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A Geomorphological Analysis of Abu Zneima Area, Western Sinai, Egypt

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Abstract

Abu Zneima area (600 km^2) is a structural headland of Gulf of Suez, some 150 km south east of Suez. The study area comprises variegated limestone rock formations and a complex structure of rift system. Most of Abu Zneima area is dissected by old fluvial networks and influenced by folding and faulting-associated landforms. Few locals contain current geomorphic process and landforms under the hegemony of hyper arid climate. The aim of this paper is to analyze the geomorphic characteristics of fluvial and structural effects on the development of the study area. Various techniques of data collection and interpretation have been followed, especially field survey, GPS data collection, digital cartography and remote sensing methods.

Introduction

Sinai Peninsula occupies the northeastern shoulder of the Egyptian land, comprising multi geomorphological systems and complicated geological history. With its various natural sub-systems, from the Mediterranean to the hyper-arid, it resembles all Egyptian environments; hence it deserves the nick-name of "*petite Egypt*"

Abu Zneima area (Figures 1 and 2), lying some 120 km southeast of Suez, extends 25 km eastward reaching El-Tih Plateau across a hilly terrain of limestone formation. Between Suez and Abu Zneima, Gulf of Suez has a relatively wide coastal plain, extending for more than 20 km wide, and dissected by many wadies, including Um Hammatah, Lahata, Sudr, Rawd El-Rahah, Wardan, Gharandal, Wasit, Thal, and Tayiba. The average length of theses wadies, draining most of the western part of Sinai, is 35 km.

This coastal area undergoes hot climate, where the average temperature in summer is 33°C, while 17°C is the average of winter season. The area lies in the hyper arid zone, where the average precipitation is 17 mm/year while the evaporation rate is 155 mm/year.

Evaporation in water front zone reaches 365 cm/year. This high value of evaporation, produce huge moisture flux to the atmosphere which in turn produces hyper-saline (dense) water landward. Tides, which ranges from 0.3 to 1.5 m, has a well-developed semi-diurnal tidal signal. Currents velocities reach 100 cm/sec. Coral reefs are primarily of fringing type, and confined to a narrow belt along shoreline (Roberts and Murry, 1988, pp. 105-107). In many locals, north and south of Abu Zneima area, barrier and fringing reefs protect siliciclastic alluvial fans from further sea erosion.

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Limestone outcrops, high aridity, rare precipitation, and very thin saline layer of soil, all gives no chance to perennial and/or seasonal vegetation cover. Playas and dried lakes are exceptions after flash floods and torrential runoff.

During the last three decades, western Sinai attracted many geologists and geographers, who focused on various topics such as strategraphic succession (El-Aref et al., 1988), mineralogical characteristics of the coastal plain (Samy, 1993), radiometric activity (El-Assy et al., 1990) and Paleontology (Abdel-Aal and Mohamed, 1987). Moreover, Tawadros (2001) reviewed most of geologic literature concerning western Sinai.

The area of study (600 Km^2) consists of a limestone depositional environment along a regressive Red Sea coastline of Western Sinai. Rock outcrops belong to a wide range of marine and fluvio-marine deposits ranging from Upper Cretaceous to Lower Miocene.

Topographically, the area of study lies in the meso-relief topography, where most of the elevation ranges between 0-300 meters. The area has a general slope from east (500 m +) to west (sea level). Four major wadies discharge Abu Zneima rea, the most prominent are Thal and Nukhul (Figures 3 and 4).

Marine area is relatively shallow, where average depth in open sea reaches 70 m. The coastal plain has a narrow strip zone and composed of calcareous and very fine sand transported from El-Tih plateau. In comparison, alluvial fans southwards of study area have silicate sediments (El-Qa'a plain) where deposits were transported from the Precambrian granitic and metamorphic massif. In subtidal, nearahore zone the water energy is usually low, where waves are breaking far from the shoreline, over numerous patch reefs. The general longshore-drift is southward (Nissenbaum, 1980, P. 233)

Aims of Study and Methodology

Unfortunately geographers presented not much effort to shed lights on the geomorphology of western Sinai. The reasons are clear: this coastal belt is very complicated in its geological structure and structural composition. While Abu Zneima area is not remote from Cairo and Suez (240 km south East of Cairo) it is less inhabited and has a sporadic and fragile human settlement. Hence, the aims of this paper are:

- Understanding geological development which is very essential to analyze the geomorphology of the study area.
- Delineating the geomorphological characteristics of old fluvial landforms through studying drainage basins and networks.
- Pinpointing structural landforms and recent geomorphic processes.
- Mapping and photographing the landmarks of the geomorphological system of the study area.

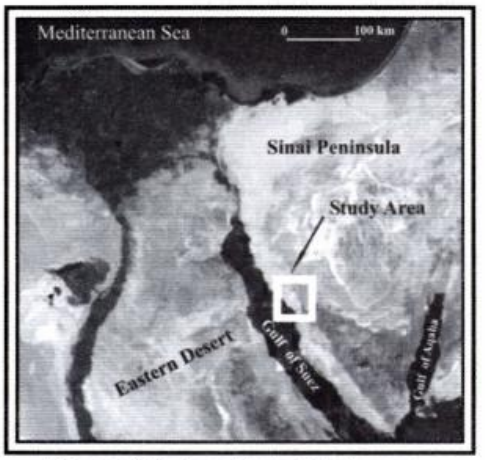


Figure (1): Location of study area.

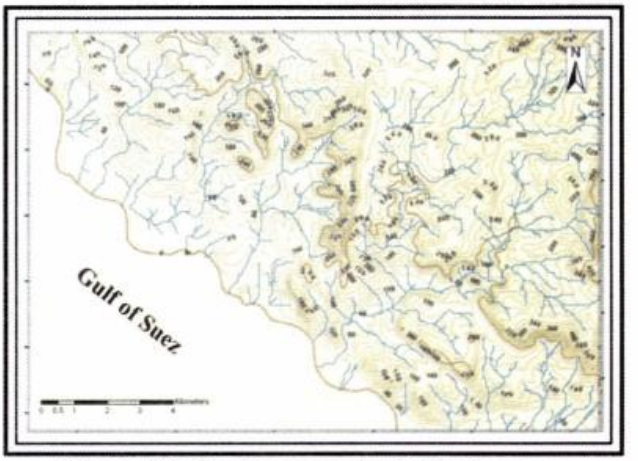


Figure (2): Contour map of Abu Zneima area.

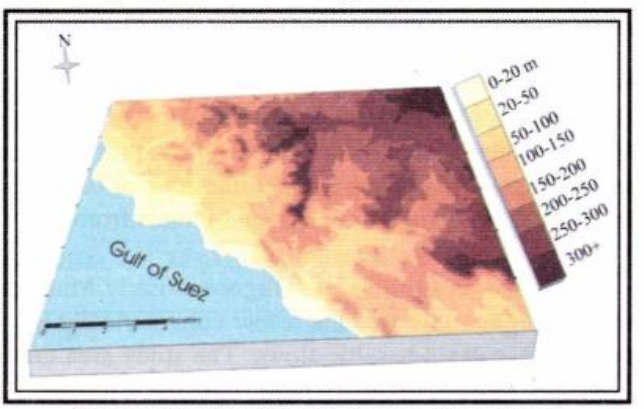


Figure (3): Relative relief map of study area.

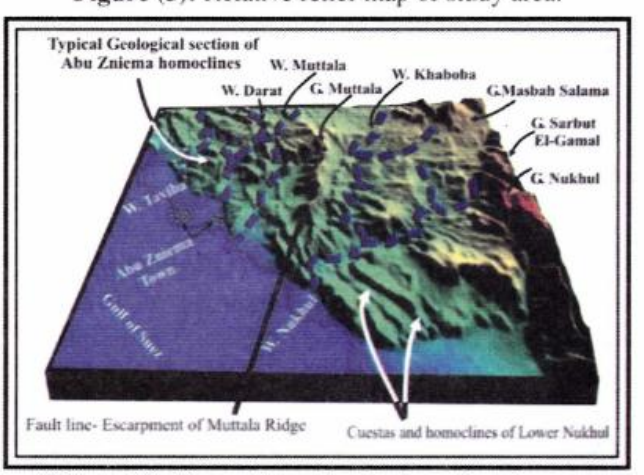


Figure (4): Three dimensional view of study area.

However, to achieve the previous aims the following methods have been followed:

- Reconnaissance survey in February (2008) covering the coastal belt of Gulf of Suez and penetrating through the hinterland till Serabit El-Khadim area (40 km eastward). This survey has been followed by a sequence of detailed field studies in July & August (2008) and final field check in March (2009).
- Analyzing geological data (scale 100.000 and 50.000) and reviewing previous literature. This step was supported by three–dimensional navigation via Google Earth, which helps in comparing slopes and escarpments of cuestas and delinating of many landforms.
- Interpretation of SRTM data and converted them by Global Mapper software into 3-D viewing and generating contour maps in addition to TIN files creation in order to interpret slope and aspect characteristics.
- Interpretation of remotely sensed data(ETM 2001, and Quick Bird image, via Google Earth 2010). This step was followed by overlaying contour maps (50.000) / Geologic map (50.000) / Panchromatic Band of 2005 ETM (15 m resolution) and field survey data captured by GPS equipment (July/August 2008 & March 2009).

Geological Development

Abu Zneima area is composed of various types of limestone (Argillaceous, chalky, marl, dolomite, and porcelaneous) intercalated with bands of conglomerate, chert, concretion, shale, marl and clay. Marine fossils are widespread among limestone of this area, especially Gastropods, Pelecypods and Nummulite (Table 1, Figures 5 & 6, and Photos from 1 to 10).

The area of study composed part of the late Oligocene-Early Miocene Gulf of Suez and NW Red Sea. As a non-volcanic region, this area has a few volumetrically insignificant, late pre-rift to early Syn-rift basic dykes and isolated basaltic flows. The study area developed, as a part of Gulf of Suez, as a result of the north-eastward separation of the Arabian plate from the African plate.

The structure of the eastern margin of the gulf of Suez is characterized by two dominant fault systems: the rift border fault system and the coastal range fault system. Both of these two fault systems consist of two main fault trends; a dominant NW trend and a NNE trend that, where lined together, form zigzag fault patterns.

Gulf of Suez has been recognized as one of the best examples of along-axis segmentation into sub-basins with different dip polarities. The formation of this Gulf gives a good example of the interaction between extensional tectonics and sedimentation. The Suez rift and the NW Red Sea coast are characterized by zigzag fault pattern, composed of NW-SE and N-S to NNE-SSW – striking extensional fault systems both at the rift borders and within the rift basins.

The pre-rift stratigraphy above the Precambrian crystalline basement is about 1.7 km thick on the eastern margin of the gulf of Suez. Syn-rift strata (Upper Oligocene to Pliocene units) vary in thickness from a few hundred meters in places along the rift flanks to as much as 6 km in basins in the center of the rift.

Table (1): Stratigraphic sequences.

Age		Formation	*Map Legend*	Description
Holocene			*Qw*	Sand dues
			Qp	Playa
			Qsd	Wadi deposits
Pleistocene			*Qfg*	Fanglomerate
			Qh	Alluvial Hamadah deposits
			Qr	Coral Reefs
Lower Miocene		Rudays	*Tmrd*	Marl and sandstone with fossilferous carbonates in the lower part.
		Nukhul	*Tmnk*	Conglomerate, and sandstone, changes in places into Calcareous sandstone
			Tv	Extrusive basaltic rocks
Eocene	Upper	Tayiba	*Tety*	Alternate beds of porcelaneous limestone, red silt, and clay, intercalated with limestone, Gastropods, Pelecypods, and Nummulities fossils are common.
		Tankah	*Terk*	Yellowish white limestone intercalated with thin laminae of dark brown marl.
	Middle	Mokattam	*Temk*	Yellowish white chalky limestone containing few chert cocertations.
		Khabubah	*Tekb*	Limestone intercalated with thick beds of beds of gypsiferous marl and clay.
	Middle to Lower	Samalut	*Tedr*	Dolomitic limestone and yellowish white thin-bedded limestone with chert nodules and Nummulite fossils.
		Darat	*Temn*	Greyish white limestone with marl and clay interbedes.
	Lower	Thepes	*Telth*	Grey to white compact Nummulitic limestone, dolomitic in the upper parts, with frequent chert bands and concretions..
		Wasit	*Telws*	White hard limestone intercalated with conglomerate bands at base, nodular at top.
Lower Eocene-Paleocene		Esna	*Tpes*	Greyish yellow marly limestone rich in fossils
Upper Cretaceous	Paleocene-Masst.	Sudr	*Ksd*	White to pale grey chalk, marly near top.
	Santonian-Coniaciian	Matallah	*Kmt*	Argillaceous limestone, marl, and shale with abundant fossil horizons

Source: Geological map of Egypt, scale 50.000.

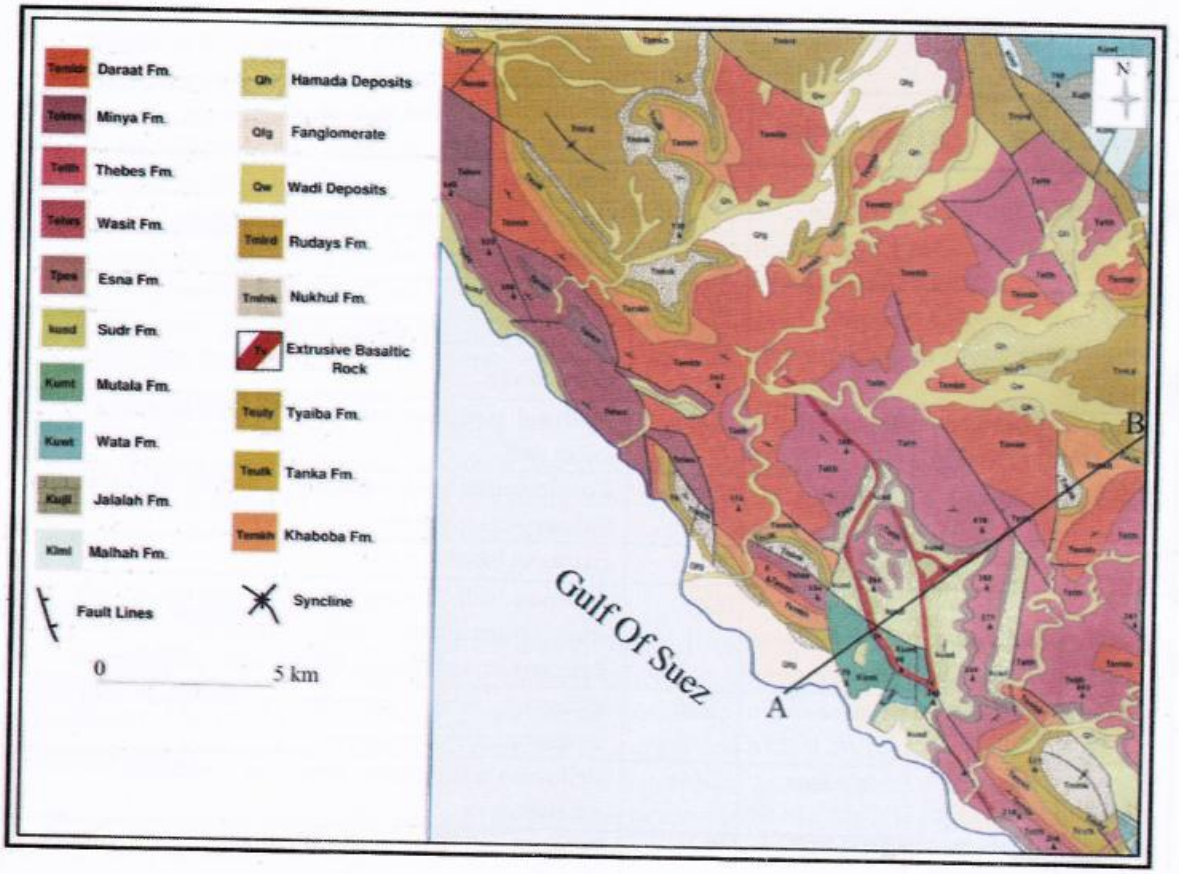


Figure (5): Geological map of Abu Zneima area.

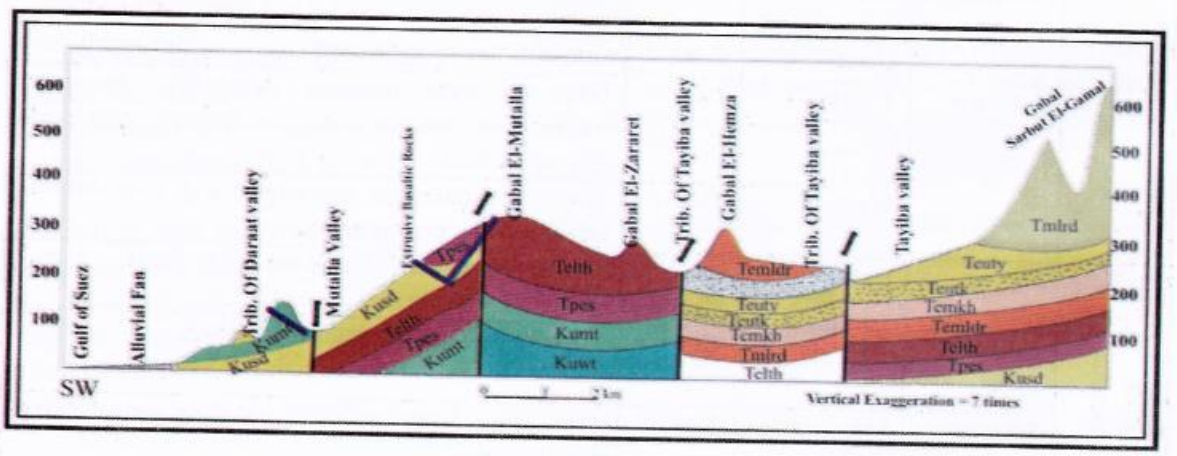


Figure (6): Geological cross section (A-B line).

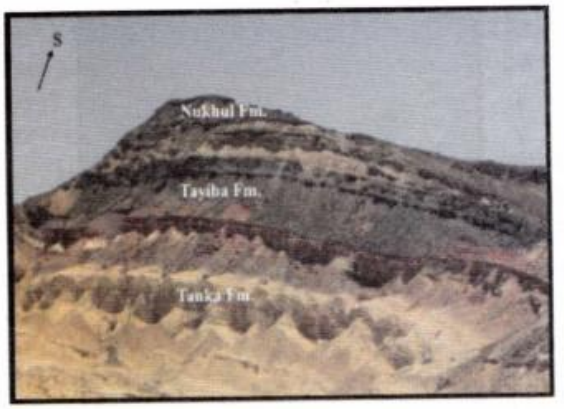


Photo (1): Classical section of Abu Zneima formations.

Photo (2): Tanka formation, gulf of Suez coastline.

Photo (3): Daraat formation, lower Thal valley.

Photo (4): Daraat formation, lower Tayiba valley.

Photo (5): Muttala formation, southeast of Abu Zniema town.

Photo (6): A typical section of Nukhul/Tayiba formations (The section is 30 m high).

Photo (7): Thebes formation, coastal wall southeast of Abu Zniema town (The section is 40 m high).

Photo (8): Wasit formation, Canyon of wadi Thal.

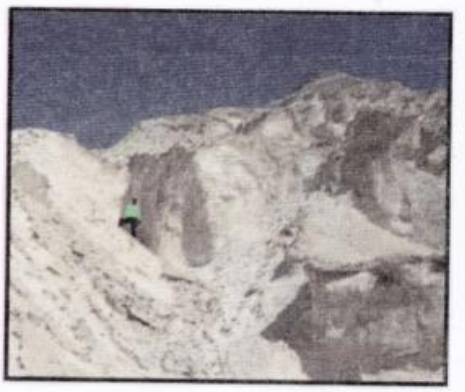


Photo (9): Esna formation, west of Gabal El-Muttala.

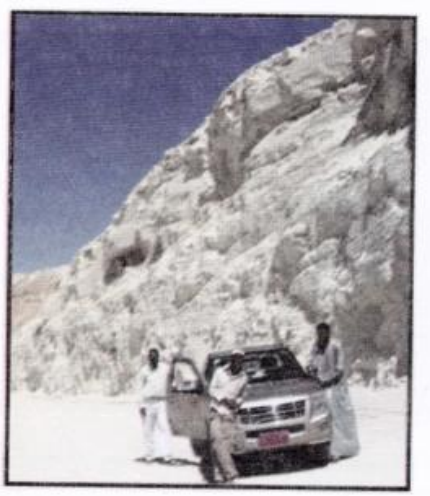


Photo (10): Sudr formation, middle course of Nukhul valley.

Khalil and Mcclay (2001) redraw the geological development of the eastern part of Gulf of Suez according to the rifting stages as follows:

Pre-rift strata

The lowermost of the pre-rift strata on the eastern margin of the gulf of suez consists of a 650 m siliclastic-dominated succession of shallow marine to fluvial sandstones with subordinate carbonates and shales (of carboniferous age). These range from Cambrian to Early Cretaceous age and are unconformably overlain by a c. 300 m Upper Cretaceous sequences of mixed siliclastic rocks and carbonates. Above this there are c. 750 m of chalks, chalky limestone, cherty limestone, and limestone of Late Cretaceous Sennonian to Late Eocene age. The uppermost pre-rift strata consist of patchily developed (preserved) continental red beds of the Tayiba Formation.

Syn-rift strata

The Tayiba formation is locally unconformably overlain by similar facies red beds of Abu Zneima formation, which locally contains subaqueous basalt flows as well as conflomerates with basalt cobbles. The Abu Zneima formation, of Late Oligocene (chattian) age, is generally taken as the transition between pre-rift and syn-rift strata, and it marks the onset of the extension in suez rift, it is unconformably overlain by shallow marine clastics deposits of the Miocene syn-rift Nukhul and rudeis formations.

The earlist syn-rift deposits, therefore, vary in age in different fault blocks and overlie different pre-rift strata as a result of varying amounts and timing of extension, rotation, uplift, erosion, and subsidence below the erosional base-level.

Pliocene-Recent post-rift strata

The Miocene syn-rift strata of the eastern margin of the Gulf of Suez are unconformably overlain by a post rift sequence of highly variable thickness of gravels and sand. The Pliocene – Quaternary sediments may locally exceed 1 km in thickness. These are clastic deposits, evaporates, subordinate carbonates, alluvial fans, and carbonate reefs platform developed in the offshore southern Gulf of Suez.

Drainage Basins and Networks

Abu Zneima area is dissected by a dense paleo –valley networks (Figure 7) comprising six wadies: Thal, A'waad, Tayiba, Daraat, Muttala, and Nukhul. Tables (2), (3) and (4) give the main morphometric analysis of drainage basins and networks.

The principal conclusions of the morphometric measurements reveal the following characteristics:

1- There is asymmetrical distribution among drainage basins. While wadi Daraat has an area doesn't exceed 13 sq.km, Wadi Tayiba has 357 sq. km. Vallyes' width also varies greatly among the studied wadies; Wadi Muttala has mere 6 km in comparison with 27 km of wadi Tayiba and 21km of wadi Thal. This variation can be attributed to the origin of formation: wadies Thal, Tayiba and Nukhul are typical valleys of rifting system, deriving their water inputs from the deep hinterland, some 25-35 km eastward. On the other hand, wadies of

A'waad, Daraat and mutalla are short-extending subvalleys deriving its water inputs from the coastal zone, just 1-2 kilometers eastward

2- Drainage basins are strongly affected by fault occurrence and density. The area of study has 131 fault lines (major and minor) with an average length of 2.5 km for each. 50 % of the total numbers of fault line lies in Tayiba basin. There are strong relationships between faults frequency and basin Parameters. Basins areas, lengths, sum of stream numbers are highly affected by fault frequency (correlation is 0.93, 0.98, and 0.99 respectively).

3- The controlling factors behind the orientation of all valleys are fault lines and folding axis of anticlines/synclines. While the orientation of all valleys is NE-SW, perpendicular to the Gulf system, the tributaries networks extends NW-SW in parallel directions with Gulf faulting forces and on perpendicular direction to the orientation of drainage basin major stream. Fault numbers and orientation are the major forces behind the semi-elongated shapes of drainage basins. In addition, the dendritic form of drainage networks also controlled by the fault frequency and the lineament features along the limestone outcrops.

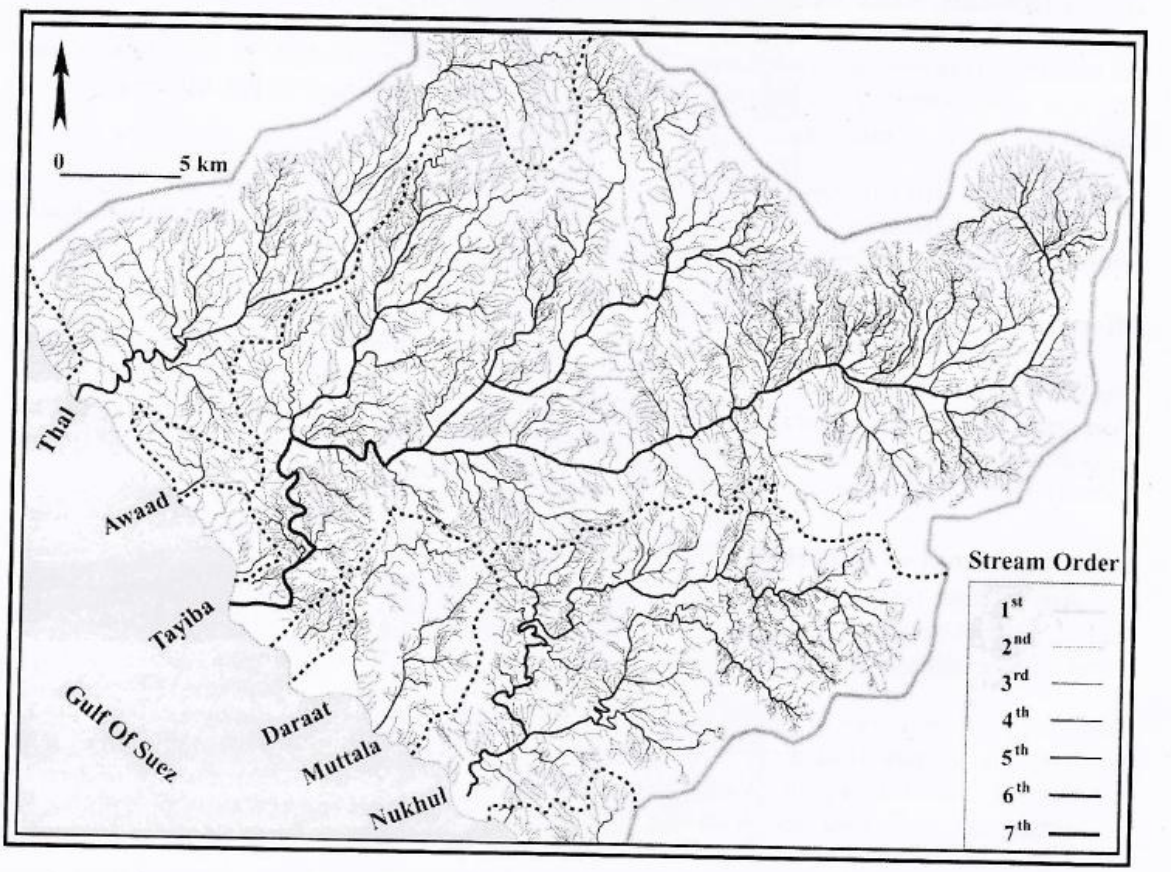


Figure (7): Drainage networks in Abu Zneima area.

Table (2): Morphometric parameters of drainage basins.

Valley	Area (Sq. Km)	Of total area (%)	Length (km)	Width (km)	Perimeter (Km)	Maximum Height (m)	Drainage Density	Elongation ratio	Form Factor	Compactness Ratio
Thal	107	17	24	21	70	840	4.5	0.48	0.18	1.9
Tayiba	357	56	34	27	122	1115	4.68	0.87	0.3	1.8
A'wad	6.5	1	3	10	13	327	4.39	0.89	0.63	1.5
Daraat	13	2	7	8	22	376	3.55	0.6	0.28	1.6
Muttala	15	2	7	6	21	398	3.3	0.6	0.28	1.5
Nukhul	113	18	18	18	65	544	4.7	0.67	0.36	1.7
Average	**101**	-	**15.5**	**15**	**52**	**600**	**4.2**	**0.68**	**0.33**	**1.66**

Table (3): Sum of stream orders.

Valley	1st Order	2nd Order	3rd Order	4th Order	5th Order	6th Order	7th Order	Total
Thal	472	95	25	7	2	1	0	**602**
Tayiba	2537	611	147	33	7	2	1	**3338**
A'wad	27	5	3	2	1	0	0	**38**
Daraat	29	8	1	0	0	0	0	**38**
Muttala	74	16	4	2	0	0	0	**96**
Nukhul	962	209	47	10	3	1	0	**1232**
Total	**4101**	**944**	**227**	**54**	**13**	**4**	**1**	**5344**

Table (4): Morphometric parameters of drainage networks.

Valley	Relief Ratio	Ruggedness Value	Stream numbers	Sum of stream orders	Total lengths of all stream (km)	Bifurcation ratio (average of all orders)	Stream Frequency ratio (stream/km)
Thal	0.035	3.78	889	6	484	2.8	8.3
Tayiba	0.033	5.21	3382	7	1673	2.4	9.4
A'wad	0.01	1.43	36	4	27	3.3	5.9
Dara'at	0.055	1.33	82	4	48	4.7	6.1
Muttala	0.056	1.3	96	4	48	4.2	6.6
Nukhul	0.031	2.58	1238	6	535	2.9	11
Average	**0.08**	**2.38**	**954**	**5**	**469**	**3.38**	**7.8**

Field surveys and remotely sensed data were vital sources for delineating the prominent geomorphological analysis of valleys-system as follows:

1. The effect of faulting/folding factors is very obvious in the morphology of cross section, where no many evidences for the vertical/lateral evolution of the fluvial erosion or deposition, e.g river terraces, islands, levees, flood plains. Moreover, there is no any positive relationship between the morphometric parameters (especially, area, length and width) and the formation of alluvial fans and vallys' entrances and mouths. A mature valley like Thal has a tiny alluvial fan which has nothing to do with its very dense drainage networks. Wadi Taybia, with its 3338 streams along its whole basin, has mere 1 x 1 km flat-surface alluvial fan. The most reasonable explanation behind this irregularity is the deformation of the base level during the Pliocene-Pleistocene period.
2. The lower courses of most of valleys represent ideal forms of gorge-like stream which doesn't exceed 50 m width. The gorge-like zigzag entrance of Wadi Thal even doesn't exceed 7 meters in some of its sectors (Photo 11). While the upper courses of valleys lie under the hegemony of folding and anticlines, the lower courses have been strongly deformed by the fluvial erosion, where undercutting is a major fluvial action (Photo 12). Moreover, numerous knick-points and dry waterfalls give another clear indications of the very complex geomorphological history of these lower courses (Photo 13).
3. Bending along the valley courses represent a prominent feature in the middle and lower sectors (Figure 8), where structural factors (blocky hills, hogbacks, and fault lines) oriented valley extension. Furthermore, structural terraces are widespread along valley-sides, where differential erosion and leaching processes are the major geomorphological factors (Photo 14).
4. The lower course of Wadi Tayiba gives a unique landforms of incised-vertical valley (Figure 10), with its convex/concave sides. The sinuosity of this course extends along six-step meanders (0.5 km width) with sinuosity rate reach 1.8. (7.8 km of actual length in comparison with 4 km of strait length). The incised cliffs create a vertical wall of 22 m height (Photo 15). The meandering channel in this sinuous sector still has a riparian vegetation composed of palm trees and dense shrubs.
5. Hyper aridity, limestone debris flow, and boulders/ pebbles debris thrown allover the valley beds give no chances to the formation of riparian vegetation. The exception can be found only in Thal valley, where the gorge-like stream blocks the torrential floods, hindering them behind and makes an ideal playa/dried lake vegetation cover (Photo 16). Ironically, cultivation of some spots in valley beds depends on transfer drinking water to irrigate illegal agriculture of narcotic plants (Photo 17).
6. Taking into account the previous morphometric and morphological characteristics, there is no flood risk record in the study area. The most potential dangerous sectors lying in wadies Thal and Nukhul (e.g the zigzag gorge-like channels) where there are no populated spots or settlement centers. On the other hand, the high risk probability associated mainly with the sinuosity of the highway road which superimposed on the sinuously of wadi Taybia where meandering and zigzag accompanied with the undulating surfaces in the lower, course making this road section (20 km) the most dangerous part in abu Zneima area.

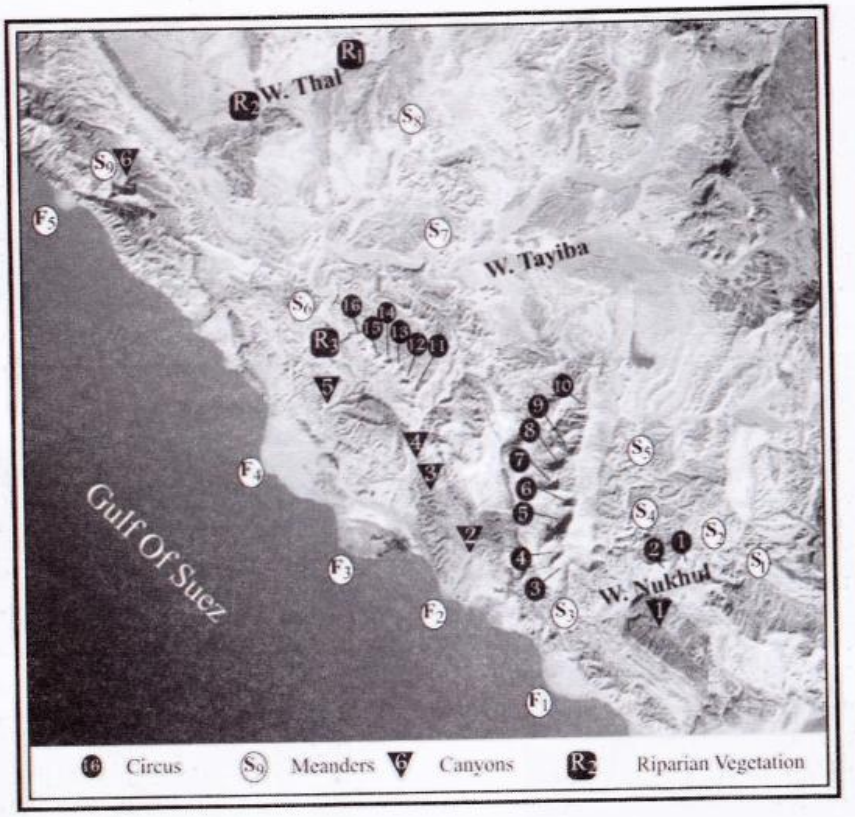


Figure (8): Major fluvial landforms in Abu Zneima area.

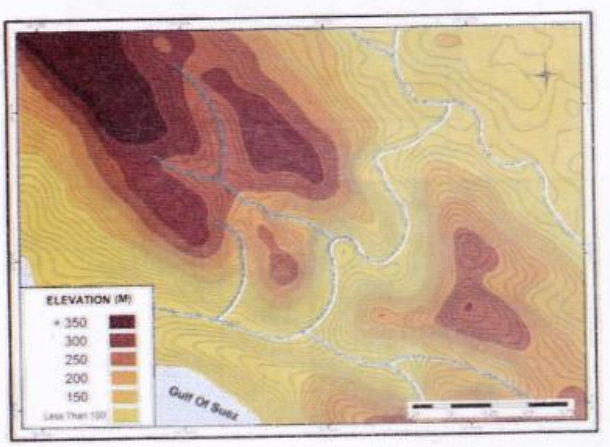


Figure (9): Canyon of lower course of wadi Thal.

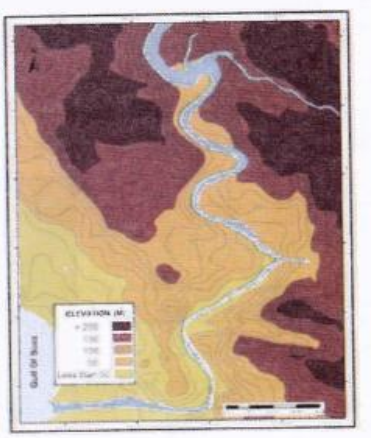


Figure (10): Meandering of lower course of wadi tayiba.

Photo (11): Gorge-like Canyon, Thal valley.

Photo (12): Undercutting enhanced by fault lines, Thal valley.

Photo (13): Nick-point at the lower sector of Thal.

Photo (14): Structural terraces, middle sector of Thal valley.

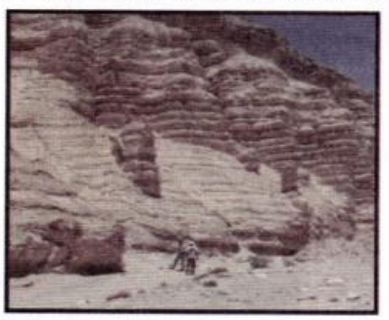


Photo (15): Incised cliffs, middle course of Tayiba valley.

Photo (16): Ripirian vegetation, Thal valley.

Photo (17): Illegal cultivation of drugs inside desert pockets.

In addition to the previous analysis, the principal fluvial landforms could be recognized as follows:

Circus Basins

Circus basins are widespread in study area (Table 5), principally as a result of the following successive factors:

- Uplifting agency which elevated rock formations, basically Thebes and Esna limestone formations.
- Retreating sea level changes.
- Sliding and collapsing along fault lines and slip faces of the previous mentioned rock types, probably with an intensification of karstification processes.
- Gulling and rilling along the free slopes.

Table (5) shows that the average perimeter is around 2 km, radius is around 240 m. All circus basins are surrounded and affected by faults and dissected by rills, gullies and shallow upper courses of dry valleys.

Table (5): Morphometric parameters of circus basins.

Series	Perimeter (m)	Radius (m)	Max. Elev. (m)	Relative Relief (m)	Rock Formation	Number of faults in 3 km radius	number of streams inside	Main nearest stream
1	2046	278	333	203	Thebes	1	9	Nukhul
2	2885	384	312	212	Thebes (upper) Esna (middle) Sudr (lower)	1	7	Nukhul
3	2825	261	280	100	Thebes (upper) Esna (lower)	5	3	Khaboba /Nukhul
4	2491	365	399	120	Thebes (upper) Esna (lower)	3	1	Muttala
5	3570	454	360	220	Thebes (upper) Esna (lower)	2	3	Muttala
6	1790	185	253	160	Thebes (upper) Esna (lower)	1	3	Muttala
7	2465	277	360	200	Esna (lower)	1	4	Muttala
8	3670	329	358	118	Thebes	1	4	Muttala
9	1007	104	343	63	Thebes/Extrusive basaltic rocks	1	1	Muttala
10	1288	132	260	60	Esna	1	1	Tayiba
11	913	108	220	80	Thebes	1	1	Tayiba
12	1214	184	200	80	Thebes	1	1	Tayiba
13	940	88	200	100	Thebes	1	1	Tayiba
14	800	118	180	60	Thebes(Upper) Daraat (Lower)	1	1	Tayiba
15	800	126	160	60	Thebes(Upper) Daraat (Lower)	1	1	Tayiba
Average	**1913**	**239**	**281**	**122**	-	**1.5**	**2.7**	-

Canyons

Table (6) and figures (8 & 9) show that Abu Zneima area exhibits, at least, five major canyons along its major wadies of Nukhul, muttala, Daraat, Tayiba and Thal. Nick- points and gorge-like channels indicate a complex history of sea-level changes and rejuvenation processes. In addition, dry waterfalls and plunge hollows are strong evidences of vertical erosion and entrenching successive stages.

Table (6): Morphometric parameters of Canyons.

Series	Length (m)	Average Width (m)	Max. Elev. (m)	Relative. Rel. (m)	Rock Type	Number of knick-points	Distance from current Sea Level (km)	Main nearest Valley
1	1428	20	140	60	Nukhul	5	2.5	Nukhul
2	2800	30	113	20	Muttala	2	0.3	Muttala
3	1055	10	60	40	Tayiba/Sudr/Muttala	0	1	Daraat
4	2624	30	105	80	Wasit/Daraat/Khabuba	0	1	Tayiba
5	3625	40	296	175	Wasit	5	0.6	Thal
Average	**2307**	**26**	**143**	**75**	-	**2.5**	**1.1**	-

Riparian Vegetation

Although Abu Zneima area is dissected by hundreds of alluvial channels, the climatic change from the pluvial period during the Pleistocene to the dry period during the Holocene had left the area bare of vegetation and undergoes high aridity levels. The exceptions are in bed-channels of Wadies Thal and Tayiba, where meanders, canyons, and gorge-like channels obstacle the seasonal floods forming ephemeral lakes and playas with relatively rich vegetation cover. However, theses sporadic vegetated spots don't exceeds 1% of the study area. Some few trees , like that in Thal valley, work not only as a magnet for grazing and shed shelters during the long and hot sunny days (Photo 18), but also as a sacred place for the native Bedween. The famous wells and underground water drilling lie around or inside the riparian vegetated areas, like Thal and Guesa wells (Thal valley).

Meanders

Meanders are a prevailing phenomenon allover Abu Zneima hinterland. Three vallies (Khabuba, Tayiba, and Thal) have the most prominent examples (Table 7 and Figure 8). All meanders are controlled by fault lines occurrence which enhanced vertical erosion. Meanders were formed because of channel' seeking to find ways to continue there courses through a rugged terrain of relatively durable rocks of Thebes, Darrat and Wasit limestones. Other less durable rock types, especially chalky limestone of Sudr formation, has no marked meanders. Associated landforms,

like incised valley sides, gorge-like channels, and riparian vegetation are well developed in the meandering lower course of Taiyba valley. Average of sinuosity rates is very high, ranges from 2 to 14, reflecting varieties of controlling factors of meanders development.

Table (7): Morphometric parameters of meanders.

Series	Length	Widths	Sinuosity rate	Rock types	Valley
1	1636	90	2.36	Thebes	Nukhul
2	2899	112	2.01	Thebes	Nukhul
3	2081	120	1.58	Khabuba/Daraat/Thebes	Nukhul
4	3475	75	2.08	Thebes/daraat/Sudr	Khabuba (trib. Of Nukhul)
5	3212	110	14	Thebes	Khabuba (trib. Of Nukhul)
6	7175	200	1.55	Thebes/Daraat	Tayiba
7	1730	150	2.4	Thebes	O'saila (trib. Of Tayiba)
8	1228	140	1.54	Daraat	La'b (trib. Of Tayiba)
9	6185	65	1.62	Wasit	Thal
Average	**3291**	**118**	**3.2**	-	-

Alluvial Fans

Each of drainage basins in Abu Zneima area has a delta-like, semi rounded, and flat surface fan. As shown from table (8) and figure (8) there is no geomorphological symmetry between fan parameters and basin parameters, especially fan area versus basin area. The average percentage of fan area (2.86 km^2) is clearly tiny when compared with basin area, a fact that gives a strong indication that the formation of alluvial fans was very recent (Holocene). The detailed interpretation of some fans, especially Thal fan, reveals that there were very recent connection between base level (Gulf of Suez) and the major course of Thal valley. The indications of these conclusion is obvious from canyon, gorge-like, nick-points, and v-shaped channels, in addition to the small size of fan area compared with the major course.

Table (8): Morphometric parameters of alluvial fans.

Series	Valley	Length (m)	Width (m)	Area (sq2)	% of its drainage basin	Type of sediments	Number of braided channels
1	Nukhul	1158	2071	0.9	1	medium to coarse Sands	Shallow Overheeting flow
2	Muttala	355	690	0.62	0.5		4 shallow channels
3	Daraat	2539	2175	2.4	10.7		Deformed by industrial and urban settlements
4	Tayiba	1733	3107	2.3	1.95		4 shallow channels
5	Thal	570	979	0.2	0.18		One major channel and shallow oversheeting flow
Average	-	1211	1804	0.82	2.86		-

Fanglomerate

Fanglomerate is a mixture of water-worn, heterogeneous fragments of all sizes, deposited in an alluvial fan. In Abu Zneima area it is necessary to mention to the fact that fanglomerate lies neither along the coastal strips nor the alluvial fans. Actually they extend far inside the hinterland, between 150 and 250 meters above current sea level. Fanglomerate forms an undulating surfaces which slope in a perpendicular direction to the axis of rift system. Though they have no connection with current alluvial fans, geological maps give this debris a name of "fanglomerate" depending on texture not origion. However, we may consider this debris "fan-glomerate" referring to its ancient origin during the Eocene and Pliocene.

From Pliocene and through the Pleistocene fluvial systems have been entrenched fanglomerate and left it above 40 meters high, making what could be a "relief inversion" where fanglomerate is lofty high and the recent fluvial channels are 20- 40 meters down. It is not excluded that endogenitic factors, especially uplifting movement, played a role in this inversion.

Field survey in 2008-2009, especially in Tayiba and Thal valleys, has revealed that fanglomerate varies in thickness from 1 to 4 meters and extends as gravel-strewn slopes overtopping grayish white to white limestone. Rock and material sliding of fanglomerate over the limestone formations give clear exhibition of this succession as shown in photo (19).

Texture of fanglomerate is principally hard and polished clastic debris, which seem alien among their surrounds of Daraat formation (white limestone interbeded with marl and clay). This texture could be interpreted as heterogeneous debris of fanglomerate derived from the far hilly terrain eastwards composed principally of Wasit formation (hard limestone). Fanglomerate in the middle course of Tayiba valley has been converted from friable and poor cemented debris into ideal hard conglomerate (Photo 20).

Structural Landforms

In an environment where exogenitic factors are very weak, the geologically-controlled landforms dominate the scene. Endogenetic factors during pre/syn/post rifting stage had created two major types of structurally-controlled landforms:

1. Fault-line ridges:

Fault-line ridges is a walled-like free escarpment, where deposits-free slopes and what called all-slopes landforms are a typical landscape. The orientations of most of these landforms are NNE-SSW and NNW-SW, definitely resembled the two major lineaments allover the study area. The average length of these escarpments varied between 3 to 7 kilometers, while the relative relief of the escarpments ranges between 140 to 180 meters Some of the misfit streams incised in some sectors of wadies Nukhul and Muttala reflect the variation between a lofty valley sides (150-200 m high) and a very shallow stream channels, less than 3 meter in depth (Photo 21). Based on SRTM data (60 & 30 m/pixel resolutions) digital elevation model shows some of the prominent examples in lower Nukhul area (Figure 11).

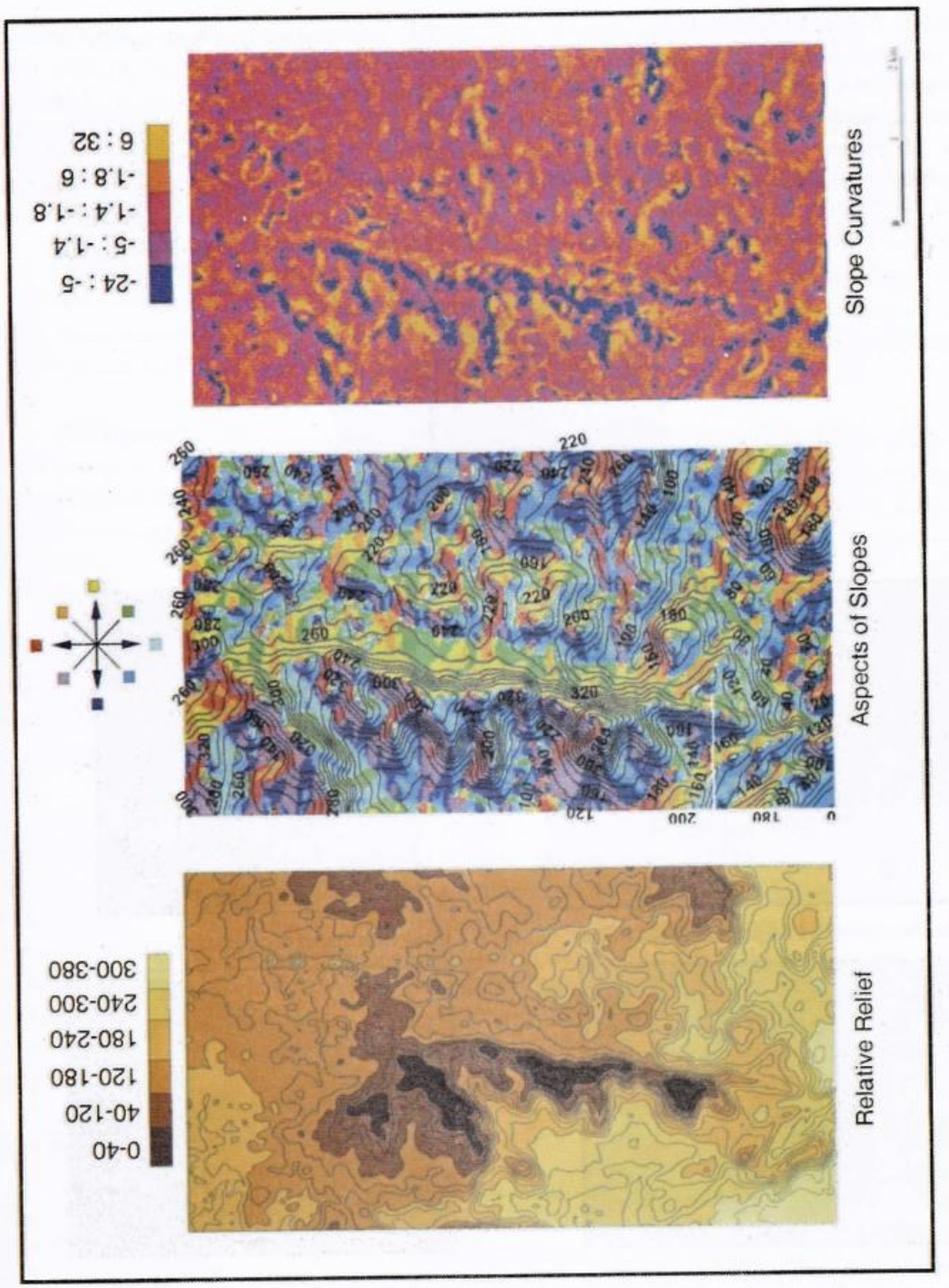


Figure (11): DEM analysis of Gabal El-Mutalla.

While hyperaridity conditions obstacle any "fluvial" deformation of these escarpments, the mass movements along these slopes are active processes. The vertical section of an ideal fault-escarpment, like that in lower Nukhul area (Photo 22) shows that the upper sections are debris-free slopes in contrast to the lower ones where talus cones, debris accumulations are widespread. Again, the debris accumulation and talus cones protect the middle and lower sections from further geomorphologic development and preserve the hidden sections from any geomorphic change. This kind of "protection" is a geomorphologic "rule" in arid regions, as it is already recorded in many rock types, especially metamorphic and igneous rocks in Sinai and Eastern Desert of Egypt.

Photo (18): The most famous Acacia tree in Thal valley.

Photo (19): Sliding of fanglomerate, Tayiba valley.

Photo (20): Sliding of conglomerate, W. Tayiba.

Photo (21): Lofty valley sides versus misfit streams.

Photo (22): Free slopes versus talus cones.

2. Cuestas and Hogbacks

Cuestas cover more than two thirds of Abu Zneima area. Field survey and ground photographing are very essential tools for delineating the extension and geographic distribution of the phenomena. Inm addition, three-dimensional views of these geologically –controlled landforms was the most suitable tools. Figures (12, 13 & 14) clarify the basic characteristics of cuestas and their geomorphic features.

One of the major structural landforms in abu Zneima area is the homocline hills, which is a uniclinal structure formed when the underlying strata are tilted in one (uni) direction, especially with near uniform dip angle. The homoclines of Abu Zneima area were principally affected by uplift of coastal plain sediments, during the syn-rift stage.

Homoclines in abu Zneima area actually is a strike ridge, typically characterized by a steep escarpment or scarp slope (strike slope or antidip slope) on the side that cuts across the strata, and a more gentle dip slope on the side of the ridge that follows the dip. Homoclinal ridges usually have strata dipping in only one direction. The most ideal homoclial ridges in Abu Zneima area are hogbacks.

Hogbacks tilting in the study area is multi-directional, with major directions perpendicular to the Gulf of Suez coastline, where the dip orientation is NW-SE and the angel between the inclination and the ground surface is anything between 20° - 60°. The very famous example of a typical hogbacks lies in front of the town of Abu Zneima (Photo 23 A and B) where the variegated colures of limestone strata and extrusive basaltic rocks are side by side.

The morphometric parameters of hogbacks are relatively small, where the horizontal extension is around 100-200 m width, 100-150 length, and the average heights is 25-40 m. in some locations, like the lower Nukhul area, the alignments of the hogbacks is so spectacular that it forms a homogenous "neighborhood" of the hogbacks (Photo 24 A and B) where hundreds of these hills when clustering together form 4 steps of cuestas. In most cases, hogbacks are covered with a deep-weathered and leached lamina ranges in depth between 0.5-3 meters, covering the fresh limestone rocks underneath. In some sectors of the study area, as on the fringe of Abu Redes alluvial fan, the strata have an obvious level of differential erosion, where the more durable erosion resistant materials stand alternated by easily eroded layers (Photo 25).

Recent Landforms and Processes

In addition to the meso and macro scale landforms, there are many micro scale features especially caves, tubes and cavity, which belong to "pseudo- karst" processes (Photos 26 and 27). Limestone Pavements resulting from leaching processes are very obvious in the middle course of Thal valley. In addition, dissolution depressions give a pseudo-types of karstified dolines in middle course of Tayiba valley (Photo 26).

Figure (12): 2-D view of lower Nukhul cuestas.

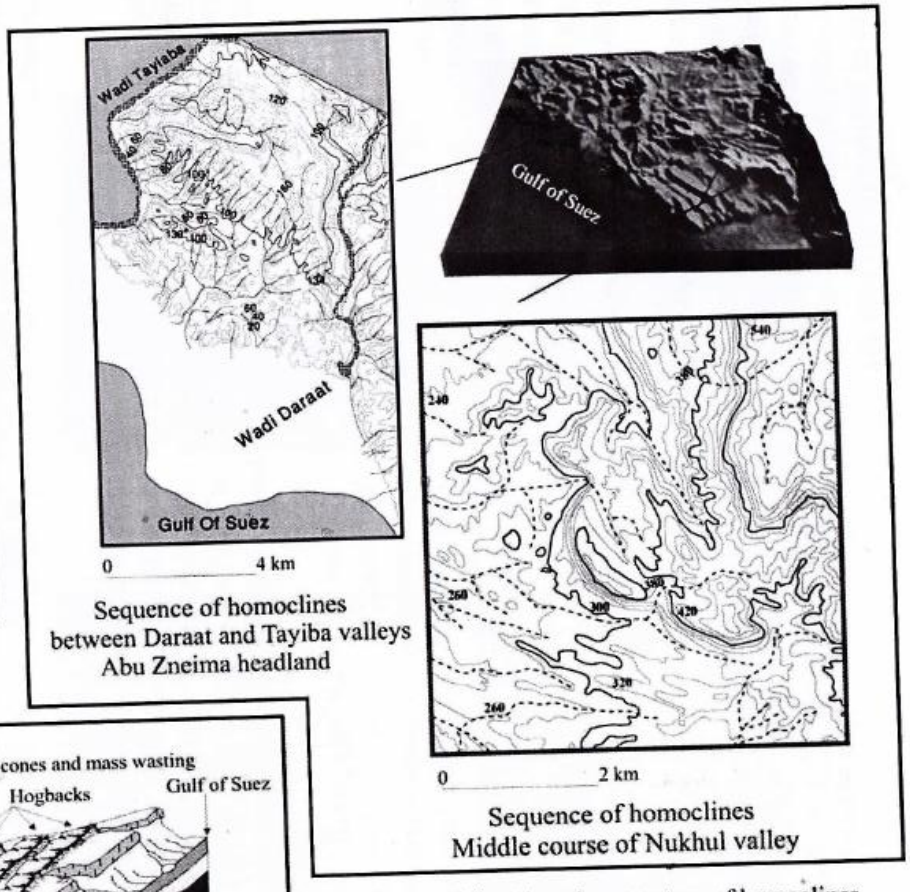


Figure (14): Elevation structure of homoclines.

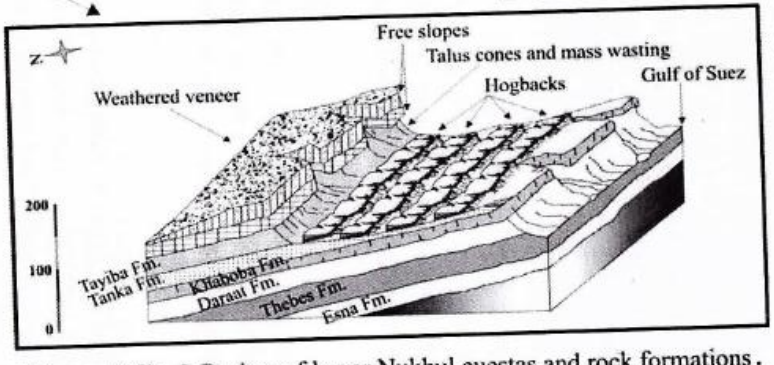
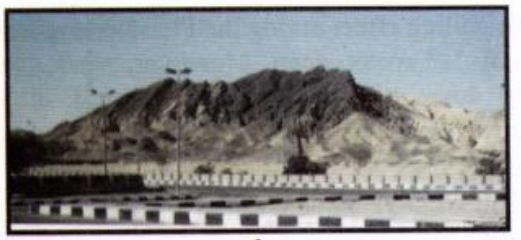


Figure (13): 3-D view of lower Nukhul cuestas and rock formations.



A

B

Photo (23 A & B): Typical homoclines, Abu Zneima town.

A

B

Photo (24 A & B): Successive lines of hogbacks.

Photo (25): Differential erosion, southeast of lower Nukhul.

Photo (26): Old Karst landforms of dissolution hollows

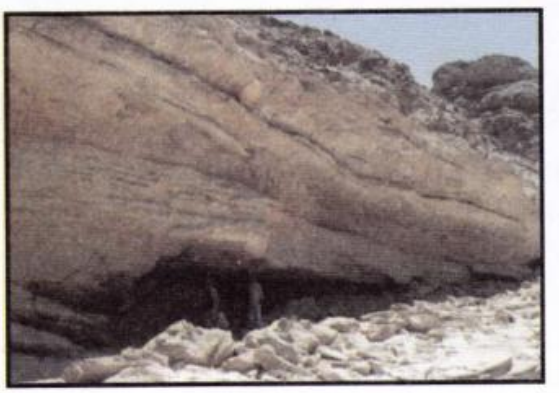


Photo (27): Psudo-Karst cave, lower Nukhul.

Rillenkarren is a micro scale feature related to the gulling effect during the Pleistocene pluvial periods while deep weathering reach a thickness of 1-2 meter deep. Moreover, sand dunes encroachment, either as ascending or descending dunes (Photo 28) are scattered in the northwestern portion of the study area. Mass movement is abundant along steep slopes, usually enhanced by fractures and fissures (Photo 29).

Along the coastal front shores and beaches were developed usually as sandy strips, and sometimes as a shingle beach. Rocky coasts created by rifting system and folding uplift undergoes sub-aeolian processes, as seen in Tanka strip (Photo 30).

Finally, man mad- features have dotted study area in many places. Examples of these landscapes are towns, villages, roads, quarries, industrial centers, and touristic facility. The latter one related mainly with access to Serabit Al-Khadim temple, 40 km in the hinterland eastward.

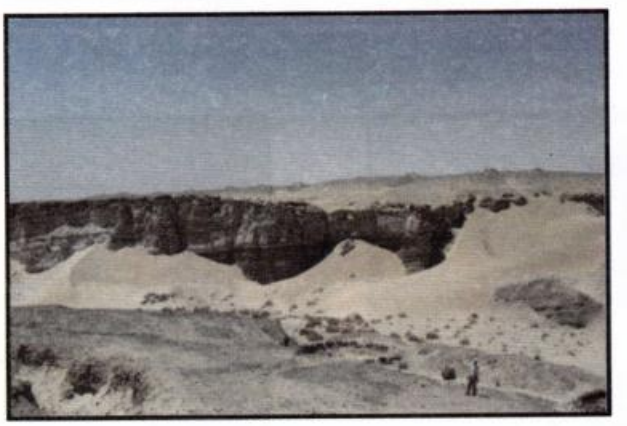


Photo (28): Descending dunes, Tyiba valley.

Photo (29): Mass sliding, middle course of Thal valley.

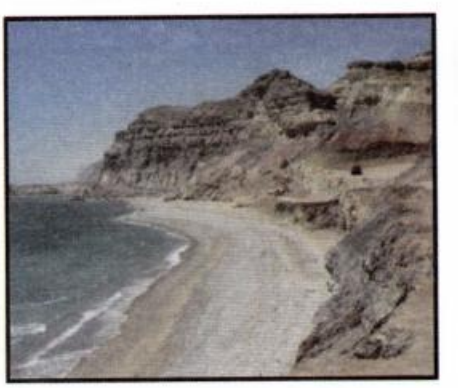


Photo (30): Shingle beaches along rocky coasts.

Conclusion

Abu Zneima area comprises multi geomorphological systems and complicated geological history, hence it deserves so much work to do, especially from geographical point of view. However, the following conclusions are essential for any further geomorphological study:

1. Exposures at the entrance to Wadi Tayiba, 1 km north of Abu Zneima town are generally considered to represent the 'type-section' for Oligocene to Miocene, late pre-rift and early syn-rift sediments. Geological interpretation indicates that the oldest pre-rift unit in the Wadi Tayiba type-section (and the study area in general) is the Upper Eocene Tanka Formation which have been deposited on a carbonate platform in an upper shelf environment.
2. The study area undergoes hyper-arid environmental conditions, where evaporation rates per year are 9 times higher than the total precipitation. Theses climatic controls didn't give any chance to perennial or seasonal run-off.
3. Furthermore, most of landforms in Abu Zneima area is attributed to a legacy of old agents and processes, while small portion is attributed to current geomorphic action. Hence, some new techniques, especially spectral signatures, are not valid for accurate geomorphic interpretation. In this context some anthropogenic activities (especially dusting of quarries and industrial pollution) has changed the reflectance properties of rock formations.
4. For delineating limestone landforms, the spectral signatures on remotely sensed images are obscure and have a little importance in mapping technique as the surfacial material is widely affected by leaching, deep weathering, and desert varnishing.
5. There are asymmetrical distributions among drainage basins morphometric parameters, where drainage basins are strongly affected by fault occurrence and density. The controlling factors behind the orientation of all valleys are fault lines and folding axis of anticlines/synclines. In addition, the dendritic form of drainage networks also controlled by the fault frequency and the lineament features along the limestone outcrops. Moreover, mapping procedures recognized few landforms attributed to vertical and/or lateral erosion, e.g terraces, natural levees, flood plains or islands.
6. In contrast to the absence of mature fluvial works, gorge-like streams, knick-points, rejuvenation sections, circus basins, and other structurally-controlled landforms, are widespread in Abu Zneima area. structural terraces are the most remarkable landform along valley-sides, where differential erosion and leaching processes work very slowly, but permanently.
7. There is no flood risk record in Abu Zneima area, where vegetation cover represents only small patches, and riparian vegetation is sporadic.

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