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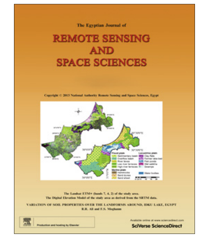

RESEARCH PAPER

Applications of geomorphology, tectonics, geology and geophysical interpretation of, East Kom Ombo depression, Egypt, using Landsat images

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Abstract In the Southern Eastern Desert of Egypt, A NW–SE oriented structural graben extends from the North of Aswan to the Red Sea coast with a length of about 400 km and an average width of 30 km. The area has significant potential for development as it may be provided with water from surface and subsurface sources and is the site of prospection for petroleum. The present paper is an attempt to understand the structural evolution and genetic development of the geomorphologic features of the area and constructing presently a new geomorphological map at a scale of 1:250,000 using Landsat ETM images and field checks. Available geological maps and the produced geomorphological map are digitized by using the ARC-GIS software. The same program is also used to produce a 3D DEM for surface and subsurface features. Based on new interpretations of aeromagnetic and radiometric data, the subsurface features of the basement cover were illustrated on a 3D map. Geological–geomorphological profiles have been constructed in different directions in the area to identify present and ancient geomorphologic features. The place and shape of subsurface deep seated NW–SE trending faults have been determined. The faults, which generated the graben have downthrows in the order of 900–5800 m. The surface and subsurface observations delineate the dominant downthrow of about 3750 m. Three E–W subsurface faults have been detected under Nubia sandstone, one of them, displaying a downthrow of about 845 m, cuts through the basement rocks.

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1. Introduction

Garara structural graben is the most pronounced Phanerozoic rock inlier in the Precambrian exposures of Egypt. Many workers referred to Garara graben as the biggest one of the NW structural grabens bordered by deep-seated faults of the Red Sea trend in the Eastern Desert of Egypt in the North East African Shield, e.g. Schurmann (1974). It extends in the

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Southeastern Desert from Kom Ombo (40 km North of Aswan) to the Red Sea in the SE coast, with a length of about 400 km and an average width of 30 km. The area lies between latitudes 23° 00′ and 25° 00′ N and longitudes 33° 00′ and 34° 30′ E (Fig. 1). Fig. 2 illustrates the location discussed in the text, the names written from topographic maps.

This area was not geomorphologically mapped before, in spite of the fact that a good knowledge of the geomorphology and terrain characteristics of a region is very important for efficient planning. This paper deals with how the tectonics, lithology and geomorphic processes were integrated to sculpt the landscape of the Garara graben, the structural evolution and genesis of the landscape geomorphology of this sector were studied through the investigation of the endogenetic and exogenetic geomorphological processes during geological time, as well as subsurface geophysical interpretations.

2. Geological setting

The investigated area is a part of the Pan African Arabian–Nubian Shield that was discussed by many workers. Proterozoic igneous and metamorphic and Phanerozoic rocks are

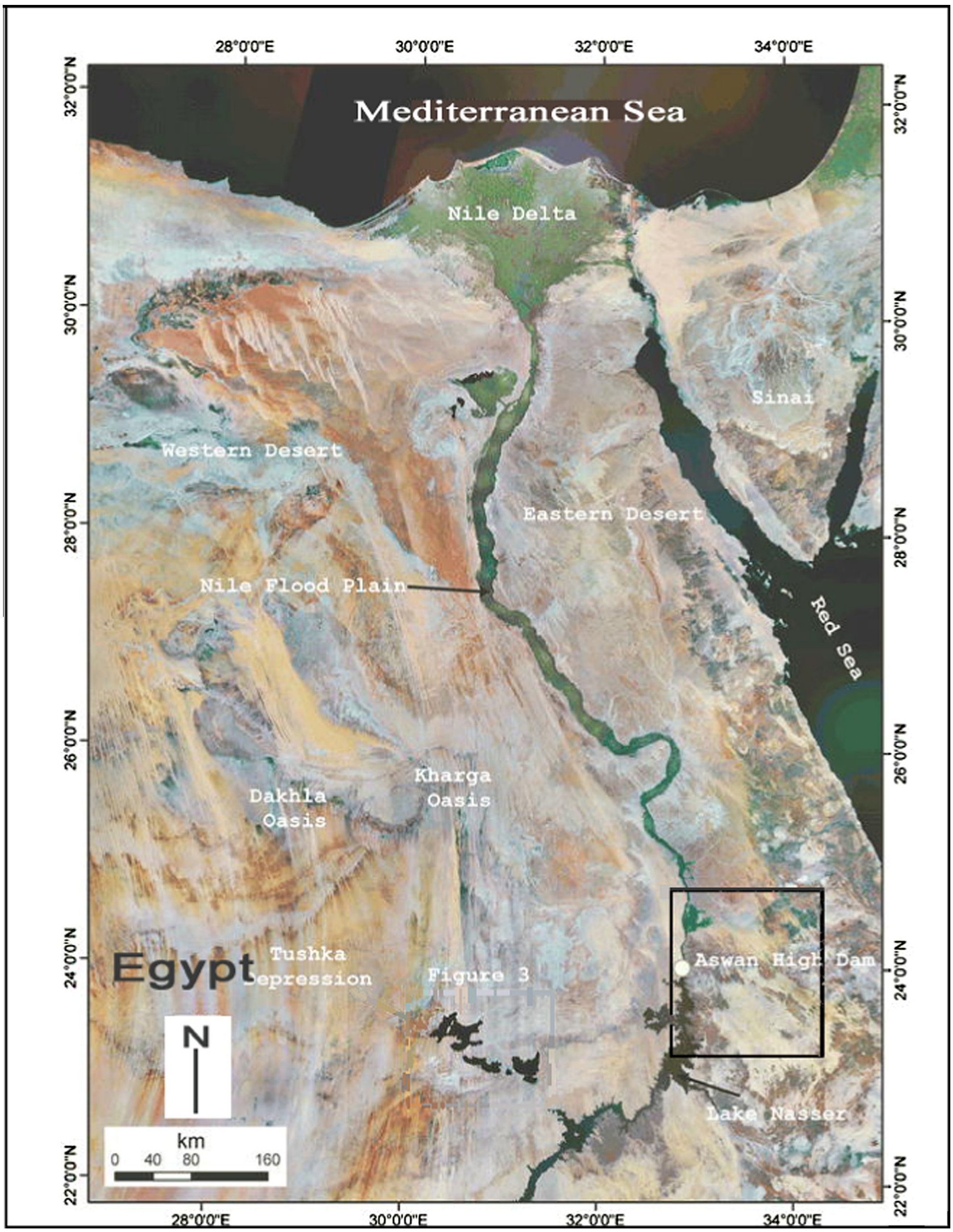

Figure 1 Location map, the study area marked by frame.

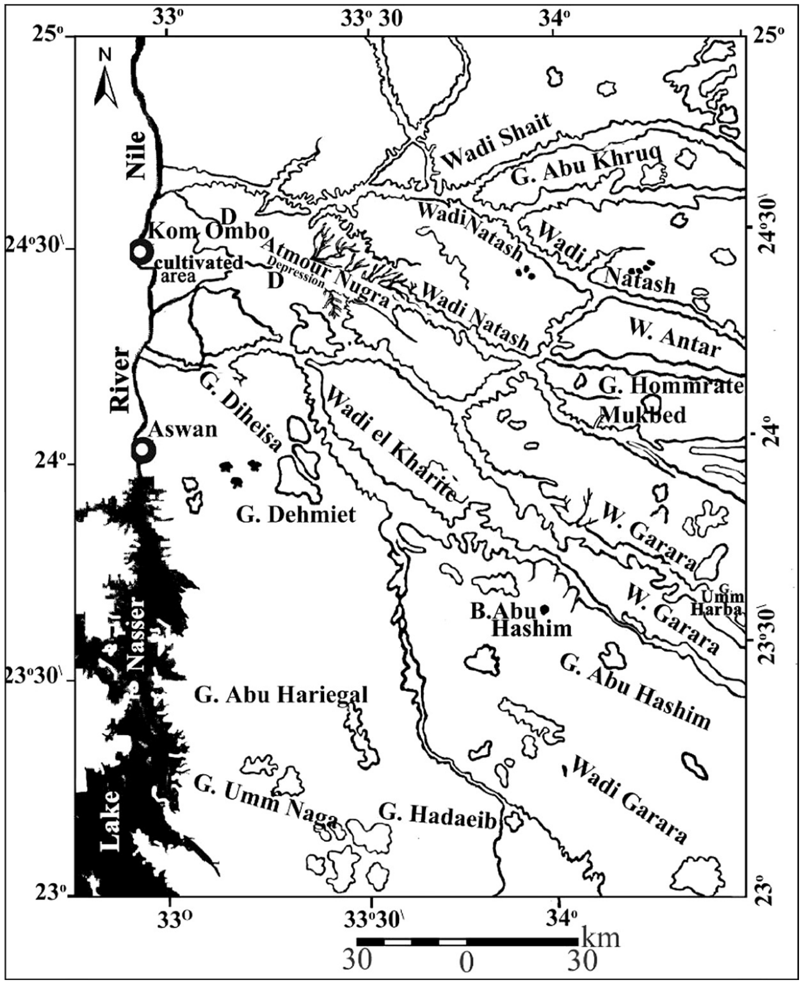

Figure 2 The localisations discussed in the text (G – Gabal, W – Wadi, B – Bir and D – depression).

exposed within a geological map of the area illustrated in Fig. 3 from Conoco Coral map (1987). The field observations in South Eastern Desert demonstrate that the volcano's sedimentary-ophiolite-plutonicis were tectonically controlled showing a three-tier succession based on normal or formal nape stacking (De Wall et al., 2001). The basement rocks in the South eastern Desert include island arc metasediments and metavolcanics over oceanic crusts subjected to major orogeny, causing thrusting and mixing of the ophiolitic melange. Gneissesare the oldest Precambrian rocks in the study area, outcropped Southwest Wadi Garara and in the Eastern part of the study area as highly fractured weathered hills. They are composed of leucocratic and melanocratic medium to high grade metamorphic rocks of gneiss, granite gneiss, schist and amphibolite Stern (1994) postulated ophiolite occurrences around Wadi el Kharite in the investigated area. Ophiolite group includes serpentinites and their varied derivatives occur as allochthonous masses of various sizes down to small clastics in typical elongated masses of mélange. High relief small bodies of serpentinites are scattered around the Nubia Formations. They are altered to talc carbonate rocks and magnesite veinlets frequently observed in the outer serpentinites. Metasediments that cover vast areas have considerable thickness and include metamudstone, greywacke and conglomerate. They are frequently metamorphosed up to chlorite and biotitezones and certainly older than the calc-alkaline intrusive rocks. They strike mainly in NW–SE direction, and are folded along NE and NW trending axes. Metavolcanic rocks are present in the Southern and Eastern parts of the mapped area of medium topography composed of meta-basalt-andesites overlain by rhyolite and rhyolite-tuffs; they have schistose texture in green-schist grade. Older granitoid rocks described elsewhere as ''Shaitian granites'' occur as a composite pluton of batholithic dimensions in Wadi Shait (its type locality). Shaitian granite is composed of trondhjemite, tonalite, and granodiorite of medium grain size in equigranular texture. It contains abundant xenoliths and rafts of other rocks in various stages of digestion Hashad and El Reedy (1979) determined the age of the Shaitian granites at Wadi Shait as 876 Ma. High relief younger granitic plutons composed of laccolithic dimensions with pink and red colors intruded the adjacent rocks in the Eastern part of the area. Ring complexes named the Abu Khruq ring composed mainly of syenite, trachyte and nepheline–syenite occurred. The granite is affected by post Nubian faulting which causes local blockling in a series of Cretaceous-Tertiary sediments, volcanism of minor extrusions is associated with these types of faults. The young volcanic extrusions inside and around the Wadi Natash are distributed in the NE direction according to the structural control of Phanerozoic. They formed a cone-shape and plugs in

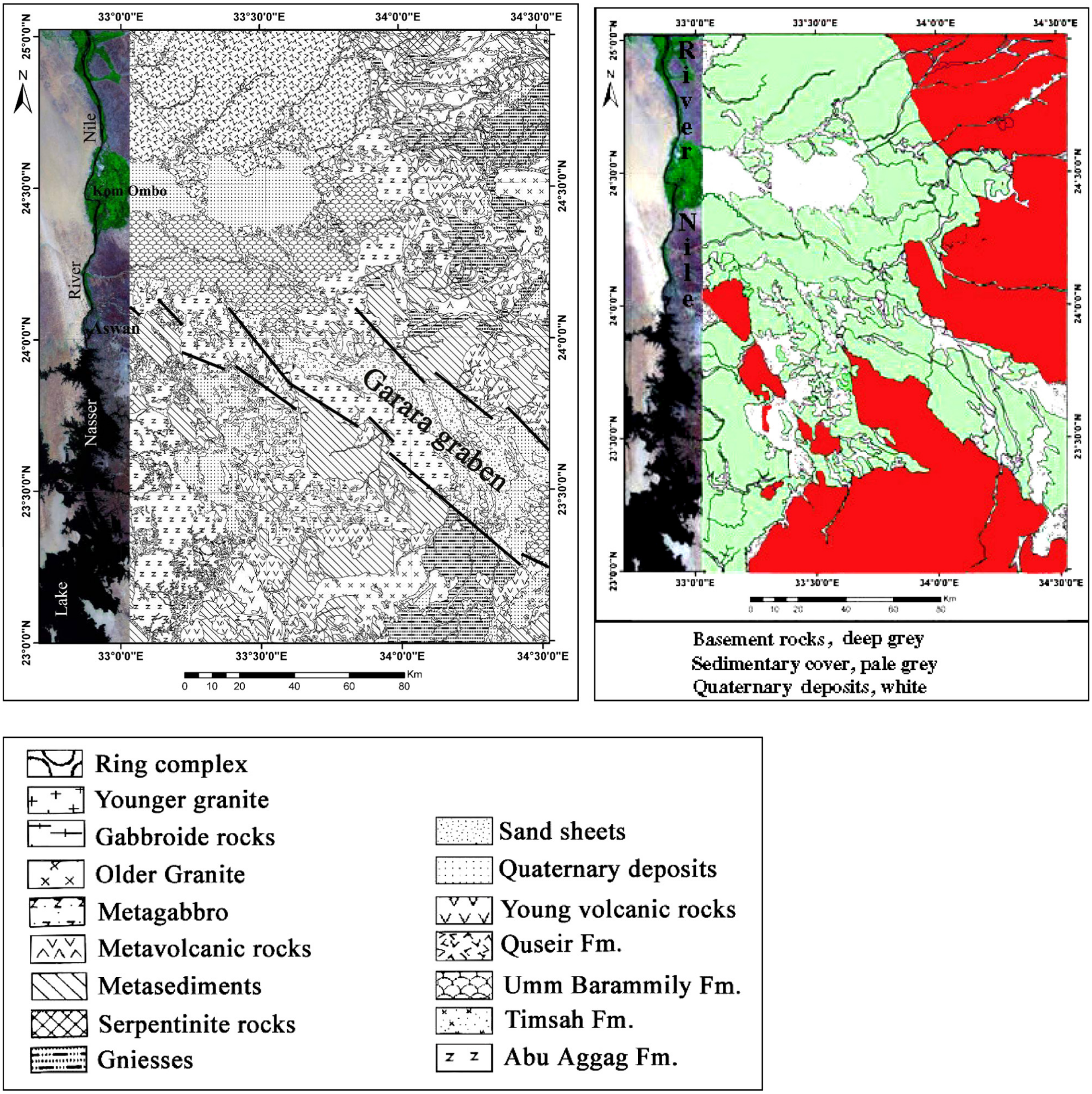

Figure 3 Geological map of Wadi Garara area from Conoco (1987).

black color and were named by some workers as Natash volcanics. The albitized volcanic varieties and trachytic basalt volcanics are very abundant in the Wadi Natash i.e. the alkali and sodium reach magma are extruded in different ages along the NW trend around the graben. The basement rocks described above are traversed by many dyke systems in different compositions from basic to acidic and different ages. The older granitoid rocks are mostly influenced by the dyke extrusion forming hard peaks of the exfoliated older granitoid weathered blocks in the Wadi Shait and the Wadi Natash. The Phanerozoic sedimentary cover is unconformably overlying the Precambrian basement (Fig. 3). It is composed mainly of sandstones, siltstones, and shales, represented by the Abu Aggag-, Timsah, Umm Brammily and Quseir Formations of Upper Cretaceous age according to Conoco Coral Geological Map (1987). Abu Aggag Formation stretched in NW–SE lagre belt of horizontal beds covering the western part of the Garara graben forming Gabal Abu Hashim and the surrounding area is bordered in the West by structural contact with metasediments. It is composed of fluvial deposits with cross-bedded sandstones, ripple-laminated sandstone, lenticular sand bodies and channel fills and local paleosols. Timsah Formation outcropped in NW–SE belt inside the Garara graben and was bordered on the east by metasediments with structural contact and wide wadis that formed after major faults (Wadi Garara and Wadi el Kharite) and was bordered in the west by Abu Aggag Formation with NW–SE faults. Timsah Formation is composed of fluviatile near-shore marine and local eoliansanstone, with interbedded channel and soil deposits. Umm Brammily Formation overlies unconformably the Abu

Aggag Formation i.e. the northwestern part of the graben covering broad area of the South and East Atmour Nugra depression. Umm Brammily formation composed of fluviatile sandstone, becomes more marine toward the North. Quseir formation covers a wide area north of the Atmour Nugra depression. Its elevation varies from 280 m North of Atmour Nugra depression and reaches up to 425 m in the Northern part of the study area. Quseir formation is composed of littoral varicoloured shale, siltstone, and flagy sandstone containing mixed marine and fresh-water gastropods. Thin rock beds most probably Tertiary overlie the Nubia with little or no angular unconformity but the marked difference in rock type indicates a considerable change in environment. The chalk, marl and calc-arenite sequence in East Kom Ombo is indicative of shallow open seas rather than the estuarine littoral environment of the Nubia. Quaternary deposits are represented by surficial accumulations of wadi deposits of clay, sands, gravels and rock fragments as well as sand sheets that cover the low lands.

3. Methodology

Surface mapping using Landsat TM and ETM image mosaics (Fig. 4) of 1:250,000 of principal components (PC), bands 2, 4, and 7 was used to prepare a new geomorphological map. A digital elevation model (DEM) was displayed by using Landsat ETM images, topographic maps and ARC-MAP program (Fig. 5). Geological and geomorphological profiles along different orientations were prepared to clarify the present and ancient (paleo-) geomorphology of the area. The geological and geophysical airborne data were also digitized and processed by the ARC-MAP program to be included in a GIS. The same program was also used to construct a 3D picture of the surface of the area by drawing a processed image on the DEM of the study area.

4. Geomorphology

The Landsat images used for geomorphologic mapping provide good discrimination between different physiographic features as follows;

mountains and hills constituted by metasediments, metavolcanics, or gneisses. Older (syn – tectonic) granitoid rocks are exposed as isolated hills with medium reflectance of electromagnetic radiations on Landsat TM images. Faulted denudational mountains and hills are mainly constituted by serpentinites, gabbro, and diorite. Weathered and dissected batholiths and lacoliths from serpentinite, gabbro and diorite rocks, exhibit high and medium topographic relief and dark gray and green colors (in false color). Some batholiths are highly weathered, and exhibit low relief and a green color. Lacoliths of gabbro exhibit ellipsoidal shapes. They are slightly dissected, their lineaments on TM Images display a specific perpendicular pattern. They show smooth weathered surfaces in the eastern part of the study area. Alluvial fans, sand sheets and sand dunes can be also discriminated in the Landsat images. A new drainage network and physiography map was drawn from Landsat TM image mosaics (Fig. 7). The surface flash flood(s) on the area run in general from East to West and from South to North. The main Wadis in the area are Shait, Natash, el-Kharite, Antar, and Garara. The general is from peaks of basement rocks (1300 m) in the East, to Atmour Nugra (120 m) in the West and from the Southern igneous mountains (1200 m) to the North, except some rugged terrain of basement hills in the Southwest part of the area and planation at the Wadi el Kharite. Rectangular and fine denderitic drainage patterns characterize Nubia sandstones. Subdenderitic and subparallel drainage patterns of plutonic igneous rocks parallel to subparallel patterns dominate in the ring complexes and in post tectonic granites. Wadi el Kharite is characterized by braided shallow drainage patterns in Quaternary deposits, while basement mountains and Nubia sandstones are affected by deep drainage channels.

4.1. Geomorphological units

A new geomorphological map has been drawn at a scale of 1:250,000 using Landsat TM images and field check (Fig. 8). Geomorphologic endogentic processes (such as, lithology and structures) and exogenitic processes (such as weathering and deposition) formed the present landscape of the east Aswan sector. The genetic geomorphologic classification together with the endogentic-processes, based on structure and lithology, define the main geomorphologic units, using the morphologic shape classification together with the exogenitic processes to the geomorphologic sub-units postulated by El-Gammal (1999) and El Gammal et al. (2003). The geomorphologic units in the mapped area are shown in Fig. 8. The following is a brief description of the most dominant units in the area:

4.2. Structural landforms

4.2.1. Faulted mountains and hills

Faulted denudational mountains and hills are mainly constituted by serpentinites, gabbro, and diorite. They are weathered, fractured and exhibit high and medium topographic relief and dark gray and green colors in the field. Some hills are highly weathered, and exhibit low relief. Ellipsoidal gabbro hills are slightly dissected and their lineaments on TM Images display a specific rectangular drainage pattern. They show smooth weathered surfaces in the Eastern part of the study area.

4.2.2. Bedded mountains and hills

Metasediments and metavolcanics with some exposures of gneisses constitute eroded mountains and hills. They exhibited as variegated forms, and formed bands on TM images.

The weathering products of the hills accumulate as pencil-shaped masses of deluvial fragments on their foot slopes. The rocks exposed in these hills are highly weathered, dissected and tectonically tilted. Metavolcanic rocks are more resistant to weathering and develop higher reliefs than the metasedimentary rocks. and some hills constitute hogbacks.

4.2.3. Dissected batholiths

Older granitoid batholiths are weathered and dissected and now form the present denudational structural landforms with onion-shape and tors landforms. They are located in the Wadi Shait with low topographic relief and gray color.

4.2.4. Lacoliths

Younger granite plutonic rocks are located in Eastern and Southern parts of the area. They have ellipsoidal-and rounded-shapes with high topographic relief and red color. They are hard plutons and are slightly weathered. Some of

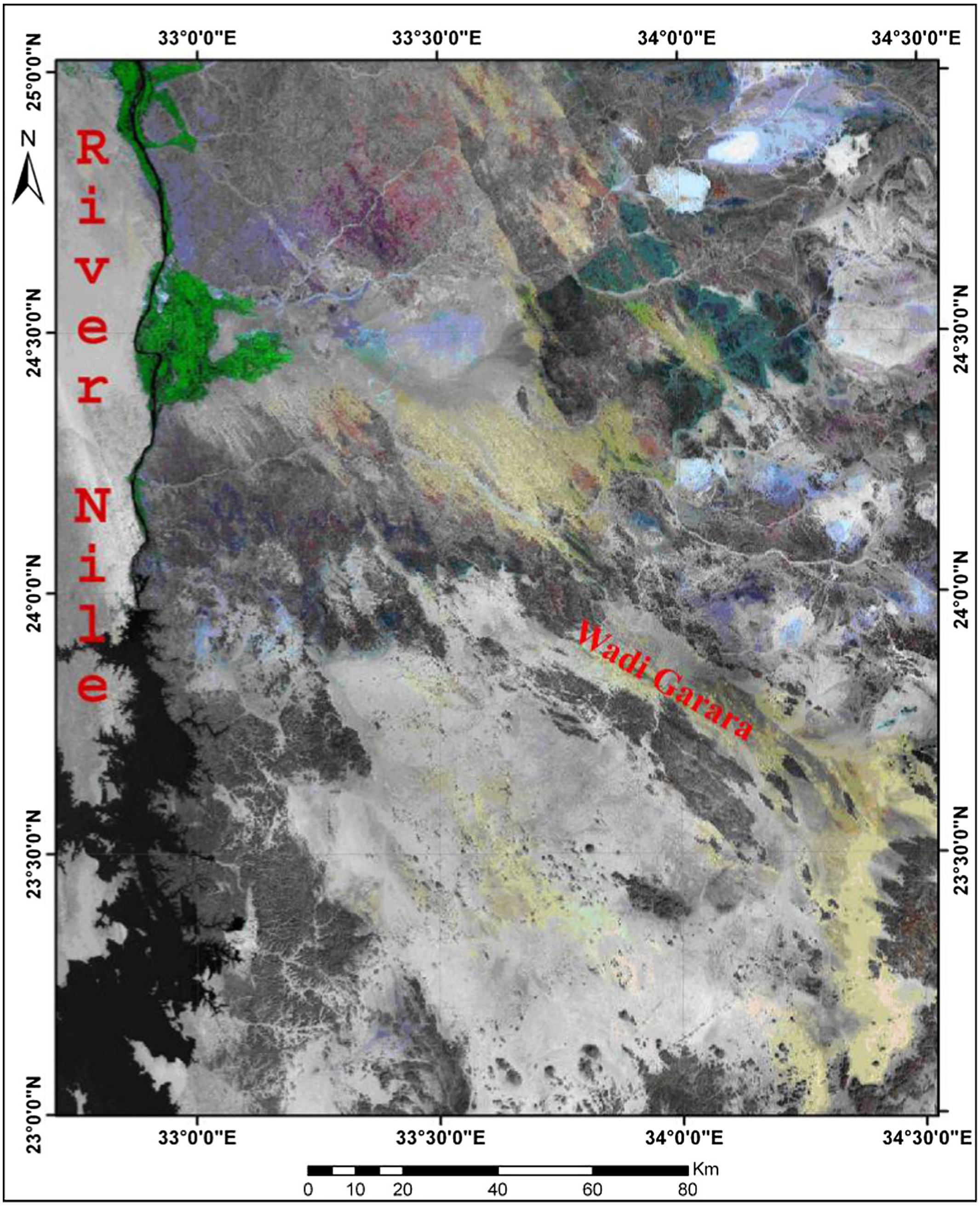

Figure 4 TM images for the study area.

them show parallel and vertical drainage patterns. There are small metals on the red granite surface. Circular and ellipsoid masses from intrusive gabbro in laccolithic dimensions with high relief and steep slopes are located in the northeastern part of the area and are traced by faults and fractures cutting this oval-shape. These masses have peaks forming water divide lines and formed parallel drainage patterns with deep drainage channels.

4.2.5. Ring complexes

The main ring complexes in Egypt are present in the study area. Gabal Abu Khruq is slightly dissected, eroded and has moderate to high relief syenite, alkali granites and trachytes. The rings were intruded at fault intersections. The main fault trends are: NE–SW, E–W, N–S and NW–SE. Others of considerable size occur; Gabal Umm Naga 644 m and Gabal Abu Hariegal 604 m in the Southern part of the mapped area. Other ring complexes in Wadi el Kharit (500–510 m) formed as a result of Cretaceous tectonic movements. They are slightly dissected hard rocks and located in zones where major ESE–WNW and ENE–WSW faults intersect the NNW–SSE faults of the Nubia border. They are arranged similar to the Wadi Natash lava plugs. Dissected plateau extended at the north of Atmour Nugra with heights ranging from 265 to 400 m with a general gentle slope (about 4°) toward the West to the Nile Valley. It is composed mainly of sandstones, shale, siltstone, and marl. It is cut by major faults and several Wadis in NE–SW and NW–SE directions. Another NW–SE highly

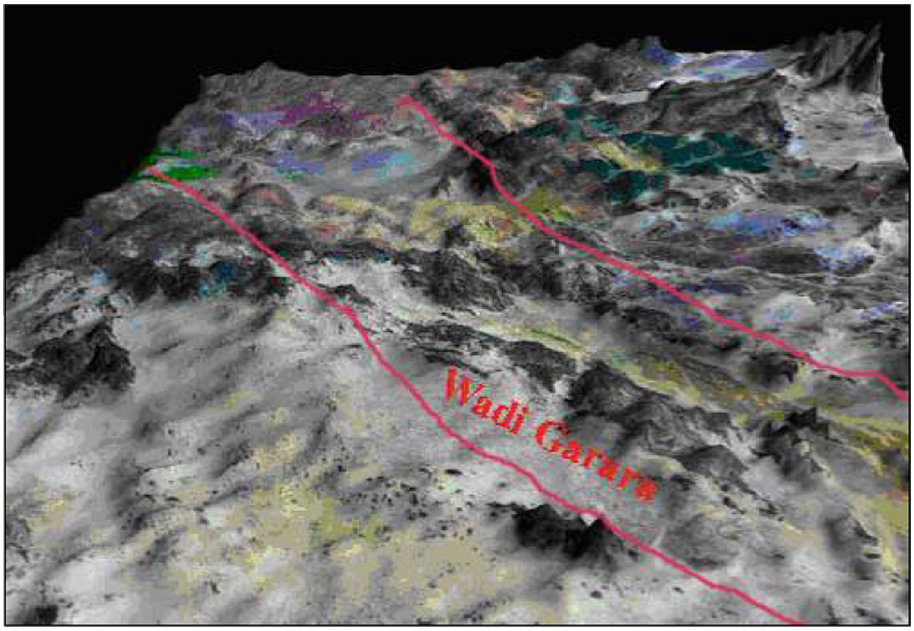

Figure 5 A digital elevation model, (3D) prepared from Landsat TM images of the Wadi Garara area.

dissected plateau extends at Wadi Garara, composed mainly of nearly horizontal Nubia sandstones. Itsheight ranges from 250 to 350 m.a.s.l.

4.2.6. Cuestas and mesas

More than 25,000 square Kilometers in the mapped area are present as cuestas with a dip angle of 7–15° in different directions (Fig. 7). Cuestas represent the main landforms of sedimentary rock, fill of the Garara graben of Nubia Formations, and are composed mainly of sandstone interbedded with some clay, mud and marl. Some cuestas are capped with iron oxides. They are covered by clay and mud beds of the Tertiary age Southward and Eastward of the Wadi Nugra and in the Southwestern part of the area (Fig. 7).

4.2.7. Volcanic landforms

Volcanic landforms, cone-shape, plugs and dome-shape with medium to low topographic relief showing radial drainage patterns occur in an area extending NW–SE between Wadi Shait and Wadi Antar, it is called the Natash volcanic. Numerous exposures of basalt are met with in the area of the Wadi Natash. The cones and sheets of volcanic rocks are very abundant around the Wadi Natash and are arranged along the NW trend around the graben Cretaceous volcanics extruded periodically in Abu Khruq and Umm Naga ring complexes.

4.2.8. Fluvial Landforms

Fluvial landforms are present in low relief localities of the area. They are mostly of Quaternary age and divided in the current search into depositional and erosional fluvial landforms.

4.3. Depositional fluvial landforms

4.3.1. Alluvial fans

There are alluvial fans present in the northern part of the area with more than 25 m thick deposits of different grain sizes and rock fragments derived from drainage basins, most probably during the Pleistocene age. They are sloping in the Northeast direction. Two major accumulated fans are present in the central part of the mapped area. And lie on the foot slope of a steep fault scarp of the Nubia Formation. They are large and accumulated from gravels, boulders, sand and rock fragments. They are widespread in the NW direction and highly dissected. These fans are formed by gravity and wind actions together with fluvial processes.

4.3.2. Playa

Playa deposits occur in low areas in the Wadi Garara. They are composed of fine silt beds of brown color(s) intercalated with sand and gravel. Playa and proluvium deposits are recognized at the southern and eastern parts of the area. They are located at the foot of the Gabal Abu Hashim and Gabal Umm Harba which are structurally elevated. The proluvial deposits are composed of angular to subrounded rock fragments of different sizes, derived from the near elevated areas. They also contain amounts of sandy silt, which cement the rock fragments.

4.3.3. Wadi deposits

Wadi Deposits occur along the courses and banks of Wadis. In composition they are not uniform and depend on the rock types of the area surrounding the course of the Wadi. They consist of non-cemented fine to coarse grained sand, gravel and boulders. In a few places the sediments are cemented by loam materials. Many Wadis have been eroded along major fault zones as denoted by the rectangular nature of many Wadi courses.

4.4. Erosional fluvial landforms

4.4.1. Depressions

Atmour Nugra-Kom Ombo depressions (Fig. 2) have generally flat surfaces stretching in an East–West direction for 70 km to a detached hill near the Eastern scarp. The depression is about 100 m below the encompassing scarps and its floor is covered by thin Quaternary sediments with relics of older rocks. A

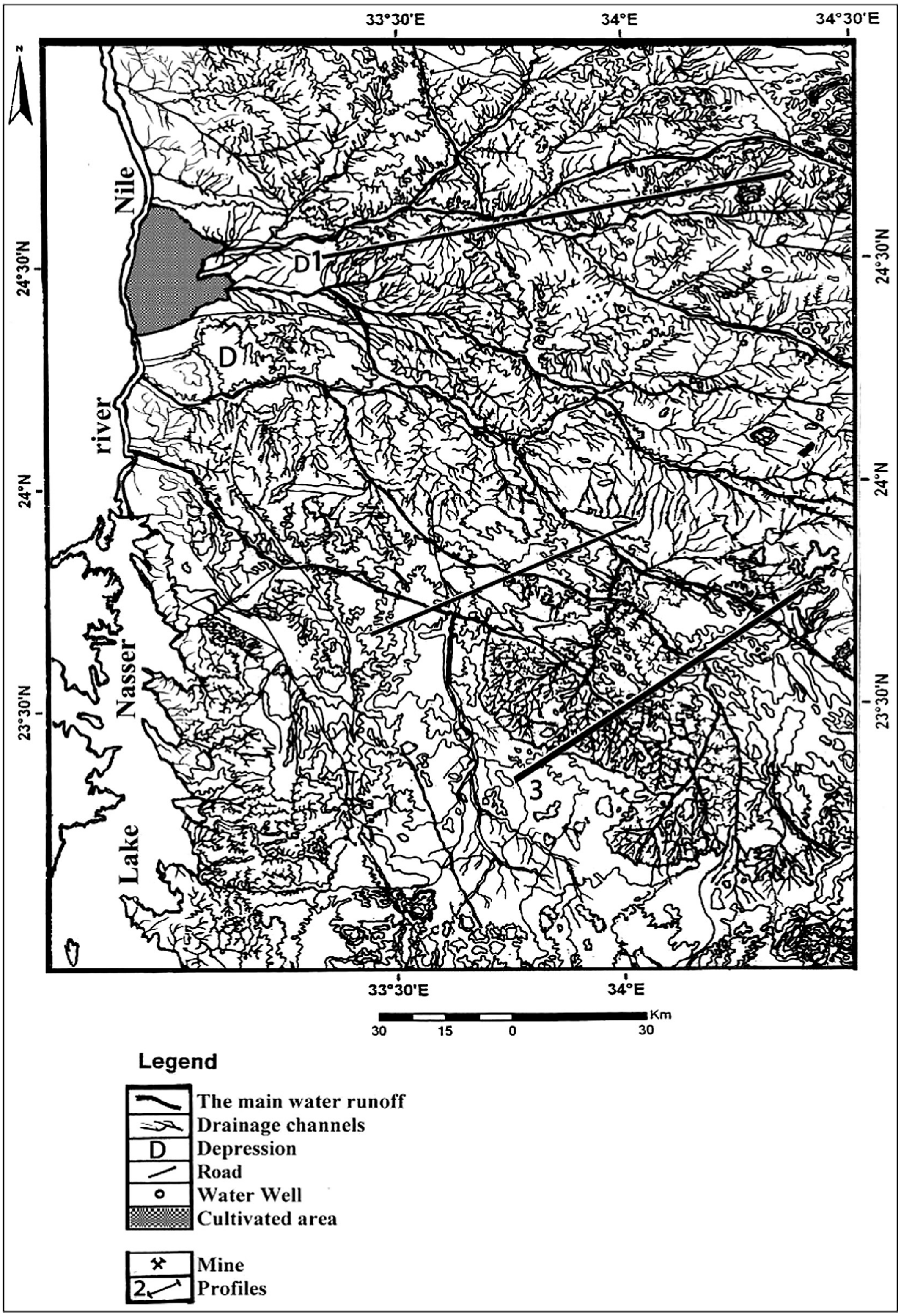

Figure 6 Drainage network of the Wadi Garara area prepared from Landsat TM images.

big mesa of Nubia sandstones separates the Atmour Nugra and Kom Ombo depression, this mesa rises 100 m above the east and west plains assuming the same elevation of the scarps around the depression. The Kom Ombo depression is less flat than the Atmour Nugra (Fig. 2). Atmour Nugra-Kom Ombo depressions are structurally controlled by subsurface and surface faults, indicating by local fault scarp and affected by cycles of fluvial erosion causing scarp-retreat and subordinately

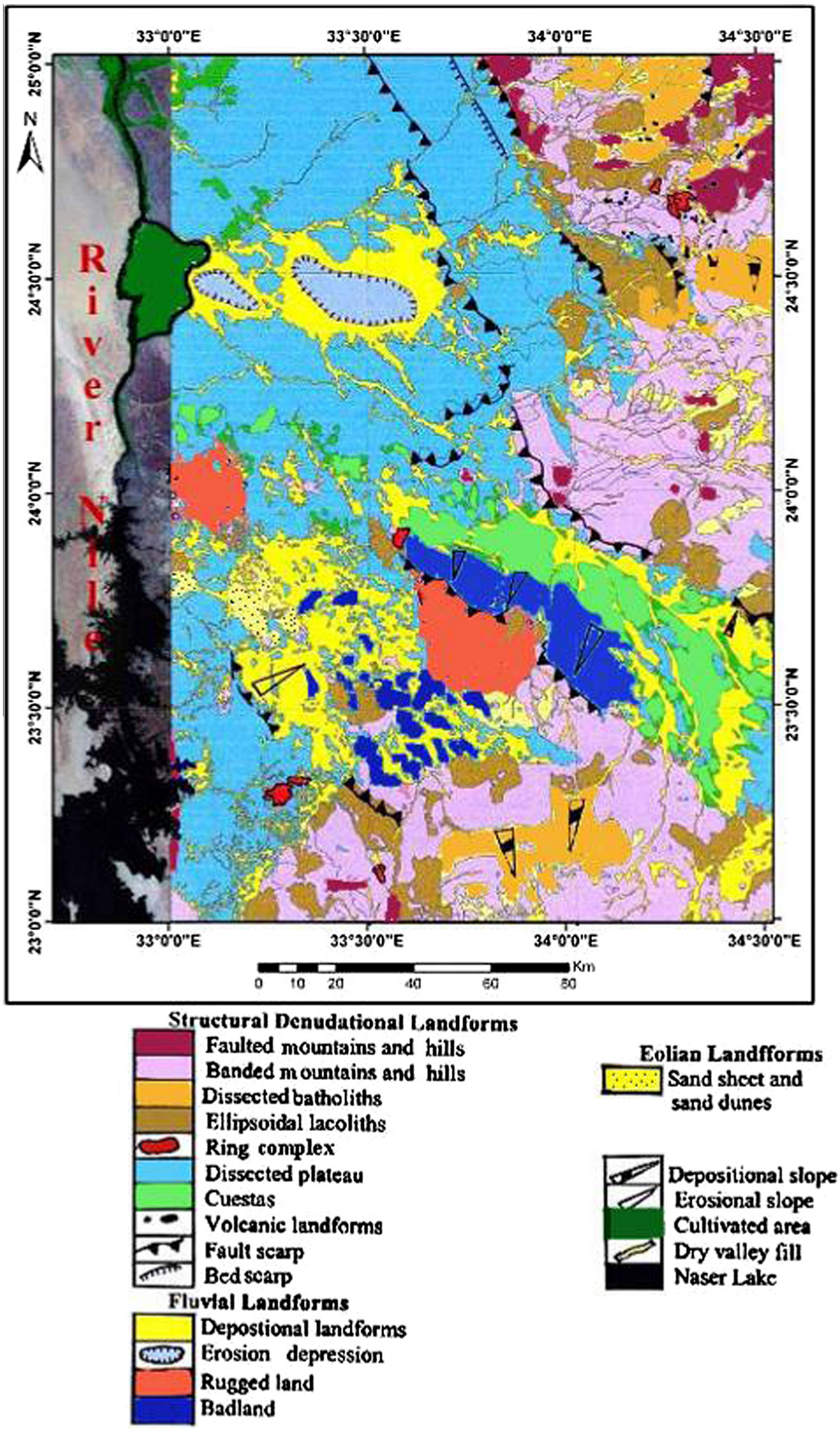

Figure 7 Geomorphological map of the Wadi Garara area.

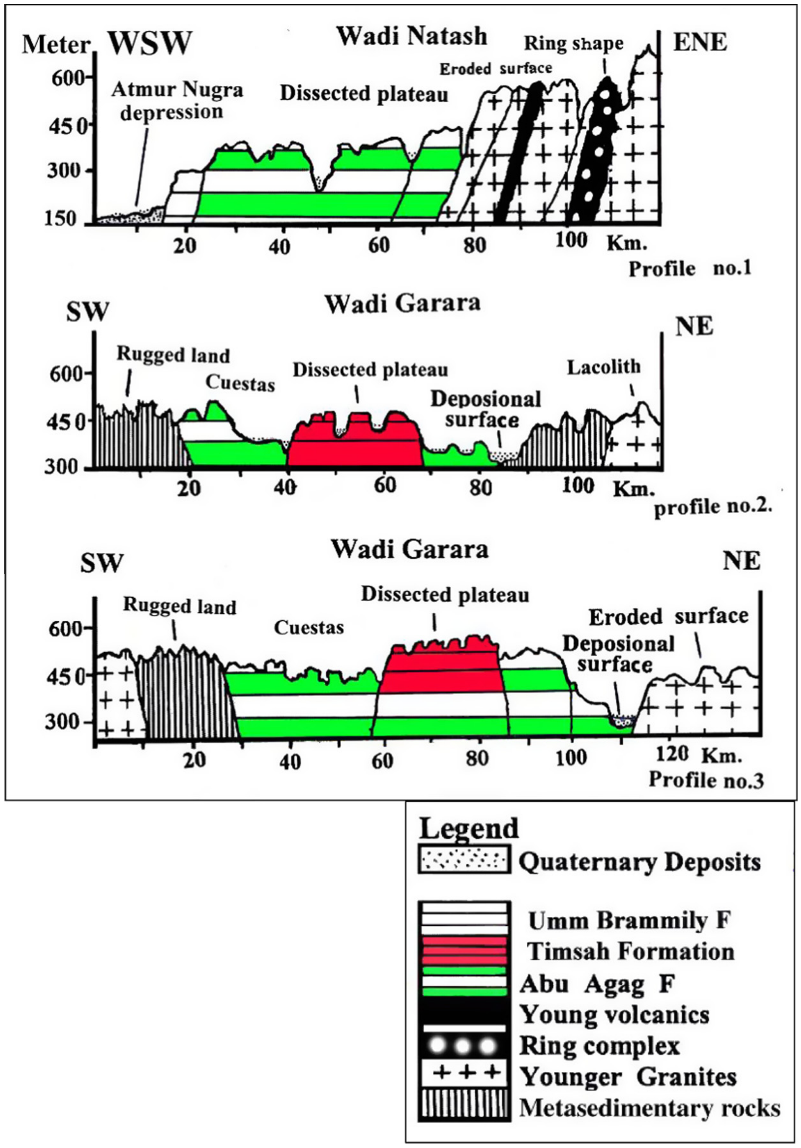

Figure 8 Geolgical-geomorphological profiles at the Wadi Garara area prepared from topographic and geologic maps, their locations marked on Fig. 6.

by aolian erosion giving the recent planation surface. It is covered by thin Quaternary sediments with relics of older rocks.

4.4.2. Rugged land

Rugged land lies in the eastern part of the investigated area, and is denoted by highly rugged, hilly terrain which is filled in-between by sands. Older granites and metasediments occupy wide areas. They are highly weathered with corridors in different directions. Sand sheets cover areas between isolated granitic hills. Several volcanic cones and plugs are scattered in these lands. This unit is formed after exogenetic processes.

4.4.3. Badland

In the western edge of the Wadi Garara and inside the graben, there are badlands in the sedimentary exposures due to high weathering and high drainage density in some sedimentary beds. They exhibit steep slopes and overlie beds of rock fall and rock sliding. This unit is formed by exogenetic processes in thick sedimentary succession.

4.4.4. Eolian landforms

Sand deposits cover small parts of the exposed low relief rock units. They accumulate in the form of sand dunes and sand sheets starting from the hill-slope of basement rocks around the Wadi Garara. Eolian deposits consist mainly of well worn quartz grains and dust, forming sheets in between the older granitoid exposures at Wadi Shait. Few centimeters thick sand sheets cover the northern mouth of Wadi el Kharite and south Atmour Nugra. There are sand dunes between Kom Ombo depression and the cultivated land. These dunes are small seires with low elevations forming parallel sandy ridges running in a NNE–SSW direction. Three geological–geomorphological profiles were prepared nearly perpendicular to the graben direction (Fig. 8). Their locations are plotted on

Fig. 6. Profile, elucidates that there is a Northern downthrow of EW fault, which coincides with the present side (wall) of the Wadi Natash and nearly coincide with the subsurface magnetic airborn interpretations. Therefore, there is down throw after the graben development, and there are later other downthrows more recent than the Atmour Nugra depression. In locality of profile No. 2, (Fig. 6) the airborne magnetic interpretations suggest that the granitic rocks appear in the subsurface bigger than on the surface geologic maps.

Profile No. 3 elucidates that extensive fluvial weathering processes affected the metasediments and Nubia sandstones forming rugged land followed by eolian deposition processes filling the rock grooves with sands and covering the lower lands with sand sheets.

5. Structure

In the interior of the African–Nubian Shield, steep vertical movements are accepted and for the Precambrian rocks and the Phanerozoic rocks. These faults are often regenerated with quite steep graben borders intersecting the uplift in the Miocene age, in connection with the variations and oscillations in the vertical pattern of faulted areas on the plunges of old massifs, (Schurmann, 1974). The orientation of the Late-Paleozoic to Mesozoic large-scale undulations indicates that the reason for the SE–NW compression in the rotation tendency of Africa start in Carboniferous and culminate in Tertiary regions of Africa separated from Asia (Schurmann, 1974). The ancient platforms of East Africa have existed as continental blocks since mid-Archean times nearly 3000 million year ago (m.y.). Their basement was consolidated during late–Proterozoic (1600 m.y.) time, a sedimentary cover of the ancient platform began to accumulate. The basement of the young platform began to form with fold-belts much later, in the mid-Proterozoic time. Some of these young platforms attained stability at the beginning of the Paleozoic time, others at the end of the Paleozoic time while some margins of the platform in the studied area attained stability at Cretaceous times. Schurmann, 1974 postulated two structural stages can be recognized in the history of the young platform in North east Africa: The first stage involves the formation of the depressions, some of them very long and deep, seated faults cutting the basement. On all platforms, some of these depressions are disturbed by folds and contain volcanic series and small igneous intrusions. Being of epi-Hercynian age, they are generally filled with Triassic and Jurassic series. They are often thick, containing such volcanics such as andesite, basalt, and related tuff. Unlike the aulacogens of ancient platforms, scientists have suggested calling these depressions taphrogenes. The second stage in the young platforms is characterized by the generation of gentle uplifts, similar to shields, and by extensive and long-developing depressions looking like syneclizes and pericratonic down-warps of ancient platforms. The depressions were initiated in the Jurassic time and then developed during the Cretaceous, Paleogene, and Neogene times; some of them are subsiding at present. Morgan (1990) suggested main fault directions as tectonic events that have directly or indirectly affected the geology of Egypt and he classified these events chronologically and stated that the Northeast–Southwest faults pattern have not been explicitly recognized in Egypt, but a parallel of Northwest–South faults system is predicted, to coincide with the present study in the Garara area forming the graben.

The structural data are obtained from Landsat images, the interpreted structural elements from geophysical aeromagnetic survey and faults from the Sigaev map (1959) are also plotted in Fig. 9 that have enabled analysis of the major structural elements in the investigated area. Geomorphologically, NW–SE, NE–SW, WNW–ESE and NNE–SSW structural sets traversed the rock units in the area through major tectonic movements that can be summarized as follows:-

- Precambrian to Rephian (pre-Nubia) structures on the Basement rocks.
- Cretaceous (Nubi structures)
- Tertiary (Post-Nubia structure)

5.1. Precambrian–Rephian (pre-Nibia) structure

Paul Morgan (1990) stated that during the Precambrian proto-crust for Nile craton there is reworking and stabilization of the Nile craton followed by Pan African island arc accretion. In the study area, the Precambrian–Rephian faults trended WNW–ESE, NW–SE and NE–SW with displacement throughout the basement rocks In the Southern part of Eastern Desert of Egypt, there is a series of strong fractures trending NNE from the Wadi Allaqi (South of the study area) West North West wards can be seen, although much diminished, in the extreme NE of the area. The zone in which these faults could be expected to cross the Nubian "tongue" in the basement rocks, has few faults of similar trend and these are minor effects. The NNE faulting appears to be of pre-Nubian age. In the West of the Wadi Hodein (east of the study area) area a considerable element of shear is present in the NNE–SSW faults. This is not reflected in the distribution of the Nubian over the basement shear element is therefore of pre-Nubian origin.

Major NW–SE deep-seated faults (Red Sea direction) formed the Garara graben (Fig. 9). Series of fractures trending NE-SW and NNE forming Wadis in the NE part of the area and these major faults do not cut the Nubian sandstones. NE–SW and E–W faults cut the older granite and NE–SW faults cut the younger granite. Dyke swarms before Nubia formation are locally very intense, as in the South eastern border of the area. Three dyke trends are present: NNE–SSW, NNW–SSE, and ENE–WSW. Many of them continue into the major fault zones, yet none of the major swarms cut the Nubia and only isolated dykes occur in the eastern part of the mapped area.

5.2. Nubia structure

The Nubia sandstone within this area was deposited in an aqueous environment varying from littoral to estuarine. This is indicated by cross bedding exclusively of aqueous origin, well-rounded conglomerates, clayey sandstone, ripple marks and spotted ferruginous sandstone, the proximity of the source of detritus is indicated by large local thickness of very coarse deposits with torrential cross bedding. The persistence of the Nubia sandstone and the occurrence of dykes reflect continued uplift of the source of detritus.

The Nubia Formation is an essentially horizontal formation but there are dipping beds in different directions due to

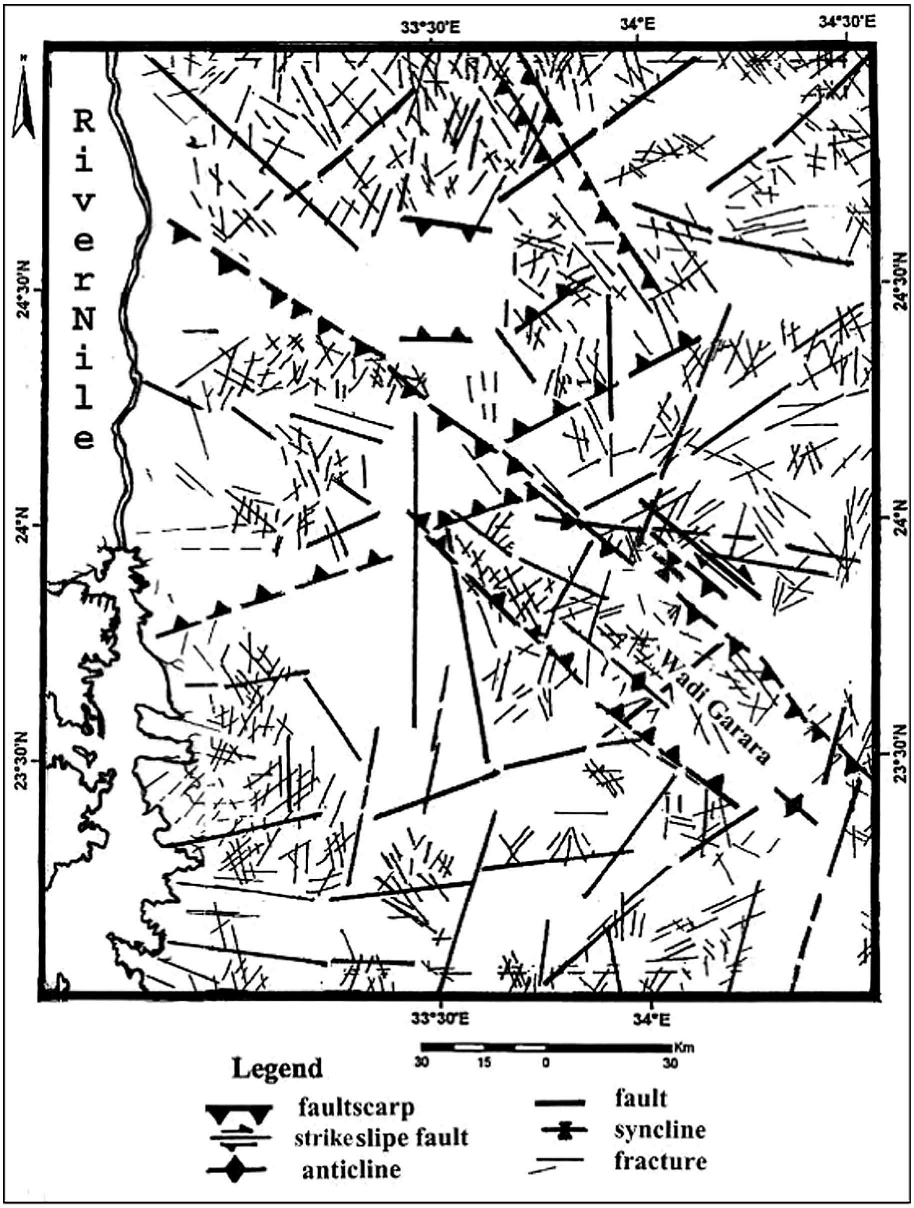

Figure 9 Structural features in the study area collected from Landsat images interpretation, aero magnetic survey and from Sigaev (1959).

faulting and folding inside the Garara graben. The Eastern and Western margins of basement rocks (bordering Garara graben) are generally irregular due to complex rectilinear fault patterns before and after the graben formed.

Main folding movement affected the Nubia formation as the NW–SE folding followed by a series of superimposed, secondary folds trending NE–SW that were although more open in style and less continuous then in development folds, these probably have an important effect on the regional distribution of rock types in the area. In Wadi el Kharite area, a series of isolated first folds in the schists show sharp flexures around NE–SW trending second fold axes of similar trend that deformed the first folds more sharply into an irregular isoclinal pattern. It seems clear that the first fold complex was asymmetric with an overall dip of the axial surface to the NE, a steeply dipping near-vertical Northern limb and a more gentle Southern limb. Steeply plunging folds trending N–S appears in the gneisses and migmatite belt of the Eastern part of the area.

5.3. Post Nubia structure

Two major NW–SE faults affected the Nubia sanstones with about 60 m WS downthrow extending in the Northern border of the graben forming a post Nubia structural regeneration phase in the graben development. Tertiary volcanics arranged in the NW direction indicate deep seated structures in Tertiary times along the Red Sea coast. Rift faulting then took place, along NNW–SSE fault zones that were established during the Precambrian. These are associated with plugs and domes aligned on the ENE–WSW trending faults, the lava decreases rapidly in amount both laterally and upward. Some are rich in ore minerals especially hematite and it is suggested that contemporaneous erosion of these gave rise to the sedimentary iron ores within the Nubian.

6. Geophysical interpretation

Geophysical data are taken from airborne gamma-ray spectrometer and magnetometer surveys of the Eastern desert, carried out by Aero service division, Western geophysical company of America for Egyptian General Corporation (1985).The values of both reflected aeromagnetic and radiometric rays for measured points are taken from this report. These values are determined by the magnetic and radiometric responses reflected on the surface of the basement rocks to refer to the distance from the basement rocks to the airborn. Few points have simple interpretations and are not linked to each other. Using ARC MAP Program we calculated and adapted these measured values to the sea level and plotted and prepared an Isopach map (Fig. 10) to establish the surface of the basement rocks under the Phanerozoic sedimentary cover. In the following portion, a brief summary of new interpretations on the aeromagnetic and radiometric values and calculations is given.

6.1. Aeromganetic interpretations

At the Wadi Shait, there is a very strong magnetic response in serpentinite rocks (rom service division, Western geophysical company of America for Egyptian General Corporation (1985). This suggests a body larger than that presently in the geological map. Under Wadi Shait's Nubia sandstones, the depth of basement rocks is calculated between 300 and 1000 m below sea level (m.b.s.l.), while at the southeastern part of Wadi Shait, the depth reaches up to 2000 m.b.s.l., Under the Southern part of the Wadi Shait, the basement depth reaches up to 3750 m.b.s.l. in a large basin of 3000 m.b.s.l., due to Northwest down at a NE–SW major fault. Under the Wadi Natash, the values suggest that the deepest basement subsurface magnetic response is at 4700 m.b.s.l. depth. This indicates a deep basin below the East end of the Wadi Natash. This means the basement rocks exhibit a high magnetic response of true depth of the basement surface or there is a deep magnetic source. To the South of the Wadi Natash there is a very broad gradient depth 3100 m.b.s.l. for the basement surface. In the south of the Wadi Natash the basement levels flatten at a depth of 1000–1500 m.b.s.l., i.e. there is a Northern downthrow in this area, this downthrow can be calculated and result is about 3100−(1000 + 1500/2) = 1845 m.b.s.l. To the South, the depths range from 2100 to 2700 m.b.s.l. inside the Garara graben. In the Western–South of the Wadi Natash and near Aswan, the basement rocks are generally very shallow near its exposures. They range from 300 to 500 m.b.s.l. In the contact area between the basement rocks and Nubia sandstones, there is a high magnetic response potentiality indicating a large mineralized magnetic body. In the Northern part of the Wadi el Kharite, there are flattened areas with a depth of 1000 m.b.s.l, with the exception of few minor structures which are present due to the second downthrow to the North of the E–W fault at the Wadi el Kharite. Several depths at the South are calculated at 3300 and 3400 m.b.s.l and the depth of the basement magnetic response (subsurface depth) ranges from 300 to 700 m.b.s.l. East Aswan value of 800 m.b.s.l. indicates the presence of fault steps and accordingly several structural movements.

At the Wadi el Kharite area, there are lineaments and individual basins in the subsurface. Shallow basement rocks are interpreted from magnetic data which vary between 300 and 400 m.b.s.l. These individual basins are more shallow in the East in this area. A fault in the E–W direction at a depth of 300 m.b.s.l. in the Nubia sandstone is suggested by magnetic data in the western part of the Wadi el Kharite.

Under Wadi el Kharite in depths for faults rich with radiometric anomalies in granite rocks may be due to subsurface mineralized fissures filling in the granites.

There are three faults (structural disturbance) ranging from E–W to NE–SW with downthrow to the North (Fig. 9).

> It is noteworthy that the shallower subsurface depth is 300 m.b.s.l. of the basement magnetic response near the contact between basement rocks and Nubia sandstones and at the Northern part of the present area under Wadi Shait's Nubia sandstones, the depth of basement rocks is calculated between 300 and 1000 m.b.s.l.Under Atmour Nugra, the depth of basement rocks is calculated about 700 m.b.s.l. and near East Aswan, it is 500 m.b.s.l.

6.2. Radiometric interpretations

Under Wadi Natash, the Potassium radiometric anomalies have been interpreted in younger granites and in adjacent Nubia sandstones, this is due to the presence of potach feldspars or may due to a mineralized anomaly.

Gabal Diheisa granites exposures exhibit strong radiometric responses and can be a good target for further mineral explorations.

Radiometric data indicate an anomaly at the northern part of Wadi Natash Nubia sandstones. There is a radiometric anomaly over Nubia sandstones under the Wadi Natash and under the Wadi el Kharite. It may indicate an unmapped exposure of granites or radioactive mineralized zone in the unconformity zone (paleosole beds) between basement rocks and sedimentary rocks.

Radiometric data indicate that the granitoid rocks which intruded in metasediments and metavolcanics are larger than those present in the geologic map. This is due to the emanations of radioactive minerals into the surrounding metamorphic rocks from granites, and may due to contact metamorphism. Radiometric data indicate that dykes cause a zone of radiometric potential in the surrounding sedimentary rocks and may be due to contact metamorphism.

7. Disscussion

7.1. Geomorphological Indications

The Geomorphological features reflect the genesis of the present landscape of the east Aswan sector as follows;

- In the Atmour Nugra depression, the Quaternary surface height is 110–120 m.a.s.l. It represents the lowest part in the considered area. This depression is a deep basin and indicates repeated fault movement, and erosion cycles.

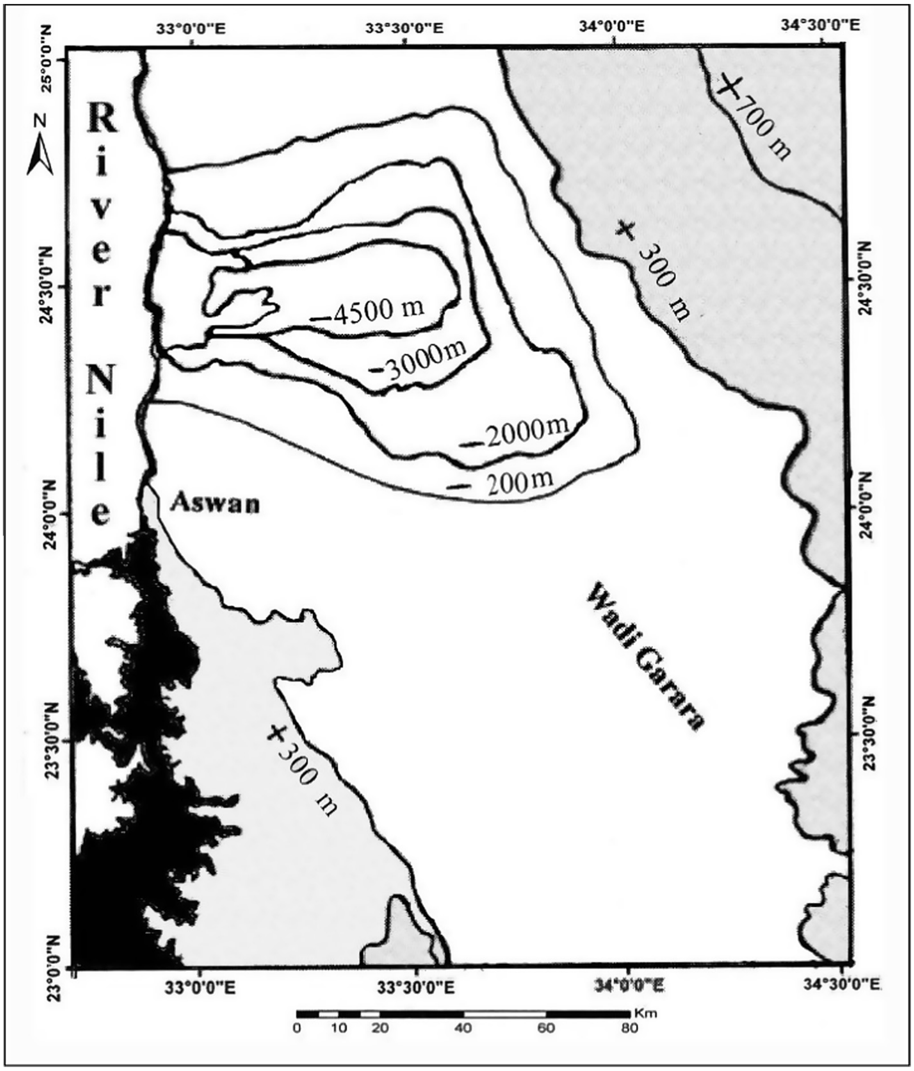

Figure 10 Isopach map for the surface of basement rocks in the study are.

- The slopes and dip directions of the cuesta landforms in Wadi el Kharite, indicate that the sedimentary rocks in the graben have NW folded post Cretaceous (most probably during the Miocene tectonics) due to load pressers of Nubia formations.
- Volcanic landforms in the Wadi Natash include different cone shapes such as: plug, domes and shield.
- Young Volcanics are present at the Wadi Natash, Wadi Shait, Wadi el-Kharite and Wadi Antar. Most of these volcanic exposures are arranged along major structural trends.
- Most ring complexes indicate NW and NE trends, surrounded and/or cutting the Nubia formation. Natach volcanics and ring complexes e.g. Abu Khruq 875 m in the Northern part of the area and Gabal Umm Naga 800 m, and Gabal Abu Hariegal in the Southern part of the area, other two ring complexes at the graben cut the Nubia formation. Hot spot swells are typically several hundred kilometers across and rise more above the surrounding area. Mesozoic sedimentary thickness reaches up to 1.2 km.
- The surface processes such as erosion strongly affect the metamorphic rocks in the southern part of the studied sector which are elucidated by the surface profiles that coincide with the recorded geological facies of more high regional metamorphism to the South of Egypt.
- The Nubia sandstone plateau around the Atmour Nugra depression has topographic elevation of about 400 m, while the elevation of the adjacent basement rocks attains about 750 m. The topographic features elucidate that a post Nubia structural regeneration phase took place in the history of the graben evolution .The surface downthrow of the basement rocks in the graben is equal to 750 m., where the depth of the basement surface under Nubia sandstones in the graben is around 3000 m from aeromagnetic interpretations plus 750 m calculated from the surface topography, so the downthrow is equal to 300 (from subsurface data) + 750 (from surface data) = 3750 m.
- In the East northern part of the area, there are two major NW–SE faults affecting the Nubia sandstone plateau with about 60 m WS downthrow located in the Northern part

of the graben forming a post Nubia structural after Cretaceous and considered as a regeneration phase in the graben history.

7.2. Geological History

Two stages can be recognized in the geological history of the depressions in the basement platform in North eastern Africa: The first stage involves the formation of the depressions, some of them very long and deep, seated faults cutting the basement. Some of these depressions are disturbed by folds and contain a volcanic series and small igneous intrusions, often thick, containing such volcanics as andesite, basalt, and related tuff.

Hashad and El Reedy (1979) concluded that the distribution patterns of the trace elements indicate a typical "within plate" non-orogenic setting for the Wadi Natash volcanic area. They are characterized by milicy alkalic and exclusively sodic nature. "Hashad and El Reeddy (op. cit.) suggest three phases of igneous activity which are tentatively assigned the following ages:-

1-. The 230 ± 20 m.y. Phase: massifs of Zargat Naan, (Zargat Naan lies North of the mapped area) and other Paleozoic rocks.
2-. The 140 ± 15 m.y. Phase: massive of some ring complexes are early Cretaceous.
3-. The 90 T ± 20 m.y. phase, during which the Wadi Natash alkalic volcanics erupted followed by the intrusion of the Abu Khruq ring (Late Cretaceous) extending to the Wadi Natash volcanic activity to 70 m.y. It is believed that a tholeiitic basic melt crystallized through a limited fractionation process, injected in the continental crust. A second pulse gave a felsic injection which assimilated most of the pre-existing basic rocks, giving rise to the microdiorites, microsyenites then finally the aplites.

A study of stratigraphic section of the sandstones sequence in the South eastern Desert of Egypt leads to some understanding of the epeirogenic history of Egypt. Klitzsch (1984) considers the Late Caledonian positive element oriented approximately NW, this trend corresponds with the Gulf of Suez trend. Issawi and Jux (1982) suggested that the sedimentation environment at the Gabal Abraq (adjacent to the Eastern border of the study area) is composed of the oldest sedimentary rocks in the Eastern Desert, showing evidence of being deposited under the shallow marine and coastal margin incursion. The present plant remains indicate the Carboniferous age. Abu Ballas formation shows evidence of being deposited in braided fluvial systems invaded by shallow marine conditions in Jurassic times. Nubia Formation was deposited under fluvial to shallow marine conditions in problematic age. Tarif sandstone member was deposited under fluviatile to braided channel deposits and assigned a Santonian age. In the Kom Ombo area, the Jurassic–Nabian tectonic stage is conformable with the bottom of the Upper Cretaceous. In the Komb Ombo area, there is an unconformity between these tectonic stages (Issawi and Jux op.cit.). Jux and Issawi (1983), described the Paleozoic section of about 150 m, in Gabal Umm Besilli adjacent to the Eastern border of the study area. They suggested that these sedimentary rocks are deposited under continental and marine environments. Seleim and Said (1992, 1993) believed that the Paleozoic sedimentary rocks in Wadi Garara about 150 m underlay the Cretaceous formations. They found a paleosol with iron concretions on top of the Paleozoic rocks, below the Taref member of the Nubia sandstones (Cretaceous). Conoco Coral geological map (1987) draws the Nubia sandstone in east Aswan and Wadi Garara as Cretaceous (Abu Aggag Formation (F), Timsah F, Umm Bramil F. Magdy et al. (1995) suggested that the Nubia sandstone in the Gabal Abraq (East of the area) is Cretaceous, and is composed mainly of sandstones, siltstones, and shales, represented by the Abu Simbel Formation of the Late Jurassic to Early Cretaceous age, the Abu Ballas formation of Aptian age and the Sabaya formation of Aptian to Cenomanian age.

These Stratigraphic observations elucidate the importance of paleo relief induced mostly by epeirogenic movements related to cycles of erosion and sedimentation. A paleosol with iron concretions indicates a pronounced depositional gap between the Precambrian–Paleozoic and Cretaceous.

Paleozoic uplifts in the South eastern Desert are documented by paleosole, conglomerate, and disconformities. The consistent clastic nature of the Paleozoic sequence and its general lack of carbonate and clay facies are indicative of high relief, – accentuated repeatedly by block movements. Differential motion led to the formation of intracratonic basins, which were sites of clastic accumulations.

Depression movement in the Wadi Garara had old sedimentary rocks and alkaline volcanic eruption in the Natach area. Local uplift in the central part of the Wadi Garara took place in the Paleozoic age and was followed by erosion cycles, then by Cretaceous sedimentation and dykes were extrusive in Cretaceous structure. It could be demonstrated that the graben happened first during the Precambrian and was followed by uplift and erosion cycle, then precipitation of Paleozoic rocks which were eroded by extensive erosion cycles before the sedimentation of Cretaceous rocks, the major downthrough happened in Cretaceous rocks and there are post Cretaceous movements.

7.3. Subsurface geophysical events

It is noteworthy that the shallower subsurface depth is 300 m.b.s.l. of the basement magnetic response near the contact between basement rocks and Nubia sandstones and at the Northern part of the present area under Wadi Shait's Nubia sandstones, the depth of basement rocks is between 300 and 1000 m.b.s.l. While toward Atmour Nugra, the depth of basement rocks is about 700 m.b.s.l and near east Aswan, it is 500 m.b.s.l.. Under the southern part of Wadi Shait, the basement depth reaches up to 3750 m.b.s.l. in a large basin with a range depth of about 3000 m.b.s.l., Under Wadi Natash, the values denote that the deepest basement subsurface magnetic responses are 4700 m.b.s.l. This indicates a deep basin below the west end of the Wadi Natash i.e. it is the deepest basement block in the South eastern Desert. This means that either the basement rocks exhibit a high magnetic response of true depth of the basement surface or there is a deep magnetic source, any way, the deepest subsurface basement blocks lie between the Wadi Shait and the Wadi Natash and it is the maximum downthrow at intersections of the major NE and NW faults. It is noteworthy that this geophysical subsurface interpretation coincides with the surfaces' geomorphological profiles and features as well as explains the present depression shape of Atmour Nugra and the presence of the badland due to high erosion processes. The potassium radiometric anomalies have been interpreted in younger granites and in adjacent Nubia sandstones under Wadi Natash and at Gabal Diheisa granite exposures exhibits strong radiometric responses and can be a good target for further mineral explorations. Radiometric data indicate the presence of anomaly at the unconformity zone (paleosolic beds) between basement and sedimentary rocks due to uplift movement and erosion processes. Radiometric data indicate that the granitoid rocks are more larger than those present in the geologic map and indicate the presence of imanations of radioactive minerals from granites to the surrounding metamorphic rocks due to contact metamorphism. These data indicate that dykes cause a zone of radiometric potential in the surrounding sedimentary rocks.

The Nubia sandstones surface elevation is about 400 m at the border of graben, while the adjacent basement rocks elevation is about 750 m, i.e. the surface downthrough is apparently at least is equal to 750 m. The surface measurements on the sides of the graben delineate 750 m graben's downthrow and the aeromagnetic survey interpretations give a subsurface downthrow of 3000 m, in major parts, so, the actual graben downthrow is equal to 3000 + 750 = 3750 m.

Mineralization known in the present area includes gold, copper, tin, tungsten, lead, zinc, nickel, chromium, iron, radioactive minerals, alumina, carbonatites and titanium. Other economic resources include, talc, barites, asbestos, graphite, marble and various ornamental and building stones.

The Nubia iron ores, are exploited east of Aswan. Further exploration might first take the form of visual Landsat reconnaissance, seeking concentrations of red sands. In Wadi Shait and Wadi Garara ironstone bands occur in some sand regions as cap rock or are laminated within the succession. The Wadi Natash lavas may be the primary source of the iron. Oxidation of surface flows could provide an abundance of iron-rich dust to pass into solution, or be swept into the Nile basin and redeposited under lacustrine or fluvio-marine conditions.

The alkaline stocks and ring complexes are of special interest for alumina and carbonatite mineralization. Abu Khruq and Gabal Umm Naga are considered as sources of alumina. Other ring complexes in the Garara graben and Gabal Hadaeib may possess carbonatites, which sometimes yield niobium and various rare earth minerals.

The unconformity surface between the basement and sedimentary rocks is a suitable environment for radioactive mineral deposits. The basal conglomerate and paleosol in the study area may have radioactive minerals.

8. Conclusion

The established main geomorphological units in the area are: structural landforms (faulted- and bedded-mountains and hills,volcanics, dissected plateau and cuestas), Fluvial, (depositional- and erosional-landforms), and eolian landforms.

The topographic features elucidate that a post Nubia structural regeneration phase took place in the graben development i.e. The calculated surface downthrow is equal to 750 m. The aeromagnetic interpretations show that the surface of the basement rocks under the Nubia sandstones is around 3000 m plus 750 m calculated from the surface, so the actual downthrow equals to 3750 m .

The geomorphological studies, structures and geological history together with the aeromagnetic interpretations can delineate that the Garara graben was first bounded by deep seated NW–SE faults in Precambrian in continental platform forming continental blocks. An extensive erosion cycle took place and was followed by a thick downthrow that took placed at the Cretaceous. Also crustal uplift motion took place around the graben due to thermal activity in the hot mantle. Hot spots swells of volcanic activity in the Natash alkali volcanic series, alkali ring complexes in the upper and in the end of Cretaceous and dykes are alkali magmatic eruptions characterized by high sodium content due to deep seated faults. The ruptures which formed due to uplift movement of the basement rocks were followed by the erosion cycle and did not loose their activity during the Paleozoic and Mesozoic. The downthrow regenerated during Tertiary times.

The detected shallower depth resulted from basement magnetic response at subsurface and lies 200 meters below the sea level near the contact between basement rocks and Nubia sandstones. This suggests that there are steps of parallel faulted movement in multi-temporal ages and nera East Aswan.

In the East northern part of the graben, there are two major NW–SE faults affected in the Nubia sandstones with about 60 m WS surface downthrow forming a post Nubia structural regeneration.

Volcanic landforms in the Wadi Natash elucidate that the volcanic activity happened in a long period which allows this wide magmatic differentiation.

Atmour Nugra depression formed by NE–SW deep seated faulting movement took place post-Cretaceous in the northern part of the graben and affected the sedimentary rocks forming a new depression inside the graben with about 1000 m downthrow and is known as the Atmour Nugra. Then in the Cenozoic, a vertical movement took place and the duration of the erosional cycles extended until the Quaternary and was followed by a thin Quaternary deposit.

Under the Wadi Natash, the values suggested that the deepest basement subsurface magnetic responses are 4700 m.b.s.l. This indicates a deep basin below the east end of Wadi Natash i.e. it is the deepest basement block in the South eastern Desert. This means that either the basement rocks exhibit a high magnetic response of true depth of the basement surface or there is a deep magnetic, the deepest subsurface basement blocks lie between the Wadi Shait and the Wadi Natash and it is the maximum downthrow at intersections of the major NE and NW faults. It is noteworthy that this geophysical subsurface interpretation coincides with the surface geomorphological profiles and features as well as explains the present depression shape of the Atmour Nugra and presence of the badland due to high erosion processes.

Gabal Diheisa granites exposures exhibit strong radiometric responses and can be a good target for further mineral explorations. Radiometric data indicate the presence of anomaly at the unconformity zone (paleosol beds) between the basement and sedimentary rocks.

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