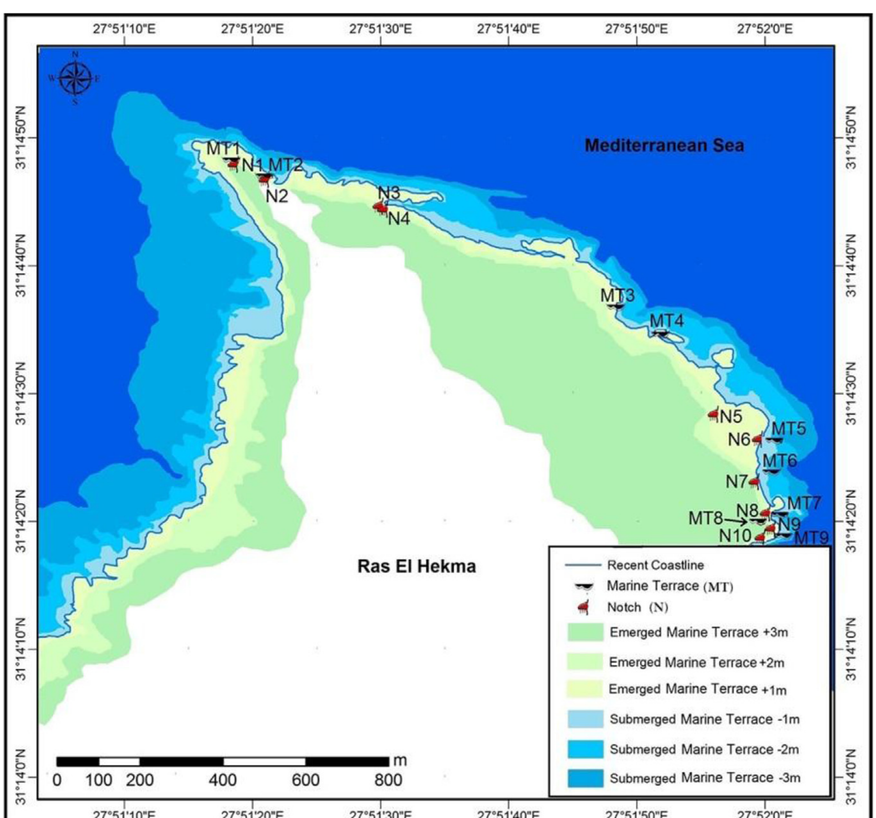

Fig. 7. Distribution of some geomorphological indicators in Site #1.

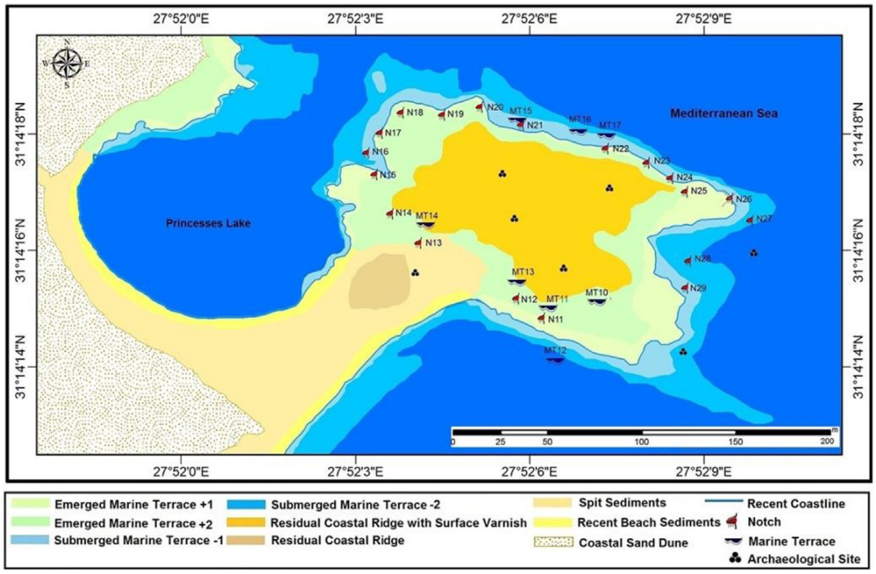

Fig. 8. Distribution of some geomorphological indicators in Site #2.

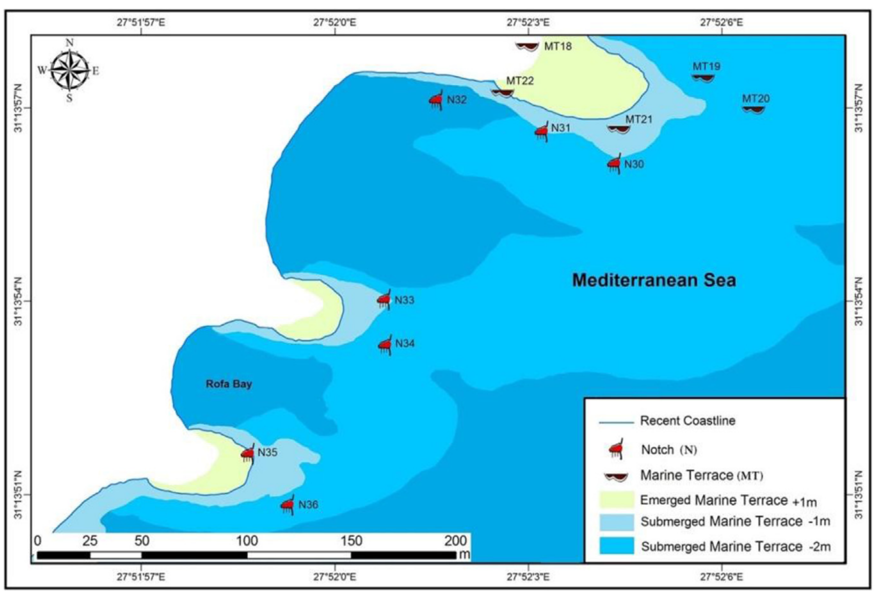

Fig. 9. Distribution of some geomorphological indicators in Site #3.

Table 7
Dimensions and classification of caves in Site #2.

Cave #	Height m	Wide m	Depth m	Remarks	Type
C1a	1.70	0.70	0.60	Over MT 0.4 m	Sea level change
C1b	1.00	1.00	0.50		
C2a	2.90	0.10	0.60	Over MT 1.0 m	
C2b	2.90	0.25	0.70		
C3	2.50	1.30	1.00	Over MT 0.4 m	Structure (Bedding plane)
C4	2.60	0,70	0.70	Over MT 0.4 m	Structure (inclined bedding)
C5a	9.50	0.50	1.00		
C5b	5.40	0.80	1.00		
C6a	5.20	0.40	0.60		
C6b	2.90	1.00	1.00		
C6c	2.70	1.80	1.00		
C7	2.10	0.30	0.60	Over MT 0.4 m	Sea level change
C8	2.50	0.60	0.70		
C9	3.70	1.70	0.60	Over MT 0.4 m	Solution
C10a	2.50	0.35	0.70	Over MT 0.4 m	Sea level change

(*continued on next page*)

Table 7 (*continued*)

Cave #	Height m	Wide m	Depth m	Remarks	Type
C10b	1.30	1.10	0.85		
C11a	3.90	3.00	0.40	Over MT 0.4 m	Solution
C11b	3.90	3.00	0.40		
C12	3.70	1.60	0.40		
C13a	5.10	0.70	0.60		
C13b	2.90	0.50	0.50		
C14	1.65	0.80	0.40	Over MT 0.4 m	Sea level change
C15	2.10	2.10	0.70		
C16	3.00	0.80	0.90	Over MT 0.4 m	Solution
C17	1.80	0.90	0.60		

Table 8
Dimensions of marine arches in Site #2.

Marine arches#	Height m	Wide m	Long m	Remarks	Type
A1	1.40	0.70	1.70	Over MT	Sea level change
A1b	1.50	0.40	1.70	0.4 m	
A2	2.70	0.80	0.90	Over MT 1.0 m	Structure

Fig. 10. Location of ancient harbors in Ras El Hekma area according to (Fourtau,1893).

facing sea waves (Pirazzoli, 2005). They can be seen as indicators of sea level changes, for both emerged and submerged coasts. They also provide information not only about former levels, but also regarding the accuracy of the reconstruction (Evelpidou and Pirazzoli, 2015). Some marine terraces are also surveyed in the study area. Dimensions are as shown in (Tables 4–6) and distributions are evident in (Figs. 7–9). They can be classified into three emerged heights from the current sea level; $\geq \pm 1$ m, ± 2 m and ± 3 m in addition to two submerged levels below current sea level; $\pm$ 0.10 m, $\geq \pm 1$ m.

2.1.3. Marine caves and arches

A marine cave is a hole formed by sea wave action on the vertical rocky cliffs by the horizontal sea level. As such, it may be seen, among other indicators, as a geomorphological indicator for interpreting relative sea level changes. Some marine caves and arches are also surveyed, especially in site #2 (Table 7&Fig. 6). It is, thus, classified into structural caves (formed on bedding plane or due to inclined bedding), solution caves (formed by solution action by sea salt water and/or rain fresh water), and eustatic caves formed due to sea level changes mainly in the following heights from the current sea level; $\pm$ 1 m, ± 2 m and ± 3 m, at the same levels of some recognized marine terraces such as (C12 & N 28) in (Figs. 6 and 8) (Table 8).

2.1.4. Dating

Two shell samples are dated by using of radiocarbon samples collected from tidal notches. The first sample is collected for emerged tidal notch # N24 (Vertex height 1.8 m from SL formed on limestone cliff). It is dated from around 3080 BP $\pm$ 145 with an erosion rate of about 0.58 mm/y. The second sample is collected for submerged tidal notch #N33 (Vertex height −0.45 m from SL). It has been dated from 480 BP45. It means that the second tidal notch has been submerged by the relative sea-level rise during the 16th century by erosion rate of about 0.94 mm/y.

2.2. Geoarchaeological indicators

Some historical writers mentioned the location of ancient Ptolemaic & Roman harbors in the NW coast of Egypt; such as (Fourtau, 1893), (Muller, 1901), & (Ball, 1942), they mapped the location of some ancient harbors in Ras El Hekma area as a part of NW coast of Egypt (Figs. 10 and 11). "*Hermaea*" harbor (Fourtau,1893) or "*Cap Leuke*" (Muller, 1901) is located on the NE side of Ras El Hekma's triangle, a short distance from the headland. It is constructed inside a bay-area and protected from the northern waves by a tombolo and bordered to the West by some coastal dunes accumulated upon calcareous ridges, in addition to a coastal sabkha and wadi mouths (Fig. 12).

At the moment, some archaeological evidence were discovered by the paper's authors in two locations in Ras El Hekma area. The first location is in site #2. It can be seen as part of "*Hermaea* or *Cap Leuke*" ancient harbor. All found indicators lie under recent sea-level for about 3–4 m as a result of sea-level change and monoclinal subsidence, but some basaltic blocks has accumulated on the shore by stormy waves (Figs. 12 & 14a). The second location is in site #6 at Tell El Zaytoun area. Some archaeological evidence supporting the argument that this was a used harbor during WW II and as well as during ancient Roman time (Fig. 13).

3. Discussion and conclusion

Some geomorphological and geoarchaeological indicators are surveyed in six selected sites in the eastern side of Ras El Hekma area. What is Vertex! heights of some emerged notches measure between ($\geq$+250 $\pm$ 37 cm) in limestone above SL. One such vertex in site #2 measure 1.8m and dates to around 3080 BP $\pm$ 145, and several submerged notches measure between −70 and −10 cm below SL. The deeper notch with vertex −65 cm

Fig. 11. Location of Ptolemaic ancient harbors in the NW coast of Egypt (Muller,1901).

Fig. 12. Geomorpholo/archaeological map of Site #2.

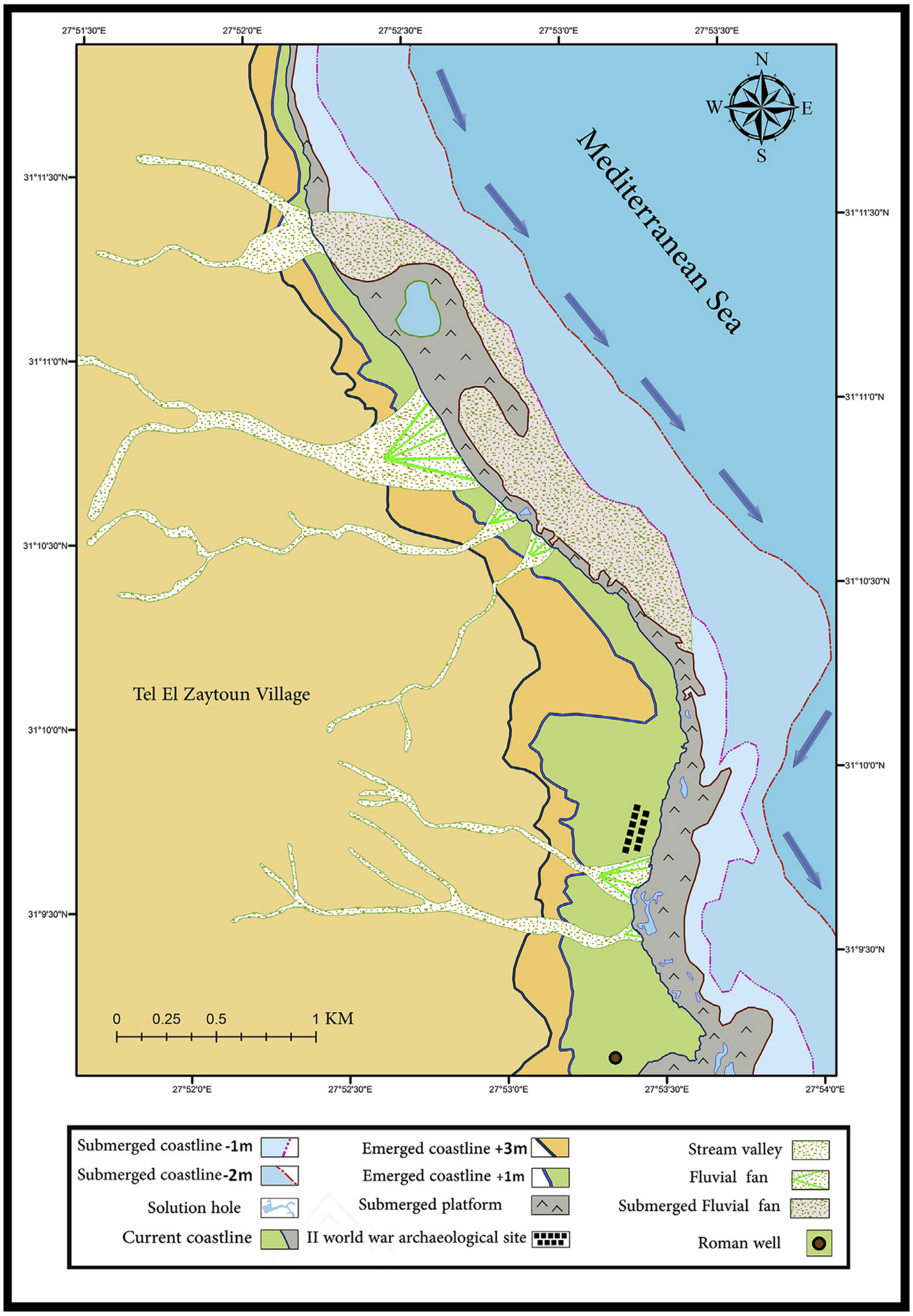

Fig. 13. Geomorpholo/archaeological map of Site #6.

dates to the 16th century with an erosion rate of about 0.94 mm/Yr. It is recognized at the same level of other geomorphic indicators. This is to add to the marine terraces and caves observed on three levels ≥ ± 1 m, ±2 m and ±3 m at the same level of other indicators as well as two submerged levels below the current sea level; ±0.10–0.20 m, ≥ ±1 m in Sites #2,4,5 and 6 of the study area. Some geomorphological features are formed by other erosion agents which do not indicate sea-level changes have been neglected such as aeolian and solution caves and structural benches.

Some georachaeological evidence for ancient Roman harbors is recognizable in two locations 3 m below present SL; such as an ancient wine press and some Roman columns of crushed limestone in site #2, fish tanks near the current SL in Tell El Zaytoun (Site #6), as well as a rectangular remains of military bases from the 2nd WW at site #6 above SL that was used during 2nd WW. The Remains of pier from the 2nd WW at site #6 can be used as an indicator of the SL during this period of (about 0.30 m under the current SL).

Using the above geomorphological and geoarchaeological indicators, we could estimate the evolution of the SL as follows: During the last 3000 years, sea-levels fall from 1.8 m to 65 cm below the current SL during the 16th century, then to 30 cm below the current SL during the 2nd WW.

Fig. 14. Some geoarchaeological evidence in the study area: a) some basaltic blocks accumulated by waves on the beach of Site #2, it can be consider as a part of the pier of "*Hermaea* or *Cap Leuke*" ancient harbor. b) Rectangular remains of military bases from the WW II at site #6 c) Remains of pier from the WW II at site # 6 d) Roman well at site #6 e) Remains of olive press under current sea level for about 3 m at site #2 f) Remains of Roman columns under current sea level for about 3 m at site #2.

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