Geomorphological Evolution of Palaeosurfaces in the Central Eastern Desert of Egypt

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Abstract:

The Red Sea Mountains are extremely rugged and have been inferred as a vast old erosion surface underwent multiple uplifting. The present study aims to recognize the old paleosurfaces in the Central Eastern Desert of Egypt to reveal their implications to the geomorphologic evolution. The study based mainly on field study, geological and topographic maps integrated with remotely sensed data and DEM.

The study distinguished between two palaeosurfaces, they are: exhumed and buried palaeosurfaces. The exhumed one is more or less flat distinguished with low relief. The buried erosion surfaces were discovered on the eastern low cliff of Jabal Naqarrah and they have a vast extent in Jabal Abu Shaara west of Hurghada. These surfaces are preserved in very constricted rock outcrops. Two phases of denudation were proposed: 1. Hammamat Phase that took place ~680-640 Ma, where significant volumes of igneous rocks were vigorously eroded; 2. the later phase took place ~33.9-11.6 Ma where a great hiatus in the sedimentation cycle has been observed between the Pre-rift sediments and the coastal Syn-rift sediments. According to the study these palaeosurfaces are polygenetic denudation surfaces. The study supposed two episodes of landscape evolution. The first episode began with the elevation of the Arabo-Nubian Shield accompanied with the early rise of Dokhan Volcanics ~ 620/600-590 Ma. The second episode started where more or less of the area was covered by the pre-rift sediments (probably Cretaceous). During early Oligocene-Middle Miocene the surface mostly formed etchplain and rate of erosion was estimated as 1mm/44.6 yr.

Keywords: Palaeosurfaces, Eastern Desert, etchplain, superimposed drainage systems.

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1. Introduction:

Geologically features of the great African rift characterize the Eastern Desert of Egypt (Akkad and Abu El Ela, 2002) and the surrounding areas along the Red Sea and the Gulf of Aqaba. Although the Red Sea Mountains are extremely rugged, Moawad (2008) inferred the general terrain as an old erosion surface underwent multiple uplifting before it attains its present-day altitude since the study area spans over a passive continental margin. Evolution of large bedrock landforms along passive continental margins has recently become an increasingly interesting topic for geologists and geophysicists as well as for geomorphologists (Japsen and Chalmers, 2000; Summerfield, 2000; Doré et al., 2002; Bonow, 2004). However, planation surfaces occupied a central position in geomorphology in the days, when establishing denudation chronology of a given area is considered the main objective of geomorphology and cyclic development of landforms served as a paradigm (Migoń, 2004).

Normally, topographical surfaces which are nearly flat over longer distances are called in geomorphology planation surfaces, but this term is one of the more controversial in geomorphology (Migoń, 2004). Accordingly, the term palaeosurface has been used within this study to describe the old erosion surfaces, which have long-term evolved in response to particular combinations of geomorphological processes (Widdowson, 1997) with saprolite remnants (Lidmar-Bergström, 1982; Bonow, 2004) and not in accordance with the present climatic or tectonic conditions (Bonow et al., 2006). The term was used as well without any genetic connotation to adequately describe any identifiable surface or horizon of demonstrable antiquity (Widdowson, 1997), since the Eastern Desert of Egypt has undergone intense endogenic and exogenic activities (Moawad, 2008).

It is well known that palaeosurface has been produced and maintained flat surface over protracted time spans (Migoń, 2004); therefore, they are partly destructed or reshaped, but still recognizable and their former wider extent may be reconstructed (Widdowson, 1997). On the other hand, Ollier (1981) and Ahnert (1982) used drainage systems as evidence for palaeosurface evolution and uplift events. Ahnert (1982) revealed that stepped surfaces by multiple uplifts interrupted by long pauses. During each event the surface adjusted to the new base-level.

The early deduction of palaeosurfaces in Egypt was made by Clayton (1933) in his expedition to the western side of the Gilf Kebir; Awad (1951) in Central Sinai; Philobbos and Hassan (1975); Moawad (2008) in the Eastern Desert. Palaeosurfaces have been distinguished partially in the Arabian shield as well, exhumed or buried beneath alluvial and/or eolian sediments (Vincent, 2008).

The main objectives of this study are: 1. mapping and analyzing the origin of palaeosurfaces regarding to geological and geomorphological evidences; 2. evaluating the role of the palaeovallyes in denudation processes; 3. formulating a preliminary concept on landscape evolution of the study area.

2. Study Area:

The study area locates along the Red Sea Coast of Egypt between Wadi el Barud (Long. 33° 56`55" E and Lat. 26° 45` 39" N.) about 2.6 kilometers to the north of Safaga and Wadi al Ambagi (Long. 34° 17` 05" E and Lat. 26° 05` 41"N.) south of El Quseir in the Central Eastern Desert of Egypt. Its western border pursues the watershed line that separates the Red Sea drainage system and the Nile-Mediterranean system, while the Red Sea demarcates its eastern border. It covers approximately 4600 km^2. the study area spans over a passive continental margin and is characterized by features of the great African rift. The Precambrian basement complex rocks form the most widespread rock types. They leave a narrow longitudinal coastal plain that is formed by laterally coalescing large ancient deltas and coral reefs. Endogenetic processes significantly influenced the evolution of the existing landforms resulting in exceptionally rugged relief (Red Sea Mountain chain). Strike faults gave rise to a remarkable topographic complexity. The Pre-Miocene (Cretaceous-Eocene) strata were preserved and deformed in morphotectonic depressions forming warped forms of which Jabal Duwi is the most conspicuous (Said, 1990). The study area is impressed by numerous wadis (dry valleys) which drain the Red Sea Mountains and debouching into the Red Sea (Figure 1).

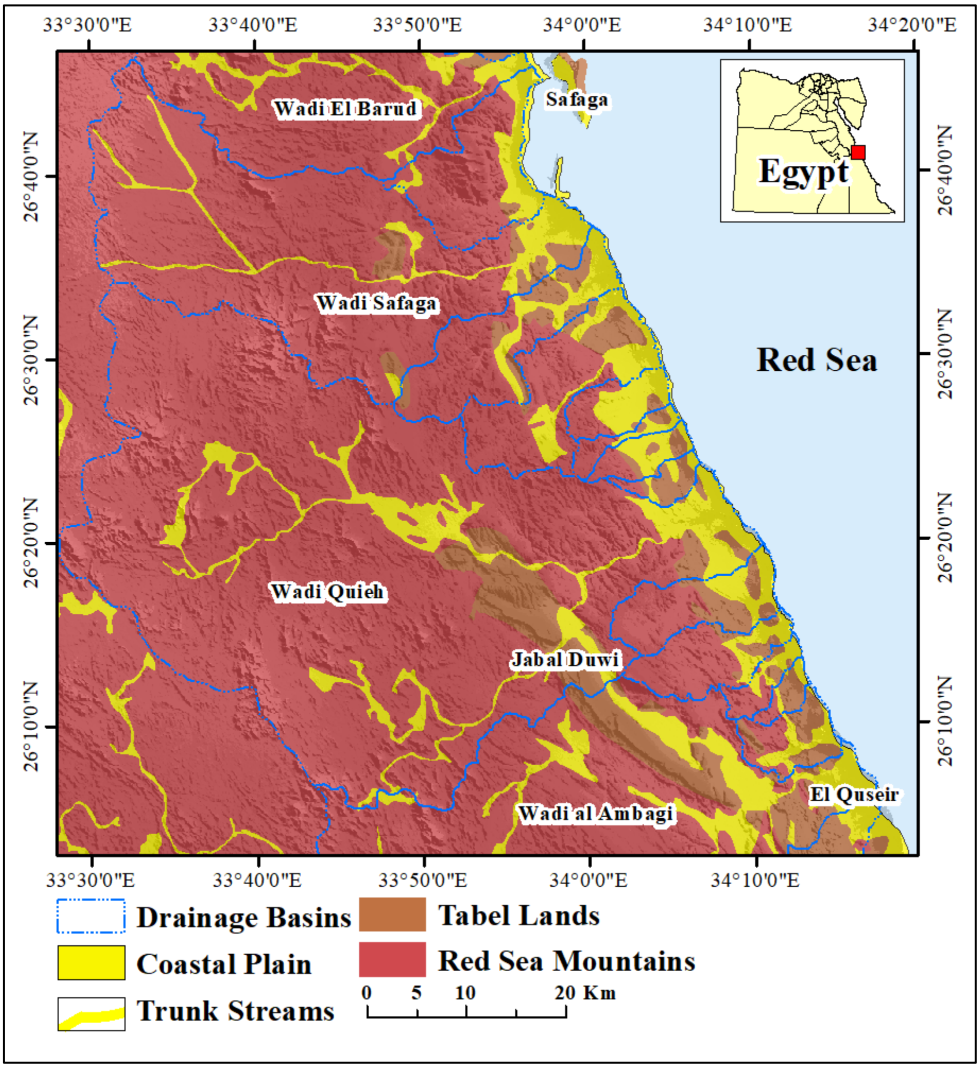

Figure 1. Location and the major geomorphological units of the study area (Source: compiled from the topographic maps, scale 1:100.000)

3. Geological Setting:

The Precambrian basement rocks are the dominant rock types within the study area (Figure 2). They are mainly crystalline in character forming a complex of igneous and metamorphic rocks. They contain wide variety of rock types (Geological map of Qena 1:500.000). They are: paragneisses and migmatites (the oldest rock types); geosynclinal metasediments; metavolcanics; serpentinite, metagabbro-diorite complex, the older granites (Shaitan Granites), Dokhan volcanics (andesites, felsites and tuff interbeds); Hammamat group (unmetamorphosed conglomerates, greywackes, sandstone, siltstone, tuffstone and rare andesites); the younger gabbro; the younger granitoids (Gattarian Granites). Sedimentary rocks are divided by Said (1990) into two major successions they are: 1. Cretaceous and Eocene rocks (Pre-rift) occupying the morphotectonic inland depressions; 2. Miocene and later sediments (Syn-rift) restricted to the coastal strip. However, sedimentary rocks rest unconformably over the basement complex rocks. There is a great hiatus between the two successions of the early Eocene and the middle Miocene (Figure 3). It has been assumed that the Cretaceous and Eocene succession was covering the entire surface along the Central Eastern Desert of Egypt; since it has been trapped and preserved in the morphotectonic depressions and the succession is already exist on the western flank of the Central Eastern Desert.

4. Geomorphological Setting:

The study area was classified into four major geomorphological units, namely: 1: coastal plain; 2: table lands; 3: Red Sea Mountains and, 4: drainage basins (Moawad, 2008). The coastal plain occupies the lowlands parallel to the Red Sea coast. It is formed primarily by coalescing alluvial fans and fossilized coral reefs. Table lands are slightly tilted seawards with general slopes varying between 5°-20° and attain an elevation about 162 m asl. as in Jabal Abu Hamra. They locate whether along the coastal plain or in the intermountain morphotectonic depressions. The inland cuestas and/or mesas represent remnants of the earlier sedimentary rock covers, which had been existed before the area was prone to the orogenic and erosion processes. They are significantly controlled by geological structure resulting in intensive faulting and folding that gave rise to distinctive single and overlapping cuestas (e.g. Jabal Duwi 627 m, Umm al-Hawaytat 325 m; Mohamed Rabah 435 m). The Red Sea Mountains are composed of the Precambrian rocks (igneous and metamorphic rocks). The terrain extends more or less parallel to the Red Sea in the vicinity of the coastline. On the one hand the terrain does not form a continues range or chain, rather a series of mountainous blocks, which are more or less adjacent and dispose linear trend parallel to the coastline with some detached masses and peaks (Said, 1962).

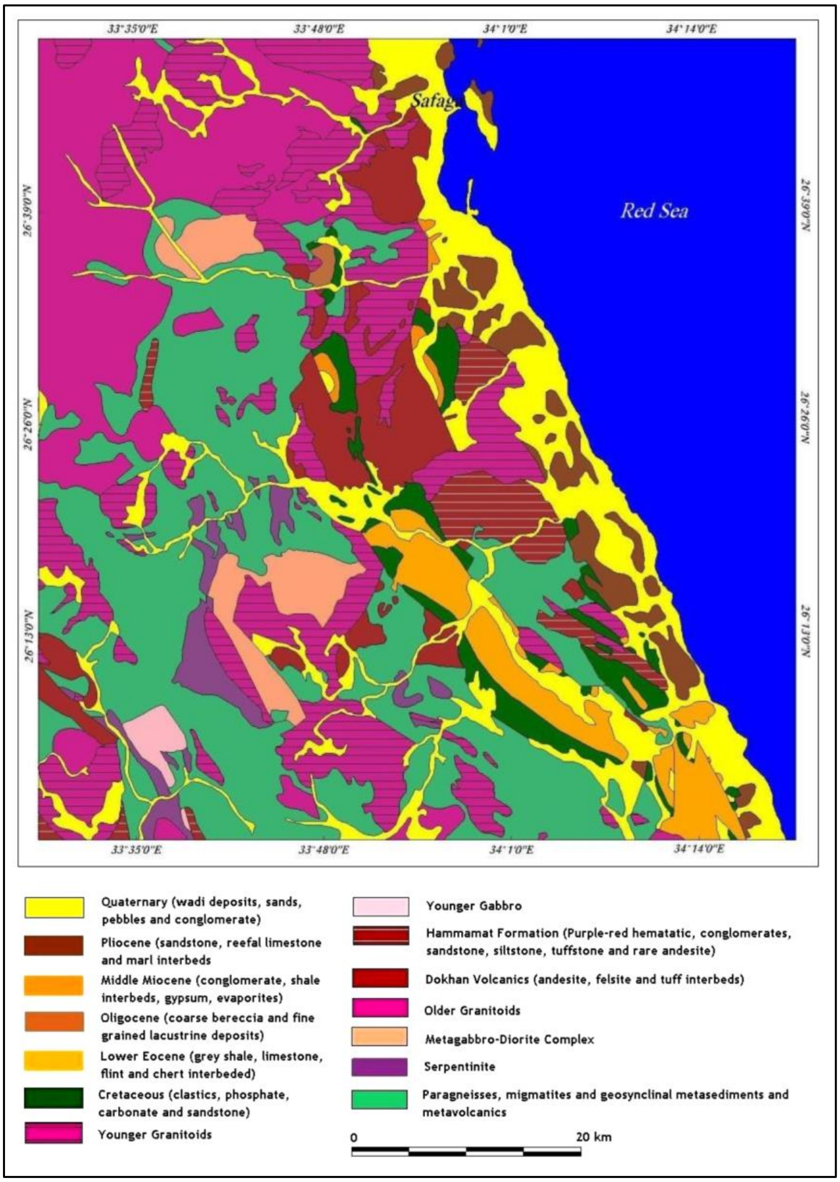

Figure 2. Geological Map of the study area
(Source: Geological map of Qena, scale 1:500,000)

The mountains themselves are not folded; instead, they have been formed due to a large extent by uplifting the margins of the rift (Braithwaite, 1987). Red Sea Mountains are stringency dissected by deeply incised wadis, which are divided into two opposite drainage systems. They are: the Red Sea wadi system characterized by short wadis and relatively small catchments areas; and the Nile-Mediterranean system distinguished by relatively long wadis and large basins (Embabi, 2004). Most of drainage systems pass through the morphotectonic depressions exhibiting antecedent-like wadis and maintained their water courses through the uplifted Red Sea Mountains (Moawad, 2008), so long as the wadis could erode away the uplifted rocks across their ways. Generally, drainage networks are much dense owing to geologic structure and rugged relief.

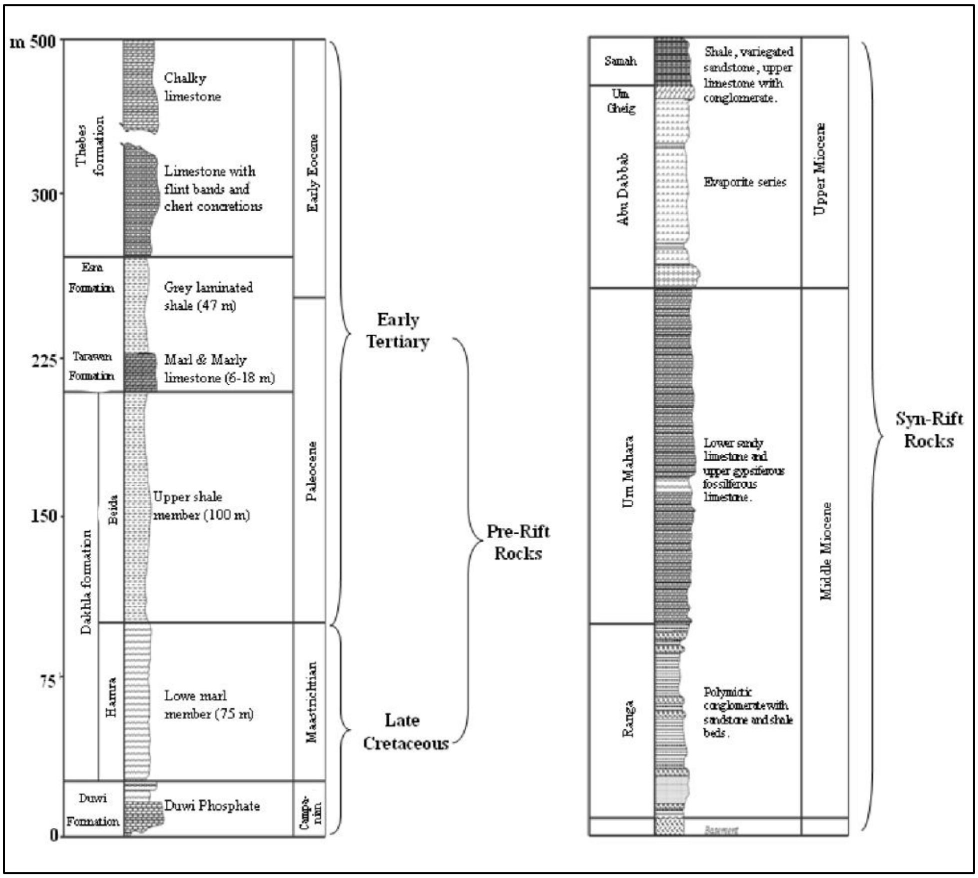

Figure 3. Sedimentary succession in the Central Eastern Desert of Egypt (Simplified after Said, 1990)

5. Methodology:

The present study based essentially on field investigations; analyzes of lineaments; interpretation of geologic and topographic maps; DEM analyzes; and drainage basin analyzes. Lineaments have been extracted using integrated remotely sensed ETM+ and SRTM data; and therefore, have been integrated with auxiliary geologic maps using GIS technique according to Moawad and Grunert (2008). Geological maps of Safaga and El Quseir of scales 1:100.000 were carefully investigated and dropped over the digital elevation model

(DEM) (extracted from SRTM images version 2 of 90 × 90 meters ground resolution and topographic maps) to reveal the relationship between rock units and palaeosurfaces. Bathymetric maps of scales 1:250.000 and 1:500.000 were analyzed to expose the submerged deltas as well. Finally, four field works were carried out between 2007-2020 to investigate the findings of the study and diligent model of landscape evolution.

6. Results:

6.1. Palaeosurfaces:

Two palaeosurfaces have been distinguished and suggested as follows:

6.1.1. Exhumed Palaeosurface:

Exhumed plain is that which has been formed, buried under younger sediments, and then re-exposed by removal of the younger sediment (Ollier and Pain, 2000). It is quite common in the geological column where it is packed with unconformities, which are marked by surfaces dividing older rocks from overlying, often flat-lying rocks (Hugget, 2007). The idea of exhumed palaeosurface has never occurred to us until the processing and analyzes of the spatial concentration map of lineaments, which has been carried out to clarify the relationship between lineaments concentration and rock types. The spatial concentration map was created using a grid of 5` latitude x 5`longitude to divide the lineaments map into 85 squares. Each square was weighted by a point to represent the total number of lineaments within each square. Thereafter, isolines were interpolated using inverse distance weighted (IDW) method with line interval of 10 lineations (Figure 4). It is noticeable that there are dispersed centers for lineament. It has been observed that these centers are mainly confined to plutonic intrusions of the younger granite and Dokhan Volcanics such as at Jabal Barud and Jabal Naqarah while the older basement complex rocks (e.g. older granite; paragneisses and migmatites) exhibiting less intense lineaments owing to their subdued surface. Therefore, it has been concluded that lineaments are controlled lithologically despite no particular orientation has been given to distinguish a specific rock (Moawad, 2008; Moawad and Grunert, 2008). The same conclusions have been deduced from the analyzes of the DEM.

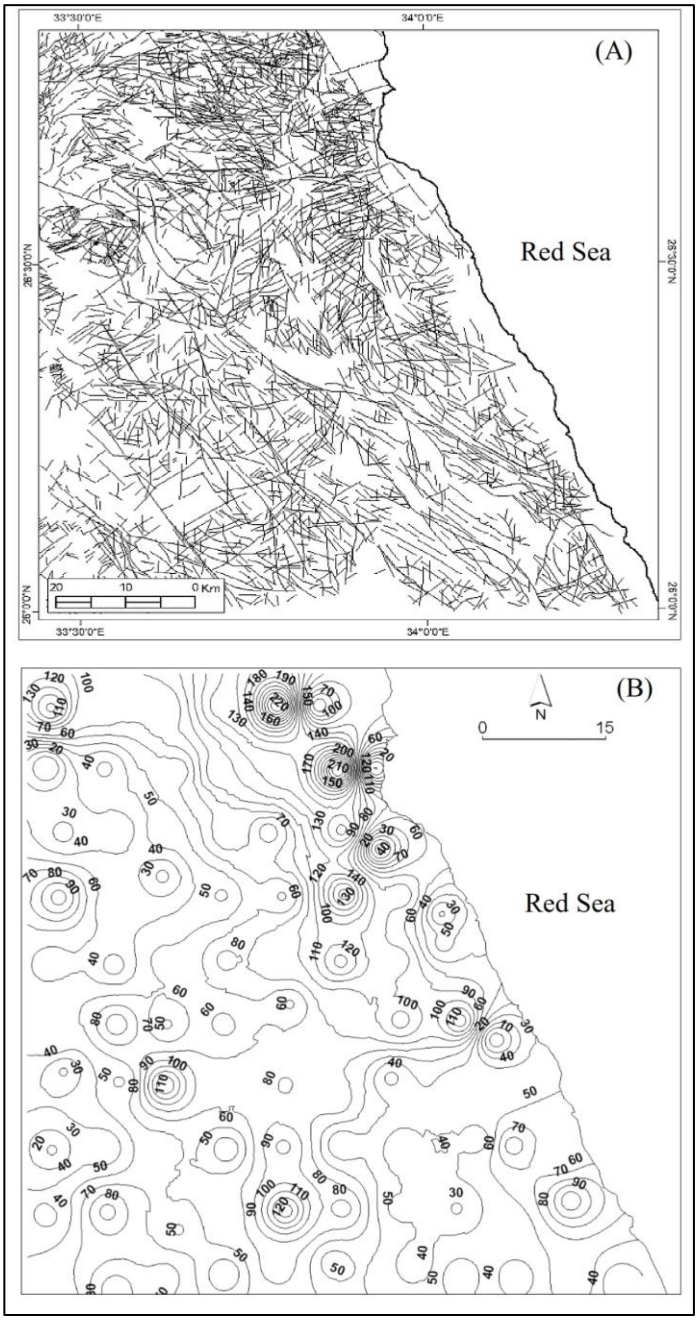

Figure 4. Lineaments map (A) and its spatial concentration (B)
(Source: modified after Moawad and Grunert, 2008)

Figure 5 shows that the exhumed Palaeosurface is quite low range in elevation between 250 - 400 m asl. It is composed of saprolites of the older granite beyond Jabal Naqarah, which is established of andesite and felsite of Dokhan Volcanics (833 m). Figure 6 exhibits the relation between Jabals El Barud (1440 m) and Jabal Kab Amiri (900 m) that are composed primarily of younger granite and their surroundings of the older granite that ranging in elevation between 280-500 m.

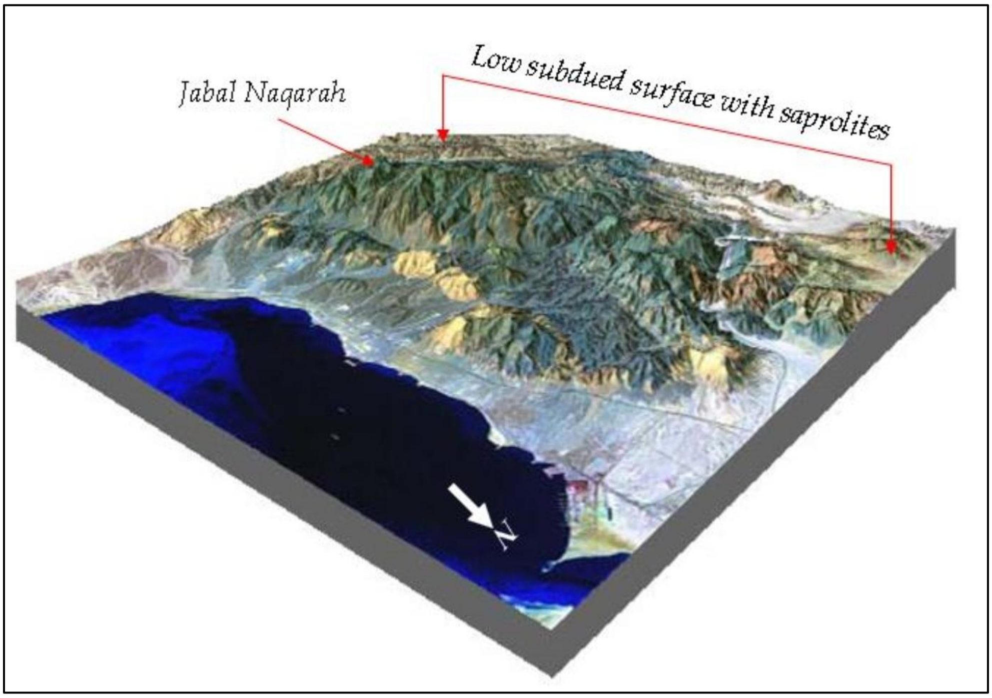

Figure 5. Digital elevation model of Jabal Naqarah and the adjacent subdued surface, overlain by true color ETM+ Landsat-7 image

Investigation of geologic and topographic maps revealed that the area of subdued surface lies approximately west of longitude 33˚ 45` E and forms an extent exhumed and uplifted palaeosurface, which has been exposed by erosion of protective cover rocks (Twidale, 1985, 1999). Lidmar- Bergström et al. (1997) assumed that much of these surfaces are exhumed Precambrian features. Migoń (2004) stated that extreme flatness truncating various bedrock structures and disregarding differential rock resistance existed by the end of Precambrian. However, the exhumed palaeosurface ranges in elevation between 250-1000 m asl. Interpretation of the ETM+ images of the Eastern Desert of Egypt gives the impression that this surface is of a regional extent. The surface is more or less flat distinguished with low relief and remnants, which are likely preserved upon the more resistant rocks and standing conspicuously above the general level (Thornbury, 1984).

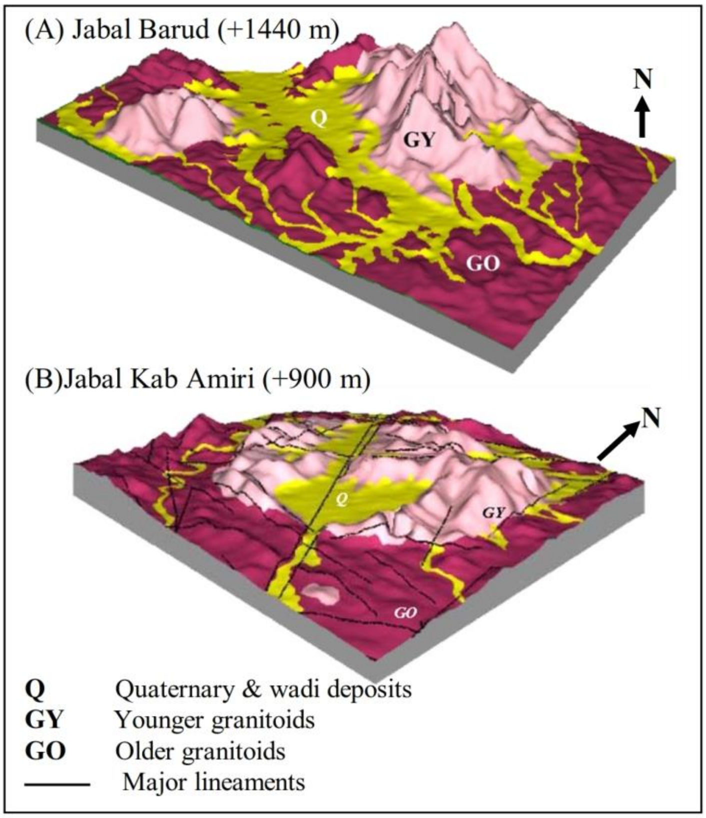

Figure 6. DEM of Jabal Barud (A) and Jabal Kab Amiri (B) overlain by the geological map of Qena, scale 1:500.000

The most crucial reason for considering this surface as an old erosion surface is that the truncation of wide variety of the basement rocks (e.g. biotite; gabbro; older granite; intermediate metavolcanics; biotite granite) of varying resistance to weathering and erosion processes (Figure 7). There is a general accordant level of its interstream areas and summits as well. The surface is significantly subdued, incised weathered and locally interposed by younger intrusions that stands exposing high rugged relief.

Additional evidence obtained from the Hamammat Group of Jabal Umm Kajura, which is composed essentially of unmetamorphosed conglomerates, greywackes, sandstone, siltstone, tuffstone and rare andesites. The group is post-geosynclinal sediments resting unconformably over the older basement rocks (EL-Ramly, 1972). Wild and Youssef (2002) argued that Hammamat Group deposited in major ancient river systems of a continental scale during the period 680-640

Ma, despite Willis et al. (1989) postdated the age of this group at 600-585 Ma. Whatever, Jabal Umm Kajura attains about 250 m asl. and its summit is in accordant with the surrounding felsite and andesite rocks (Figure 8), which implies that the later rocks have been widely eroded.

Generally, remnant summits cut across the Precambrian Basement Complex Rocks, resulting in vigorous dissected and accordant pinnacles or jigsaw-like peaks. Stripped saprolites, which are exposed to deep weathering, are also common. Figure 9 shows a comparison between the exhumed palaeosurface of relatively low relief, weathered saprolites, and rugged relief of Jabal El Barud and Jabal Umm Oradah. It could be deduced that erosion of the saprolites occurs by surface wash in semiarid areas (Büdel, 1957), and slope of the surface is being steeper. Finally, exhumed palaeosurface in the study area could be considered as ″resurrected fossil plains″, which have been uplifted or rejuvenated bodily (Cotton, 1952).

6.1.2. Buried Palaeosurfaces:

Buried erosion surfaces have been discovered fortuitously during our field trip in spring 2007 on the eastern low cliff of Jabal Naqarrah. Two years later a vast extent of this burid palaeosurface was discovered in Jabal Abu Shaara west of Hurghada by the authors (Figure 10). In Jabal Naqarah the surface is preserved in very constricted rock outcrops depart few kilometers from the coast. The lower unit of these outcrops composed of felsite rocks which are unconformably overlain by Miocene sediments about 210 m asl. The contact line constitutes typical unconformities of stratigraphic geology (Thornbury, 1984; Hugget, 2007) and it is more or less even elsewhere. No accurate elevation can be given to this surface since it appears patchy along the eastern cliff of Jabal Naqarrah at different heights (e.g. 130; 170; 180 m asl.) resulting from step faults. As far as we can tell, summit of Jabal Naqarah does not exhibit any planation surface since the surface mostly underwent sever erosion, but there is a noticeable general accordant of its pinnacles or Jigsaw peaks nevertheless.

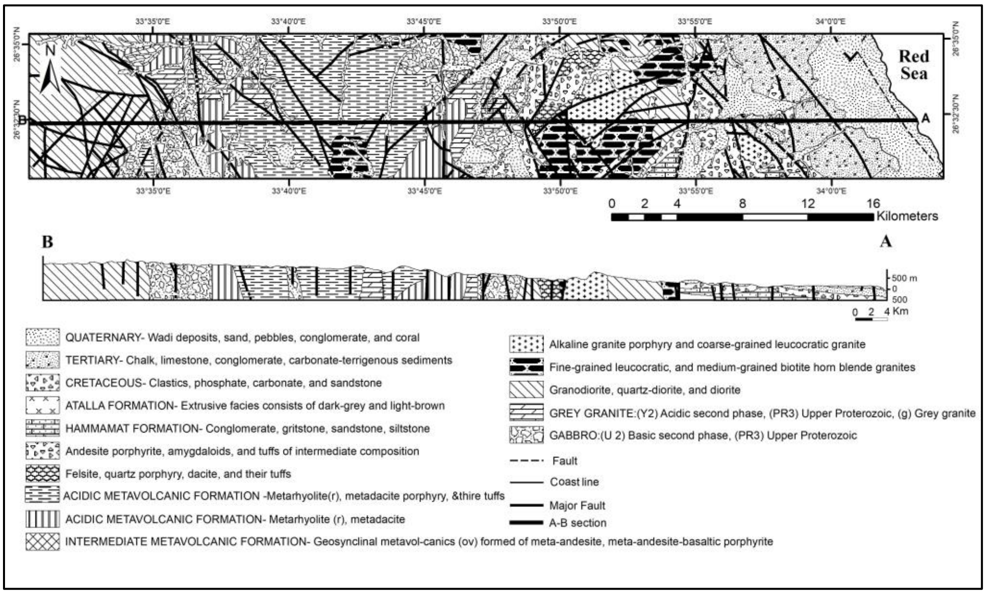

Figure 7. Geological map and section showing exhumed erosion surface and truncation of wide variety of the basement rocks
(Processed after the basement rocks Map of Safaga Quadrangle, scale 1:100.000).

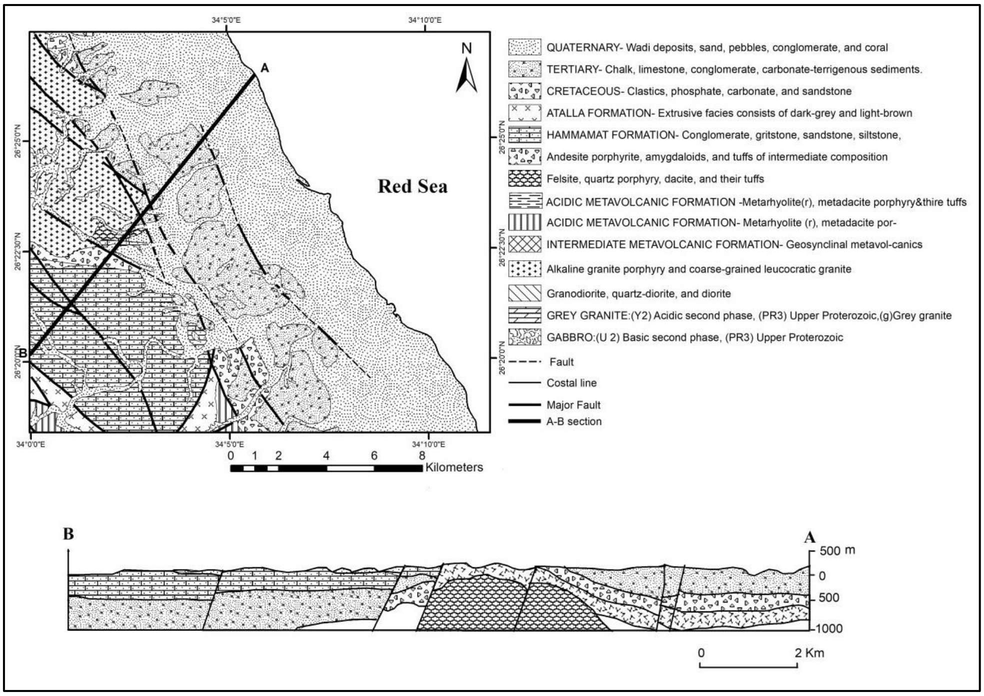

Figure 8. Geological map and section of Jabal Umm Kujurah
(Processed after the basement rocks of Quseir Quadrangle, scale 1:100.000)

6.2. Relative Timing of Surface Evolution

For the moment, it is difficult to determine absolute ages to these palaeosurfaces; therefore, we primarily depend on relative dating by overlaying rocks and tectonic deformations (Ollier and Pain, 2000). Geomorphological evolution of the study area reveals the intimately interaction between tectonism and erosion processes. In contrast to Scandinavian (Japsen et al., 2006), timing and extent of uplift movements and the Precambrian rocks in the Eastern Desert of Egypt have been discussed and to some extent well determined in many literatures e.g. Akaad and El-Ramly (1960); Said (1962, 1990); El-Ramly (1972); Francis (1972); Hassan and Hashad (1990); Morgan (1990); Meneisy (1990); Abdel-Rahman (1995); Zaky (1999); Akkad and Abu El Ela (2002); El-Sayed et al., (2002); Khalil and McClay (2002); Beniamin et al., (2005). Two major phases of denudation of a palaeosurface could be determined as follows:

Figure 9. Incised weathered saprolites (Source: Field study)

6.2.1. Hammamat Phase (~ 680-640 Ma):

The early phase was mostly synchronous with the end of the first orogeny in the Precambrian that took place between 900-600 Ma (Beniamin et al., 2005). It is corresponding to the formation of Hammamat group where significant volumes of igneous rocks (~ 680-640 Ma) were vigorously eroded. Wild and Youssef (2002) demonstrated that Hammamat sedimentation was deposited in a major ancient river system of a continental-scale. Francis (1972) and Grothaus et al. (1979) found evidence for deposition as alluvial fans and braided stream deposits in isolated intermountain basins. It is supposed that drainage systems incised into the preceding surface as a result of uplift and this was the first episode of exhumation **(hereafter known as Hammamat Phase)**.

Figure 10. Preserved buried erosion surfaces at Jabal Abu Shaara (A), and Jabal Naqarah (B). Dashed lines demarcate the unconformity between Felsites rocks and Tertiary cap rocks (limestone)

The Pre-Nubian erosion surface of the central Sinai that has been recognized by Awad (1951) coincides with the same phase as well, since a flat surface separates Nubian sandstone from the Precambrian basement complex rocks. Nubian sandstone is deposited under a tropical to subtropical climate and is formed under a variety of continental conditions. It is exposed in sub-humid, semi-arid, and arid environments (Singer and Amiel, 1974) that were prevailed along spans of time throughout Cambrian-Upper Cretaceous period. Ambrose (1964) assumed that the exhumed palaeoplains of the Precambrian shield of North America was developed in Pre-Paleozoic time. Lidmar-Bergström (1995) revealed that the primary peneplain of the Baltic Shield belongs to late Proterozoic. Bonow et al. (2006) referred to what they called "the former sub-Ordovician peneplain", whereas remnants of Paleozoic covers are present across low relief in the basement rocks. Additionally, early Paleozoic planation surface was also described in Northern Ethiopia (Coltorti et al., 2007). In Saudi Arabia the Pre-Wajid/Saq surface(s) is thought to have occurred near the end of the Proterozoic and continued into the Cambrian (Vincent, 2008). Palaeosurface of Hammamat Phase may become particularly significant since it seems to have widespread extent that might suggest major events in the Earth's history. Nevertheless, we could not accurately demonstrate whether these surfaces are correlated to each other throughout the world or not.

6.2.2. The Later Phase of Denudation (Pre-rift / Syn-rift Phase ~33.9-11.6 Ma):

A great hiatus in the sedimentation cycle has been observed between the Pre-rift sediments (Cretaceous-Early Eocene) and the coastal Syn-rift sediments (middle Miocene and later sediments). It is demonstrated that during middle Eocene the Tethys (ancestor of the Mediterranean) retreated towards northern Egypt (Ball, 1939; Said, 1962). The land was mostly higher as a result of the 1st period of tectonic activation (620-570 Ma) and the 2nd period of tectonic activation during Cretaceous-Early Tertiary, which related to the oblique convergence between Africa and Eurasia (Zaky, 1999). During late Oligocene-Miocene epochs process of the Red Sea formation mostly occurred associated with gradual uplifting of the Red Sea Mountains (Beniamin et al., 2005). The area was subjected as well to northeast movement as a result of divergent movement between Africa and Arabia caused right-lateral displacement (Zaky, 1999). This was associated with the opening of the Red Sea which began at the end of the Oligocene (Vincent, 2008). Furthermore, geological and palaeontologic data from the Sahara suggests a wet equatorial climate in the late Eocene. That is shifted during the Oligocene epoch towards a Sudano-Guinean type of savanna and then turned towards the tropical wet climate during middle Miocene (Le Houérou, 1997). We suppose that ancestor drainage systems were initiated during this period, springing the uplifted land of the early rift-stage (hereafter known as **Pre-rift / Syn-rift Phase**).

Deep weathering was probably overprinted or superimposed on to the remains of the exhumed Hammamat Phase surface. Then, peripheral coastal lands were widely eroded as a major wave-cut platform formed during the transgressive phases of sea level through late Miocene.

Evidences obtained from drainage basins revealed that the present-day streams represent inherited palaeostreams that were overprinted or superimposed as inferred in Jabal Abu Shaara (Figure 11) and antecedent wadis are common such as Wadi Sodmein (Queih); Wadi Mohamed Rabah. Our concept is to some-extent in accordance with the model presented by Issawi and McCauley (1993) concerning the Cenozoic landscape of Egypt and its ancient river system. Investigation of the bathymetric maps revealed large submerged deltas profound about 500 m below the present-day sea level in the Red Sea (Figure 12).

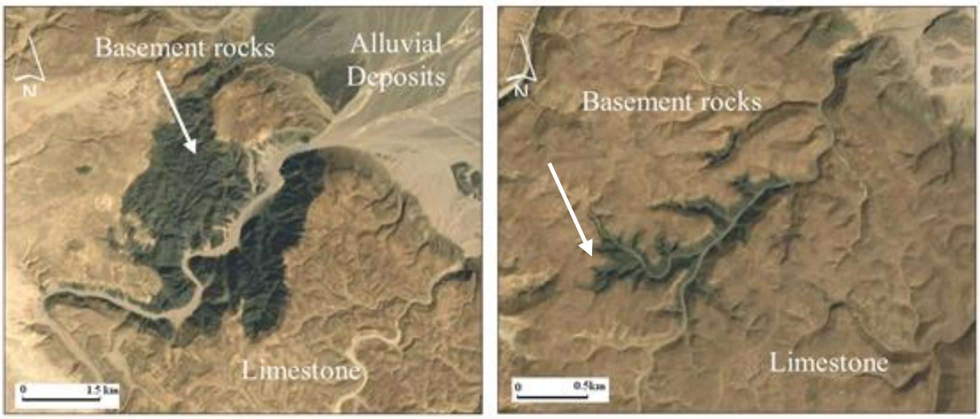

Figure 11. Typical superimposed drainages on Jabal Abu Shaara
(Source: Google Earth Pro 2022)

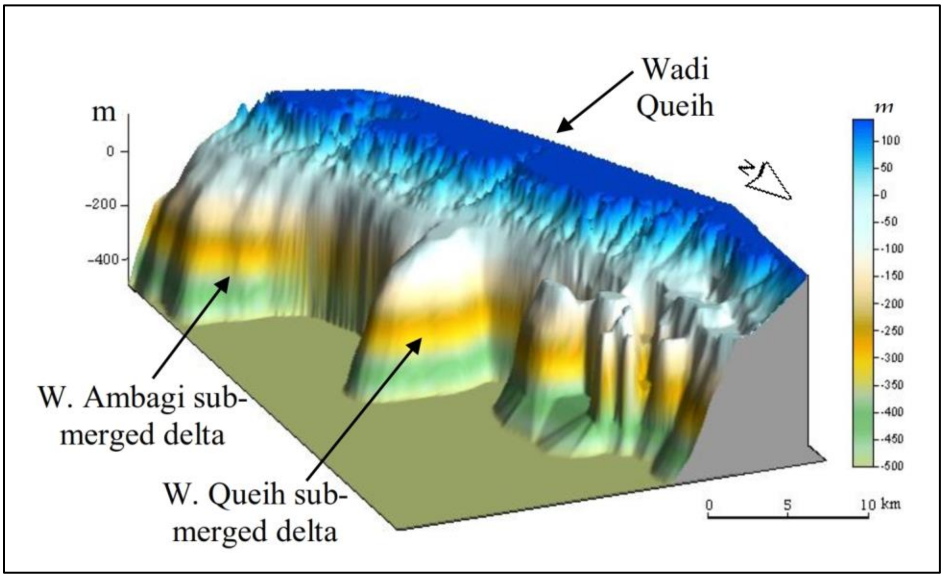

Figure 12. 3D perspective view shows the submerged deltas
(Processed after the bathymetric maps of scales 1:250.000 and 1:500.000)

The submerged deltas characterized by micro-submarine forms of which three terraces at -20, -50, -100 are conspicuous (Moawad, 2013 a, b). On the one hand, correlation between the submarine terraces and the global sea-level curve during the last glacial stage may be reasonable to give a relative age for the three submarine terraces. Terrace -100 m may be in corresponding to the Last Glacial Maximum (LGM) in the age range of melt-water pulse (MWP) 1A0 and 1A (~19.000-16.000 yr. bp.) when the ocean level rose rapidly 10-15 m in less than 500 yr. during the MWP-1A0 and followed by another increase about 16-24 m during the MWP-1A (Gornitz, 2009). Terrace -50 m is probably in accordance with the melt-water pulse-1B (11.500-11.000 yr. bp.) when the sea level may have jumped by 28 m. Terrace -20 m mostly formed during the fourth melt-water pulse 1C (8.200-7.600 yr. bp.) (Gornitz, 2009). On the other hand, the terraces are in accordance with those submarine terraces recorded in southern Sinai at -20, -60, -120 m (Gvirtzman, 1994). Another submerged terrace (-60 to -90 m) was recorded at Sharm El Sheikh and Ras Burka (Fricke and Landmann, 1983; Reiss and Hottinger, 1984) and at Elat (-50 to -90 m) (Reches et al., 1987). Terrace of Elat has likely developed between 70.000-50.000 yr. bp., when the sea level was 100 to 60 m below the present level (Reches et al., 1987). These imply that drainage initiation was mostly antique than Pleistocene time.

6.3. Model of Landscape Evolution

It is appropriate to think about these palaeosurfaces as polygenetic denudation surfaces. Geomorphic evolution of the study area could be simplified into two main episodes according our proposed model (Figure 13):

- The first episode of landscape evolution began with the elevation of the Arabo-Nubian Shield accompanied with the early rise of Dokhan Volcanics around 620/600-590 Ma (Stern and Hedge, 1985; Abdel-Rahman, 1995). This implies the presence of interfingering relationship between the Hammamat Group and the Dokhan volcanics, indicating that they are penecontemporaneous (Mohamed et al., 2000). Meanwhile, a drainage system of a continental scale was formed resulting in eroding the highland and aggradation of the basins. Around the end of this episode the younger granite has established (620-570 Ma yr) (Hassan and Hashad, 1990) and followed by a number of intrusive dykes that are known as post-granite dykes (650- 550 Ma. yr.) (Abdel-Rahman, 1995).
- The second episode started where more or less of the area was covered by the pre-rift sediments (Cretaceous). These sediments protected the previously palaeosurface, which become buried. During early Oligocene-Middle Miocene the climate was mostly wet equatorial and wet tropical (Le Houérou, 1997). This surface mostly becomes etchplain as a result of tropical deep weathering. An etchplain is a form of planation surface associated with crystalline shields and other ancient massifs which developed under tropical conditions promoting rapid chemical decomposition of susceptible rocks (Thomas 1968). Incised drainage systems were developed during the same period. Approximate average rate of erosion R_e is estimated as the apportionment of time lag between early Oligocene (~33.9 Ma.) and late of middle Miocene (11.6 Ma.) divided by average thickness of sedimentary rocks in Jabal Duwi (~500 m). Accordingly, approximate average rate of erosion was estimated as 1 mm/44.6 yr. and it is relatively high where the surface was typically a tropical etchplain. High rate of erosion is

explained by the fact that the truncated rocks are mainly of wide varieties of igneous and metamorphosed. During late Miocene the coastal margins of the area were submerged resulting in palaeowave-cut platform in Jabals Naqarah and Abu Shaara, which overlain by Mio-Pliocene sediments.

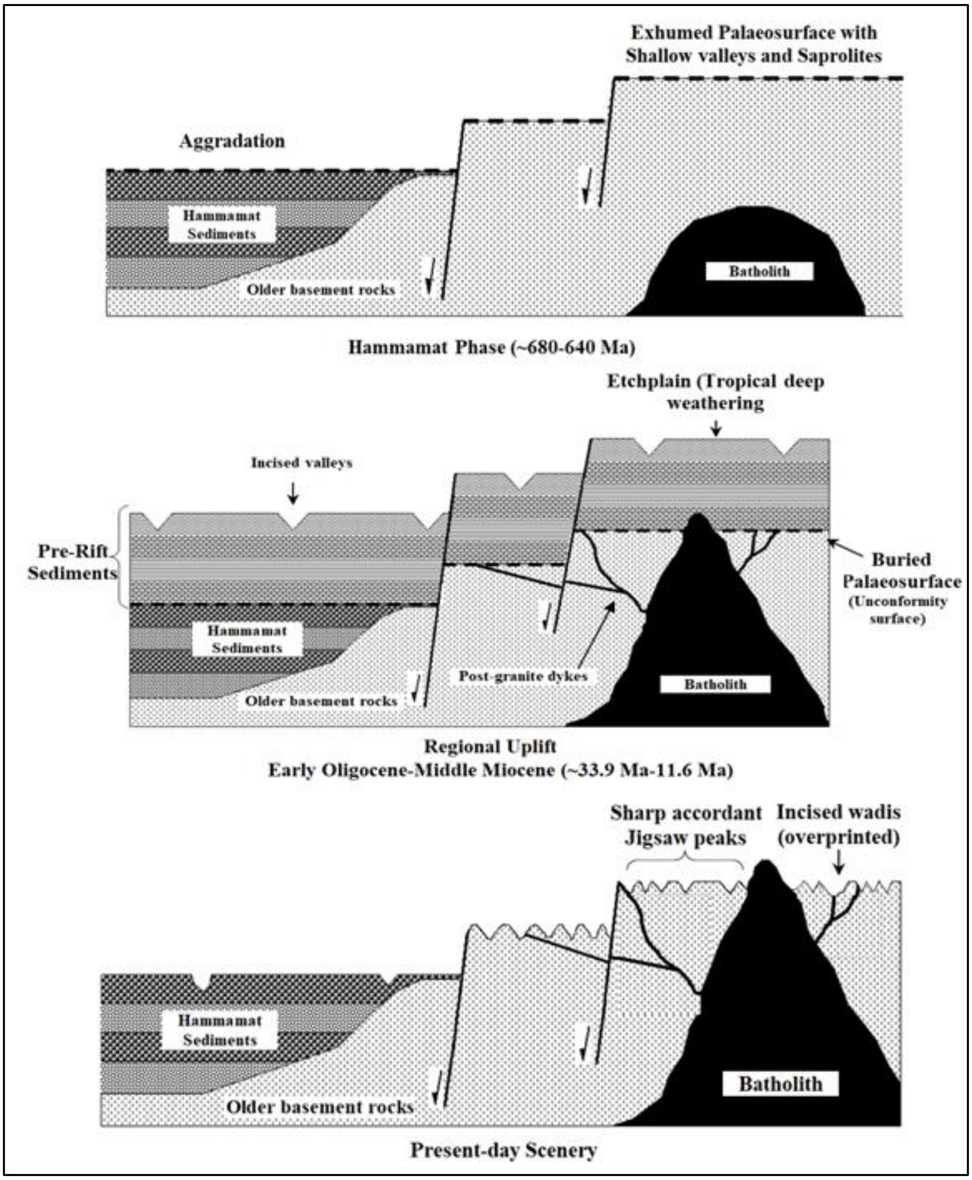

Figure 13. Simplified sketch shows the evolution of palaeosurfaces in the Central Eastern Desert of Egypt (For details review the text)

Present-day drainage system of Jabal Abu Shaara revealed typically superimposed or overprinted drainage systems on the lower felsite rocks (see figure 11) and these may help us better understanding how the physical landscape has been evolved by drainage systems throughout the time.

Conclusions:

Although the Red Sea Mountains in the Central Eastern Desert of Egypt are extremely rugged, they have been inferred as vast old erosion surfaces that underwent multiple uplifting, the study distinguished two palaeosurfaces; they are: 1. exhumed palaeosurface and 2. buried palaeosurface. The exhumed palaeosurface is quite low (250-400 m), composed of saprolites of the older granite. This surface is distinct by truncation of wide varieties of the basement rocks, and the general accordant levels of interstream areas and summits. Evidences obtained from Hammamat group revealed the role of fluvial erosion between ~680-585 Ma. Therefore, Hammamat group represents the early phase of denudation that was mostly synchronous with the end of the first orogeny during the Precambrian.

The buried palaeosurface is preserved in very constricted rock outcrops in Jabal Naqarrah and Jabal Abu Shaara. The contact line constitutes typical unconformities of stratigraphic geology. The second phase of denudation is supposed to be occurred during late Oligocene-Miocene epochs (~33.9-11.6 Ma.), where a great hiatus in the sedimentation cycle has been observed between the Pre-rift sediments (Cretaceous-early Eocene) and the coastal Syn-rift sediments (middle Miocene and later sediments). Palaeontologic evidences from the Sahara suggest a wet equatorial climate in the late Eocene that is shifted in the Oligocene towards a Sudano-Guinean type of savanna and turned towards the tropical wet climatic conditions during middle Miocene. It is supposed that ancestor drainage system was initiated during this period, springing the uplifted land of the early rift-stage.

Model of landscape evolution takes into account that these palaeosurfaces are of polygenetic denudation surfaces. The model proposed that the first episode of landscape evolution began with the elevation of the Arabo-Nubian Shield accompanied with the early rise of Dokhan Volcanics around 620/600-590 Ma **(Hammamat Phase)**. The second episode **(Pre-rift / Syn-rift Phase)** started during early Oligocene where the surface was mostly etchplain as a result of tropical deep weathering. Approximate average rate of erosion was estimated as 1mm/44.6 yr.

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