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The Nubia Sandstone (Nubia Group), Western Desert, Egypt: An Overview

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ABSTRACT

No information was given about the outcropping of the Nubia sandstone in the Great Sand Sea in the Western Desert of Egypt and actually very scarce and insufficient information has been written on the geology of the Great Sand Sea. Since 1931 the Great Sand Sea has been described as being formed of many parallel longitudinal sand dunes which cover ~72000 km^2 and are bounded in the south by the Gilf El Kebir Nubia Sandstone Plateau and in the north by Siwa Oasis. However, recently it has been found by the author and his collaborators that the rock units exposed on surface in the Great Sand Sea are belonging to the younger members of the fluviatile Cretaceous Nubia Sandstone Group. They are not covered by younger marine consolidated deposits but only with a thin veneer of accumulations of free sands originating from the disintegration and breakdown of the Nubia Sandstone bedrock, thus obscuring the original bedrock. The area exhibits a long history of predominantly continental sandstone accumulation and continuous subsiding during the geologic history so that the sequence attains a thickness more than 3500m in the subsurface. The exposed Nubia Sandstone rocks have been formed in different geomorphologic features such as longitudinal parallel sandstone ridges separated by wide flat sandstone tracks, sandstone plateaus and domes, sandstone depressions, plains and valleys. These results make it necessary to review the surface distribution and the lithostratigraphic change (both stratigraphic and geographic) of the Nubia Group in the Western Desert of Egypt.

KEYWORDS*: Great Sand Sea, Western Desert, Nubia Group, Dakhla Basin, new findings*

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1. INTRODUCTION

Because the Nubia Sandstone contains several highly-permeable water-bearing horizons which extend both vertically and horizontally below the surface of most of the Western Desert of Egypt it has been identified as the major groundwater reservoir in Egypt and hence referred to as Nubia Sandstone Aquifer system (NSAS). The system represents a part of the Nubian Aquifer System of the Eastern Sahara which extends between latitudes 13º and 33º and longitudes 19º and 34º, covering about 2.2 million km^2 in the North East corner of Africa, and extending across the borders of Egypt, Libya, Sudan and Chad. The area of the NSAS within Egypt has an extension of approximately 630,000 km (Thorweihe, 1990).

In Egypt, the position of the basement top is the best known parameter to define the base of the Nubia Sandstone Aquifer System (NSAS), i.e. the base of the groundwater-bearing strata, whereas the base of the Quseir Shale of Youssef (1957) or its equivalent Mut Formation of Barthel and Hermann-Degen (1981) is the parameter to define the position of the top of the groundwater –bearing strata. Based on calculation of thickness of the Nubia Sandstone sequence using the aeromagnetic interpretation maps (Conoco) supported by fully penetrating exploration wells, Thorweihe (1990) was able to estimate the area of the Nubian aquifer system within Egypt of approximately 630,000 Km^2. The effective porosity which is the most sensitive parameter in groundwater calculation ranges from 12% - 25% in highly permeable sections of the aquifer (GDK,1971; Ezzat, 1974; El Barkouki,1979) to 7% in the less permeable intercalations of the aquifer system (Thorweihe, 1982, 1990). Assuming the value of 7% for effective porosity is in the right range because of the difficulty of assessing effective porosity changes at higher depths in this aquifer which attains more than 3500 m below sea level, Thorweihe (1990) estimated the volume of the groundwater mass to amounts to 50,000 km^2 in Egypt. This volume represents an enormous groundwater mass in Egypt, one of the biggest in the Sahara.

Because of the economic importance of the NSAS as the major future source of water to meet growing demands in the Western Desert, the Nubia Sandstone exposures in south Western Desert have been subjected to active mapping by different workers including the geologists of the Egyptian Geological survey. Several rock classifications including different stratigraphic (vertical) and geographic (lateral) rock units have been proposed since 1978 at different localities to express the Paleozoic-Mesozoic, predominantly continental sandstone sequence in south Egypt, which partly includes thin marine intercalations, and which formerly lumped under the term “Nubian sandstone”. It is regrettable that some of these divisions did not help to facilitate knowledge of geographical and geological history of the Nubian Aquifer System which in its greatest thickness represents a unique environmental and lithological rock unit, irrespective of its age. On the contrary, these divisions increased difficulty to establish a general acceptable map for the Nubia Sandstone exposures in the Western Desert, and it can be stated that some of these divisions had undone the historic sense and stratigraphic meaning of the Nubia Sandstone.

The author had the opportunity to lead two field expeditions to the Great Sand Sea in the Western Desert of Egypt during summer of 2011 and winter of 2012 in order to update the topographic and geologic information of this area which is situated between the Gilf El Kebir Plateau at south, the Siwa Oasis at north, the - Dakhla -Farafra oasis at east and the Libyan-Egyptian borders at west. The first expedition included a combined team work from the Geology Department of Assiut University, Assiut and the Desert Research Center, Cairo under the sponsorship of the Ministery of agriculture and Land Reclamation, and the President of Assiut University. The members of the expedition investigated the surface topography of the area, the field geology, the stratigraphy and structural features of the exposed bed rocks, evidences of near-surface groundwater, chemistry of water supplied from old preliminary drills in the sand plains. Lab work has later been done on petrography, mineralogy and fossil content of rock samples in order to establish the geologic history and paleoenvironment of the total area. The integrated data revealed many valuable and unprecedented results that would change the present geologic map of the Western Desert of Egypt in such a way to meet growing demands in Egypt. A final technical report about the results of this expedition was submitted to the Minister of Agriculture and the results were announced in a press conference in Al-Ahram newspaper in October 14/ 2011. A summary of the results have been published by Ouda et al. (2012).

The results obtained by Ouda et al. (2011, 2012) made it necessary to review the characterization of the Nubia sandstone or the Nubia Group in the Western Desert of Egypt. Therefore, this article is concerned with reviewing of the surface extension of the Nubia Group and its internal litho logic variables both vertically (stratigraphically) and horizontally (geographically) in the Western Desert of Egypt.

2. Historical review

Until 1978 the mainly continental Paleozoic-Mesozoic sandstone beds which expose in south Egypt on both sides of the Nile Valley were formerly lumped under the term Nubia Sandstone. The term was introduced by Russegger (1937,1842) as " Sandstein von Nubien" for the sandstone which he mapped from north Nubia, south of Aswan, and between the Nile and Dakhla Oasis. Since this author the term has been used widely in northern Africa and southwestern Asia either restricted to the Cretaceous sandstone or emended as a facies to include various Mesozoic and Paleozoic continental sandstone strata which occupies the stratigraphic interval between the basement complex at base and the marine upper Cretaceous shale-carbonate complex at top (e.g. Bauerman 1869; Blankenhorn ,1921; Sandford ,1935, 1937; Desio,1939; Said,1960; Whiteman, 1970; El Shazly and Krs, 1973 and many other workers).

Since 1978 the Nubia Sandstone exposures in south Western Desert have been subjected to different proposed rock classifications including different stratigraphic (vertical) and geographic (lateral) rock units. The proposed lithostratigraphic units could be grouped into two main different rock sequences (Table 1): a rock sequence proposed by Barthel & Boettcher (1978), Klitzsch (1978, 1979), Barthel & Herrmann-Degen (1981), Klitzsch et al. (1979), Klitzsch & Lejal Nicol (1984), Klitzsch and Wycisk (1987), Klitzsch & Schandelmeier (1990), and Hermina.(1990), and a rock sequence proposed by Issawi(1981), Issawi and Jux (1982) and Issawi et al. (1999).

Issawi (1981) and Issawi et al. (1999), for example, considered the Nubia Formation in south Egypt as a magnafacies deposited under different environmental conditions varying from continental to deltaic to shallow marine. They restricted the term to the so-called tripartite classification which includes Taref Sandstone (originally proposed as Taref Formation at Aswan by Awad and Ghobrial, 1965), the overlying shallow-water Quseir Shale (originally proposed as Quseir Formation by Youssef, 1957) and the deltaic sandy shale of Shab Member (lower part of the Keiseiba Formation of Issawi, 1973) which represents the deltaic variant facies of the lower part of the Dakhla shale of Said (1960) to the west of Kom Umbo-Aswan. Thus, the lower boundary of the Nubia Formation as proposed by Issawi et al. (1999) will be drawn on the Turonian-Coniacian boundary in areas where fossiliferous Turonian unit occurs below (North Wadi Qena) and on the Cenomanian-Goniacian in south Egypt where there is no Turonian sediments.

Time Unit*	Rock Unit			
	A	B		C
Turonian-Santonian	Nubia Sandstone or Nubia Group	Taref Formation Awad and Ghobrial, 1965	Gilf Kebir Formation Klitzsch, 1978	Nubia Formation Emended by Issawi et al.1999
Albian-Cenomanian		Maghrabi Formation1		
Late Aptian-Albian		Sabaya Formation Barthel and Boettcher, 1978		Burg Formation Geological Survey of Egypt, 1982
Early Aptian		Abu Ballas Formation2		
Berriasian-Late Barremian-Early Aptian ?		Six Hills Formation Barthel and Boettcher, 1978		Abu Ballas Formation Emended by Issawi et al.,1999
Permo-Early Jurassic ?		Lakia Formation Klitzsch and Lejal-Nicol, 1984		Abu Ras Formation Geological Survey of Egypt, 1982 Issawi and Jux, 1982
Late Carboniferous		Northern Wadi Malik Formation3		Gilf Formation Issawi and Jux, 1982
Early Carboniferous	400 m	Wadi Malik Formation Klitzsch, 1979		
Devonian	300 m	Tadrat Formation Burollet, 1960		Wadi Malik Formation Issawi and Jux, 1982
Silurian	200 m 100 m 0	Umm Ras Formation Klitzsch and Lejal-Nicol, 1984		
Ordivician ? Silurian		Karkur Talh Formation 4		

Table 1: Proposed divisions of the Nubia Sandstone (Nubia Group) in Egypt, arranged stratigraphically from younger to older.

***Age of rock unit as given by different authors including the updated re-assessment of the Cretaceous succession in Dakhla area by Schrank and Mahmoud (1998). 1: Barthel and Herrmann-Degen (1981); 2: Barthel and Boettcher, (1978); 3: Klitzsch and Wycisk (1987); 4: Klitzsch and Lejal-Nicol (1984).**

A. **Proposed Nubia Sandstone by Russegger (1837-1842), Bauerman (1869), Blankenhorn (1921), Sandford (1937), Desio (1939), Said (1960), Whiteman (1970), El Shazly and Krs (1982) and others.**

B. **Proposed rock sequence by Barthel and Boettcher (1978), Klitzsch (1978, 1979), Barthel and Herrmann-Degen (1981), Klitzsch et al. (1979), Klitzsch and Lejal Nicol (1984), Klitzsch and Wycisk (1987), Klitzsch and Schandelmeier (1990), Hermina (1990).**

C. **Proposed rock sequence by Issawi and Jux (1982) and Issawi et al. (1999).**

This means that the Nubia Formation of Issawi et al. (1999) is restricted to the fluviatile-marine cycle belonging to the Goniacian - Early Paleocene age. Meanwhile, the Paleozoic-Lower Cretaceous fluviatile sandstone sediments which occupies the area between the Nile Valley and the Libyan-Egyptian border including those which are exposed on surface for more than 1000 meter high in the Gilf El Kebir Plateau as well as those which extend in the subsurface of the central Western Desert and the Great Sand Sea for more than 3500 meters, has been considered by Issawi (1981) and Issawi et al. (1999) to be outside the terminology of the Nubia Formation and thus given new formational names. On the other hand , Hermina et al. (1989) and Hermina (1990), suggested in case of the use of the term Nubia sandstone that is used only as a facies term and be used to relay Late Jurassic to Cretaceous sediments of similar origin without Paleozoic sediments even the purely continental Permo-Triassic sediments in southern Egypt and Sudan.

The author does not see any scientific support that calls for dropping the historical name of the Nubia Sandstone Group which is the biggest groundwater reservoir in the Sahara after its use for more than 80 years. The group covers about 2.2 million km^2 in the North East corner of Africa, and extending across the borders of Egypt, Libya, Sudan and Chad. Its sequence is assuming more than 3500 meters thick in the subsurface of the northern Great Sand Sea(Foram-1 well) where it is made up predominantly of thick continental sequence of sandstones. This sequence was transported and deposited from streams of old river systems that partly flowed in freshwater lakes in regional continental basins, and which were discontinuously interrupted by periods of uplifting, erosion and re-deposition in local basins, and intermittently influenced, in places, by marginal marine episodes and periods of soil formation. The sandstone strata show primary structures such as ripple marks and mainly tabular to trough cross –bedding interfingers with channel sediments. The sandstone grains are partly conglomeratic and exhibit a remarkable vertical variation in size, roundness and degree of cementation as well as its quartz, iron or kaolinite content. However, all these variations should not be considered reason for recognition of different vertical or horizontal mega lithic units. Only the occurrence of regional unconformities or hiatuses within the sandstone sequence should be mapped as separate lithostratigraphic units. Also the lateral variation from predominantly fluviatile sandstone in the west to interbedded marine and fluviatile shale, claystone and sandstone in the east is good reason for the recognition of different comparable rock units within the group.

Ifwe take into account theseconsiderations,in addition to the fact that the southern Egypt was submerged for the first time during the geologic history as far south as Latitude 24 30 N by intermittent pulses of shallow water seas during the Aptian and Cenomanian, followed by a long period of transgression down to Lat. 22º 30′ during the Campanian- Ypresian; it is, thus, expected that the pre-existing continental Nubia Sandstone in south Egypt will become influenced intermittently upward by shallow marine to near-shore shale, claystone and siltstone, until becoming totally overlain by open marine shale-limestone sediments north of this latitude. Meanwhile it has not proved the existence of marine strata covering or intercalating the Mesozoic fluviatile Nubia Sandstone sequence in the area lying west of Long. 27º and south Lat. 28º 30′which is occupied by the Great Sand Sea (at north) and the Gilf El Kebir Plateau (at south). In this area, the Mesozoic fluviatile sandstone sequence rests unconformably over a Paleozoic fluviatile sandstone sequence which is partly intergraded with shallow marine horizons of claystone, shale and sandstone, whereas eastward of Lat. 27º the Mesozoic sandstone sediments rest unconformably over the Precambrian basement rocks. This means that accumulation of the material assigned to the Nubia Sandstone Group has begun earlier and/or ended younger in the west than in the east of Long. 27º, and consequently the different members of this group could be represented anywhere by either relatively short or long stratigraphic interval. However, the time duration of the entire Nubia Sandstone Group or the time span exhibited by the different rock members of this Group play no part in differentiating or determining the boundaries of the lithostratigraphic unitswhatever their rank, and hence the age concept of the included members does not supporting restriction or elimination of the Nubia Sandstone Group which has been deeply entrenched in the Egyptian, Libyan, Sudanese and Chad lithostratigraphy.

So, the author supports the continued usage of the historical name of the Nubia Sandstone or Nubia Group as previously proposed by many workers (e.g. Whiteman, 1970) in order to express the natural relations of a number of associated sandstone formations. These formations were deposited during the lower Paleozoic to Upper Cretaceous under tropical to subtropical climate (in the paleoequatorial to subequatorial zone) and that were formed under various continental conditions, excluding eolian, merging intermittently into shallow marine (El Shazly and Krs, 1973). According to the latter authors positioning of the paleoequator and paleolatitude at 20° S was derived from paleomagnetic data which corroborate previous African data that there has been no polar wandering and continental drift for Africa during 210 to 110 million years and extend this period to 85 million years.

The predominant continental history of the sandstone sequence belonging to this group comes to an end during the Campanian. The interruption of the sequence by episodes of non- deposition and intense erosion, or intergradation of another rock unit particularly in areas where intermittent pulses of marine transgression accompanied the accumulation of fluviatile sandstone during the same time, are good reasons supporting the recognition of a number of rock units of lower rank (Formation) within the main sequence of the Nubia Group. The geographic restriction or wedging out of some formations of marine aspect in certain areas does not affecting the general lithostratigraphic definition of the main Nubia Group. According to Article 28 b of the Stratigraphic Code, the formations making up a group need not necessarily be everywhere the same.

3. Internal variables within the Nubia Group

Based on the foregoing, a set of internal variables within the Nubia Group could be summarized as follows:

1. A vertical (stratigraphic) change exists in the lithic characteristics of some members of the Nubia Group from older thick fluviatile sandstone to younger thin shallow water marine clastics (siltstone, clays, and shales) without a distinct hiatus in the area east of Long. 27º. For example, at the escarpment south of Abu Ballas (24º 23′ N, 27º 35′ E) where the fluviatile Six Hills Formation (500m thick) changes upward into 16-25m of marine clays and shales belonging to the Abu Ballas Formation (Barthel and Boettcher, 1978), although an erosional surface is not found everywhere (Bisewski, 1982). Also, the predominantly fluviatile sandstone of Sabaya Formation (200m thick, Barthel and Boettcher, 1978), which unconformably overlies the Abu Ballas Formation, changes upward into 60m thick of interbedded claystone, siltstone and sandstone of near-shore to fluviatile environment belonging to Maghrabi Formation. The same vertical facies change is exhibited by the Taref Formation (Awad and Ghobrial, 1965) which represents the youngest fluviatile unit of the Nubia Sandstone Group in the stretch where the Nile Valley facies are developed. The fluviatile sandstone belonging to this formation changes upward into marginal marine shale, sandstone and sandy shale, belonging to the Quseir Formation of Youssef (1957= Mut Formation of Barthel and Hermann-Degen, 1981).

This vertical change in lithic characteristics due to environmental change supports the establishment of a new lithostratigraphic unit in the area east of Long.27º. Although the Abu Ballas Formation wedges out to the west, south and east, so that it would be difficult in the field to be mapped on regional scale (Issawi et al., 1999), and the Maghrabi Formation thins out considerably over the Kharga uplift in the Baris area (Hermina, 1990), these formations are still representing formal rock units within the Nubia Sandstone Group in the Eastern Western Desert Province. Thus, grouping of both the Six Hills Formation and the overlying Abu Ballas Formation, or the Sabaya Formation together with the overlying Maghrabi Formation in one rock unit as proposed by Issawi et al. (1999), based on the concept that both formations belong to one sedimentary cycle starting with continental and ending with a marine environment, conflicts with the international stratigraphical rules and cannot be substantiated.

2. A lateral (geographic) change in the lithic characteristics of some horizons of the Nubia Sandstone sequence occurs eastward in the area to the east of Long.27º owing to influence of marine pulses during the Aptian and Cenomanian before the prevalence of permanent marine conditions during the Campanian-Ypresian. For example, the lower half to two-third strata of the Gilf El Kebir Plateau is made up exclusively of fluviatile sandstone comparable to the Six Hills Formation. However the uppermost part of this formation shows a gradual lateral change in lithology eastward, from exclusively sandstone of fluviatile origin in the area west of Long. 27º to interbedded sandstone, claystone and shale of shallow water environment (Abu Ballas Formation, Barthel and Boettcher, 1978) in the area east of Long. 27º. Also, the overlying Sabaya Formation which constitutes the upper half to upper one-third of the Gilf El Kebir Plateau shows a geographic lithologic change in its uppermost part from exclusively fluviatile sandstone in the west to interbedded marine and fluviatile claystone, siltstone and sandstone in the east (the Maghrabi Formation, Barthel and Herrmann Degen, 1981). This lateral change in the lithic characteristics of the upper horizons of both formations through intertonguing eastward supports the establishment of the Abu Ballas and Maghrabi Formations to replace the uppermost part of the Six Hills and Sabaya Formations respectively in the area east of Long. 27º. However, it does not support the elimination of the Six Hills and Sabaya Formations in the area west of Long. 27º and the establishment of a new lithostratigraphic unit in the Gilf El Kebir Plateau (Gilf Kebir Formation of Klitzsch et al. 1979, equivalent to the Six Hills, Abu Ballas, Sabaya, Maghrabi and Taref Formations). The same lithic characteristics of the Six Hills and Sabaya Formations which were originally recognized by Barthel and Boettcher (1978) in the east continued both laterally and vertically westward, meanwhile the Abu Ballas and Maghrabi Formations become gradually disappeared. In the Gilf El Kebir Plateau the Sabaya Formation is distinguished from the underlying Six Hills Formation by the presence of an erosional surface marked by paleosols. The same erosional contact has been recorded at the base of the Sabaya Formation in the east where Abu Ballas formation is represented. Thus, it seems that both the Six Hills and Sabaya Formations play a much younger age in the west than in the East.

In other words, there is a lateral (geographic) change in time duration of the different members of the Nubian Group from west to east due to prevalence of fluviatile conditions for a longer time in the west than in the east. The Six Hills Formation which belongs to the Berriasian-Late Barremian age in the Dakhla area (Schrank and Mahmoud, 1998) extends both laterally and vertically westward where it occupies the time span of both Six Hills and Abu Ballas Formations (Berriasian-Early Aptian) in the lower half to two-third part of the Gilf El Kebir Plateau. Also the Sabaya Formation which belongs to the Aptian age in the Dakhla area (Schrank and Mahmoud,1998) extends both geographically and stratigraphically westward where it covers the time duration of both the Sabaya and Maghrabi Formations (Aptian-Cenomanian in the Dakhla area, Schrank and Mahmoud,1998) in the upper half to upper one-third of the Gilf El Kebir Plateau. This variation in age concept cannot be regarded as a reason for the replacement of all these formations by another comparable rock unit in the west

3. The sandstone sequence of the Nubia Group is discontinuously interrupted by periods of variable time duration of uplifting, non-deposition, intensive erosion, transportation by river streams and re-deposition in local continental basins. These interruptions are well indicated by the presence of several erosional surfaces marked by topographic reliefs, deposition of thick kaolinitic paleosols and soil formation indicating several sedimentary breaks in deposition. For example, the Lower Cretaceous fluviatile Six Hills Formation rests unconformably over either the Precambrian basement rocks (the southernmost part of the Western desert), the marine Silurian Abu Ras Formation (the Gilf El Kebir Plateau) ,the fluvio-glacial Late Carboniferous Northern Wadi Malik Formation (the Abu Ras Plateau), or the fluviatile Permian-Triassic Lakia Formation (G. Uweinat). Also, the fluviatile sandstone sequence belonging to the Sabaya Formation overlies unconformably the marine shale of Abu Ballas Formation in the Dakhla Basin where a distinct erosional surface marked by paleosols exists between both formations. The marginal marine Maghrabi Formation had also transgressed over paleorelief on the top of the Sabaya sandstone and is unconformably overlain, in turn, with a distinct erosional contact by the fluviatile sandstone belonging to the Taref Formation. These breaks support division of the Nubia Sandstone sequence into a number of lithostratigraphic units (Formations), but do not support the restriction or abandonment of the Nubia Group.

4. Stratigraphy of the Nubia Group in the Eastern Part of the Western Desert (EWD Province, East of Long. 27).

Lying below the extended marine Campanian-Ypresian sequence which is exposed on surface in the southern part of the EWD Province is the Mesozoic Nubia Sandstone sequence (Fig. 1). The latter sequence is well exposed in the area lying to the east of Long. 27º where it is made up of the following rock units arranged from younger to older as follow:

- Taref Formation (Awad and Ghobrial, 1965): It is made up of 100 m thick of mainly fluviatile cross-bedded sandstone with thin local intercalations of clay and shale containing leef impressions and fragmentary wood of possible near-shore marine influence northward at Abu Tartur (Hermina 1967; Dominik, 1985; Mansour et al., 1979). The sediments overly unconformably the Maghrabi Formation with an erosional contact and underlie unconformably the Quseir Shale. They are comparable in composition to the older fluviatile sandstone belonging to the Sabaya and Six Hills formations (Hermina, 1990). No index plant fossils have been encountered from this unit in the Western Desert. Its stratigraphic position between the underlying Cenomanian Maghrabi and the overlying Campanian Quseir Formation has led Hermina (1990) to postulate deposition of this unit in the south during the northern uplifting phase of the Bahariya area which started in the Turonian and continued on to the early-middle Campanian. Taref Formation is equivalent to the Turonian Abu Aggag Formation of El-Naggar (1970) in northeast of Aswan. Issawi et al. (1999), on the other hand, grouped this unit as well as the overlying Quseir Shale and Shab Clastic Member (lower Member of Kiseiba Formation) within his informal “Nubia Formation” and gave the group a Coniacian-Early Paleocene age.

- Maghrabi Formation (Barthel and Herrmann-Degen, 1981= Plant Beds of Klitzsch, 1978): The type section of this unit is located south of Abu Tartur plateau. It is 60m thick of massive gray claystone alternating with siltstone, sandstone and with intraformational conglomerate bed at base. The deposits of this formation were accumulated in a marginal to shallow marine environment and show both conformable and unconformable relation with the underlying Sabaya Formation and the overlying Taref Formation in this province (Hermina et al. 1989). They thin out considerably west of Kharga (south of the type locality) where it shows mixed estuarine and tidal flat conditions. The strata of this formation have not been dated by fossils so far. They contain microflora and also brachiopods (Lingula) as well as rare Dinosaur bones, fish teeth and pelecypods. However, it is has been equated within the late Cenomanian age by Dominik (1985) who found a similarity of the mineralogical composition between this formation and the Bahariya Formation which are exposed along the floor and both sides of the Bahariya Depression at north. According to Hermina (1990) the Maghrabi Formation represents the southern spur of the Cenomanian transgression which reached its climax in the Northern Western Desert. This formation loses gradually its marine identity towards the west meanwhile the continental conditions prevailed progressively until becoming fluvial-dominated deposit in the western part of the Western Desert (WWD Province, west of Long. 27º).
- Sabaya Formation (Barthel and Boettcher, 1978 =Desert Rose Beds of Klitzsch, 1978): The type locality of this formation which is considered as one of the most productive beds in the Nubia Sandstone Aquifer System, is at Qulu El Sabaya hills on the Dakhla-Kharga road (25º 21′ N, 29º 43′ E). It measures 170 m in thickness but it reaches up more than 200 m in more basinal areas of the Dakhla Basin (Bisewski, 1982). The formation is made up of a sequence of predominantly fluviatile sandstone which is fine- to coarse-grained, white to yellowish brown in color, highly to moderately sorted, rich in plant remains and showing large scale tabular cross-bedding. South of the type locality the sequence starts at base with an erosional surface overlain by 30m thick of coarse-grained white massive sandstone with a high kaolinite content (Hermina et al. (1989).

The Sabaya Formation has a great extension towards the western part of the Western Desert where it constitutes the main bedrock in the desert surface of the Great Sand Sea and the irregularly low-scarped sandstone plains between Dakhla-Kharga road and the Gilf El Kebir Plateau. However no records of this formation have been found in the area south of Kharga according to the interpretation of logs of wells drilled in the Baris area. Hermina (1990) attributed this disappearance to the increased epeirogenic intensity on the south of Kharga uplift. No index microflora of precised age have been recorded from this formation at its type locality. However, Schrank (1987) investigated the microflora from a sample at the top of a correlative unit attaining ~170 m thick in Ammonite Well-1 and gave it an Albian-Cenomanian age. On this ground and based on the stratigraphic position of this formation between the underlying Aptian Abu Ballas and the overlying late Cenomanian Maghrabi Formation, Hermina et al. (1989) assigned the Sabaya Formation to the Albian- early Cenomanian age. Issawi et al. (1999), on the other hand, grouped the fluviatile Sabaya Formation and the overlying fluvio-marine to marine Maghrabi Formation within the Burg Formation of the Geological survey of Egypt (1982).

- Abu Ballas Formation (Barthel and Boettcher, 1978 = Lingula Shale of Klitzsch, 1978): The type locality of this formation is at the escarpment south of Abu Ballas (Lat. 24º 23′ N and Long. 27º 35′).where the formation attains about 44 m. In the Qulu El Sabaya area the formation attains a thickness of 16-25 m. The sediments are made up of a sequence of irregularly intercalating continental, fluvio-marine and shallow marine clastics including shale, clay, siltstone and sandstone yielding mixed vertebrates and invertebrates as well as abundant plant remains (Boettcher, 1982). According to Hermina (1990) continental influence prevailed during the marine deposition of this formation as deduced from the occurrence of irregular intercalations of iron crusts and mud cracks. Fully marine conditions occur only at the topmost of this formation.

The sediments show in its type locality a marked transition downward toward the underlying fluviatile sandstone of the Six Hills Formation (Bisewski, 1982), whereas upward a distinctive erosional surface separates this formation from the overlying Sabaya Formation (Hermina, 1990). Fluviatile conditions increase southward near Lake Naser where the transgressive sediments of this formation exhibit a more shallower (near-shore environment and become highly intercalated with fluviatile sandstone (Lake Naser Formation of Klitzsch, 1986). The formation also loses its marine identity westward (west of Long.27º) toward the Gilf El Kebir and Great Sand Sea where fluviatile conditions prevailed during the same time, so that it is difficult to distinguish between this formation and both underlying fluviatile Six Hills and overlying Sabaya Formation.

Issawi et al (1999) pointed out that wedging and the transitional contacts of Abu Ballas Formation (they mean contacts with both overlying and underlying fluviatile sediments) make it difficult to divide the cycle into two lithologic units. Accordingly, they proposed a grouping of both Abu Ballas and the overlying Sabaya Formation in one lithologic unit under the name of Abu Ballas Formation. However, since the justification cited by Issawi et al. (1999) is correct, it would be reasonable to combine the thin shallow marine Abu Ballas sediments to the underlying thick fluviatile Six Hills sediments and not to the overlying fluviatile Sabaya sediments. As already stated by Bisewski (1982) and Hermina (1990), the transition between the fluviatile sandstones of the Six Hills Formation and the overlying marine clays and shales of the Abu Ballas Formation is easily recognized although an erosional surface is not found everywhere, meanwhile the fluviatile sediments of Sabaya Formation start at base with an erosional surface overlain by 30 m thick white Kaolinitic paleosol sandstone rich in root remains.

Concerning the age of the Abu Ballas Formation a lower Cretaceous (Aptian) age is proposed by Boettcher (1982) in spite of the absence of index fossils in the type section. However, pollen and spores investigated by Schrank (1987) from a subsurface horizon comparable to Abu Ballas Formation in the water wells west of Mawhub (Dakhla Oasis) indicate an Aptian age for this formation.

- Six Hills Formation (Barthel and Boettcher, 1978 = Basal Clastics of Klitzsch, 1978 and Bisewski, 1982): The Type locality of this formation lies at Six Hills at Long. 29º 15′ E and Lat. 24º 10′ N, about 100 km south of Mut in Dakhla Oasis, where the formation reaches up to 500 m in thickness. The Formation is made up of fluviatile sandstone which is fine- to coarse-grained, tabular and trough cross-bedded with channel sediments representing upward-fining cycle of braided river systems (Hermina et al.1989). The sediments belonging to this formation cover large areas south of Dakhla-Kharga road toward the Sudanese-Egyptian borders (= Abu Simbile Formation of Klitzsch, 1986 in the Lake Naser-wadi Halfa area) where they overly unconformably the Precambrian igneous rocks. They also extend west- and southwestward to the Gilf El Kebir where identical lithologic sediments of the same environment and the same age were described under the name of Gilf Kebir Formation (Klitzsch, 1978) covering unconformably Paleozoic sandstone of different ages northwest and south of the Gilf El Kebir Plateau. Northward of the Gilf El Kebir Plateau in the area known as the Great Sand Sea these sediments become only known from the subsurface.

Dominik (1985) assigned the Six Hills Formation at its type locality to the Lower Cretaceous (Aptian) transgression. Schrank (1987), on the other hand, described pollen of middle to late Jurassic from a horizon about 300 m below the well-defined overlying Aptian Shale beds comparable to Abu Ballas Formation in Ammonite well-1. On this basis, the formation was given a Late Jurassic-early Cretaceous age by Klitzsch and Lejal-Nicol (1984), Hermina et al. 1989), Hermina (1990) and Klitzsch and Schandelmeier (1990).

However, new and revised palynological combined study between Berlin Technical University and Assiut University, Egypt (Schrank and Mahmoud, 1998) from 15 core samples from the Six Hills and Maghrabi Formations in ten boreholes in the Dakhla Oasis area have yielded an palynomorph assemblages which allowed the assignment of the sediments belonging to Six Hills-Maghrabi sequence to the lower and lower-upper Cretaceous. The most conclusive results obtained by this study are as follow:1) the lower six Hills contains a miospore assemblage which is tentatively regarded as Early Neocomian, probably Berriasian-Valanginian. The green algae indicative of deposition in fresh water are also present in the formation, 2) the uppermost samples of the Six Hills Formation which are palynologically dated as Late Neocomian (to early Barremian) is barren of fresh water plankton, probably due to a shift toward drier conditions, 3)the Palynomorphs from transitional beds between the Six Hills and Abu Ballas Formations are palynologically dated as Late Barremian to Early Aptian and have also yielded restricted marine dinofagellates. The Abu Ballas Formation is, thus, considered as Early Aptian, 4) the Maghrabi Formation in the Dakhla area contains no marine dinoflagellates but yields a relatively advanced angiosperm pollen, namely tricolpates, tetracolpates and tricolporates without triporates, a miospore assemblage which is indicative of Albian –Early Cenomanian age. However, in the Kharga area, the Maghrabi is relatively younger and belonging to Late Cenomanian-Turonian age as indicated by the presence of triporates. The palynofloras in the Maghrabi Formation suggest that fresh water environment existed during the time of its deposition.

On the basis of the detailed palynological study of Schrank and Mahmoud (1998), the entire Six Hills Formation should be regarded as belonging in age to the lower Cretaceous, from Berriasian to Early Aptian, not Late Jurassic-Aptian as previously proposed. The overlying Abu Ballas is regarded as Early Aptian in age, while the succeeding Sabaya Formation could range down into the Aptian, instead of Albian-Early Cenomanian as previously proposed. The Maghrabi Formation is Albian to Early Cenomanian In Dakhla area and Late Cenomanian-Turonian in Kharga area, thus indicating an eastward shift of the depocentre from West in Early Cretaceous time to East in Albian-Late Cretaceous time.

Northward in Bahariya Depression (northern part of the EWD Province), the Mesozoic sandstone sequence extends both on the surface and in the subsurface. The sequence begins at top with the Bahariya Formation (originally proposed by Said ,1962 and later emended by Akkad and Issawi, 1963; Hermina et al. 1989, Hanter, 1990) which is exposed along the floor and on both sides of the depression. The lower part of this formation is made up of fluviatile cross-bedded and coarse-grained sandstone belonging to the Gebel Ghorabi Member (Dominik, 1985) and grading upward into fine-grained well-bedded ferruginous clastics of estuarine facies carrying a large number of vertebrate fossils in the lower levels and shallow-marine invertebrate faunas in the upper levels (Gebel Dist Member, Dominik, 1985). The faunas are given a Late Cenomanian age by Dominik (1985),whereas the fluvio-marine succession of the Bahariya Formation is considered consequently as being equivalent to the Maghrabi Formation in the south although the latter differs in showing lesser marine influence (Said, 1990). The base of the lower fluviatile unit is not exposed and extends in the subsurface of Bahariya Well-1 to depth 725 m, where it is underlain by 641m of similar unfossiliferous sandstone and red clay beds of most probably pre-Cenomanian, then underlain by ~457 m thick of sandstone containing some Trilobite fragments of Early Paleozoic age covering unconformably an old high of the Precambrian basement. Thus, it can be concluded that the sandstone sequence overlying the Paleozoic sediments up to the top of Gebel Dist Formation in Bahariya Depression is comparable to the Six Hills, Abu Ballas, Sabaya and Maghrabi Formations which cover the time duration from the Berriasian to the Cenomanian. The early Paleozoic subsurface strata in the Bahariya Well-1 (Lat. 28º 30′ and long. 28º 58′) is related to the northern Cambrian transgression which had affected the northern part of the Western Desert (NWD province) and extended southward to the neighborhoods of Lat. 28º 30′.

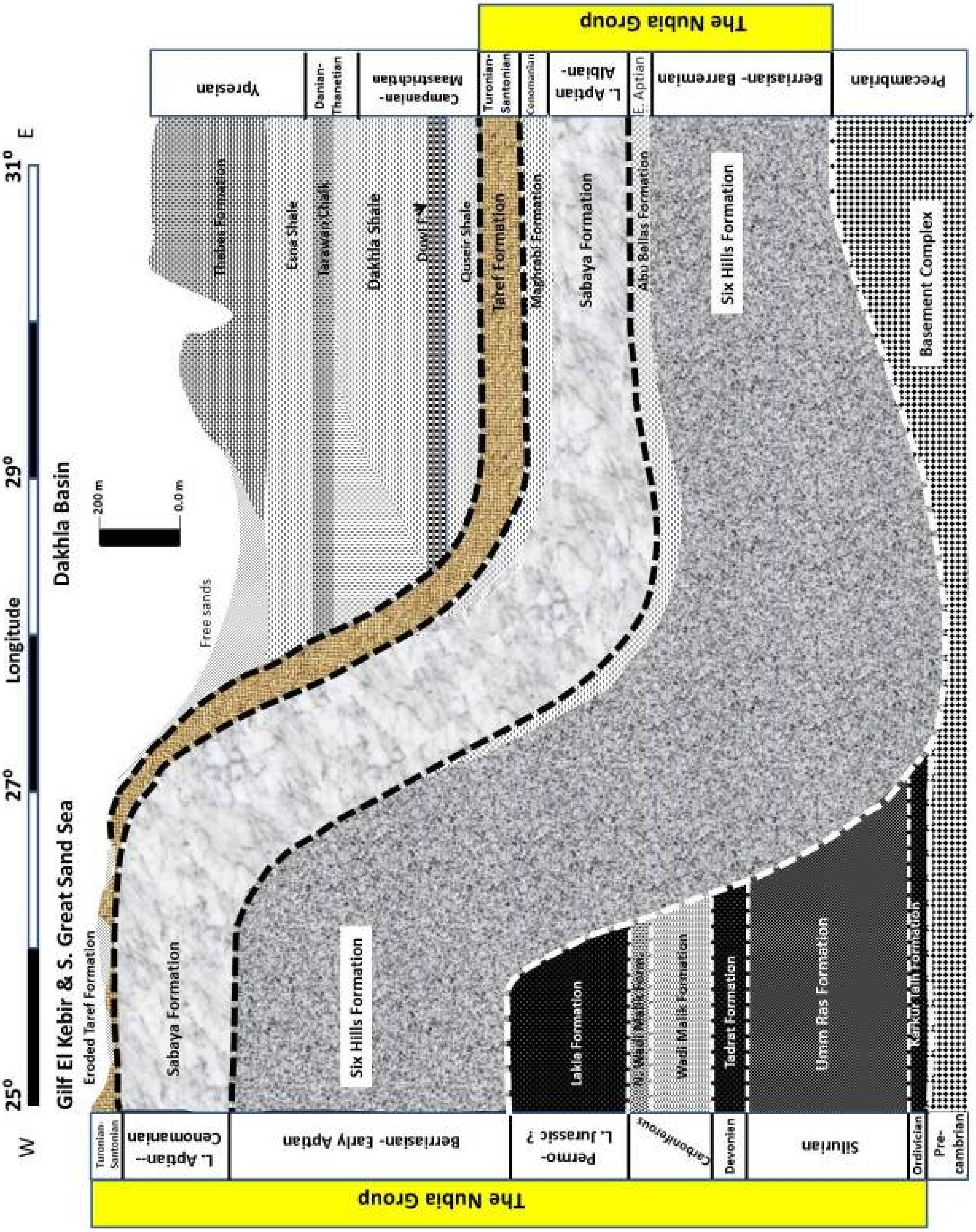

Fig. 1: Stratigraphic correlation of the different Paleozoic-Mesozoic rock units belonging to the Nubia Group between the Gilf El Kebir Plateau-southern Great Sand Sea at West (West of Long. 27^0) and the Dakhla–Kharga stretch at east (East of Long. 27^0). Note the younger marine rock units belonging to the Campanian-Ypresian age which overly the Nubia Group in the Dakhla- Kharga regions. Note also that the uppermost rock unit of the Nubia Group (Taref Formation) is almost eroded in the Great Sand Sea.

5. Stratigraphy of the Nubia Group in the Western part of the Western Desert (WWD Province, West of Long.27).

In the southern part of this province (south of Lat. 24º 45') the Nubia Sandstone sediments constitute the Gilf El Kebir Plateau which extends ~170 Km in north-south direction and gradually tapering toward south until becoming terminated at nearly Lat. 22º 40′ N. The plateau is divided into two parts by an erosional depression which strikes nearly east-west near Lat. 23º 30′ N (for detailed morphologic features see Issawi et al., 1999). The elevation of the plateau varies from 700 m at the southern part to 1064 m near Al Aqaba Pass. The top surface of the plateau is entirely flat except of few localities which are disturbed by the rise of basaltic cones and flow sheets. Many wadis dissect the plateau particularly in its eastern side, and several scarps and ridges overhang the main plateau and overlook the wide depressions north and northwestward of the plateau. Several networks of drainage pattern of old river systems originating from the hilocks on the flat-topped surface of the plateau and running north and northeast are detected.

The Gilf El Kebir Plateau is made up exclusively of Mesozoic fluviatile Nubia Sandstone sequence composed mainly of Six Hills and Sabaya Formations. According to Klitzsch and Schandelmeier (1990), the lower half to two thirds of this plateau is formed of predominantly fluviatile sandstone equivalent to both Six Hills and Abu Ballas Formations, whereas the upper half or one-third of the Gilf Plateau is made up of fluviatile sandstone equivalent to the Sabaya and the Maghrabi Formations. In Wadi Qubba, these sediments were found by the same authors to be overlain by fluvial and lacustrine sandstone and paleosol, equivalent to the Taref Sandstone of Turonian age. However, some workers are inclined to apply other comparable geographic rock units in the Gilf El Kebir Plateau to express lateral changes in environment westward from continental sandstones changing gradually in the uppermost part into near-shore environment east of Long.27º, to exclusively continental sandstones west Long.27º. For example Klitzsch et al. (1979) proposed the Gilf Kebir Formation to represent the fluviatile sandstone sequence belonging to one stratigraphically homogenous continental cycle without marine interferences in the Gilf El Kebir Plateau, equivalent to Six Hills, Abu Ballas, Sabaya Maghrabi and Taref of the southeastern part of the Western Desert. On the other hand, Issawi et al. (1999) divided the sandstone sequence of the Gilf El Kebir Plateau into two rock units representing two different sedimentary cycles, a lower Abu Ballas unit equivalent to both Six Hills and Abu Ballas Formations and an upper El Burg Formation (Geological Survey of Egypt, 1982) equivalent to both Sabaya and Maghrabi Formations. According to the latter authors each sedimentary cycle was started by continental sediments at base and ended by proper marine incursions at top and consequently should be treated as a single formational name. It is, thus, clear that the conflicting explanations about the reasons for proposing new rock units has increased the difficulty oftracingthe sedimentary cycles during the Mesozoic-Cretaceous periods in southernEgyptand consequently obscured the geologic history of the Nubia Sandstone Aquifer System.

So, we found necessary to revise the basis of nomenclatures of Mesozoic rock units in southern Egypt according to the International Stratigraphic Code. The definition of a lithostratigraphic unit must be based on composition and other lithic characteristics, and consequently the inferred geologic history and depositional environment have no place in the definition of a lithostratigraphic unit (Article 22). Also, inferred time spans, however, play no part in differentiating or determining the boundaries of any lithostratigraphic unit. As mentioned before the Mesozoic fluviatile rock units of the Nubia Group Six Hills, Sabaya and Taref Formations did not lose their lithic identity whether in the east or the west of Long. 27*, but these formations become only interbedded eastward by thin shaly or clayey sandstone beds of shallow- marine origin as a result of influence of marine pulses during the Aptian and Cenomanian, before the prevalence of marine conditions during the Campanian-Ypresian. This lateral change in the lithic characteristics of the upper horizons of the fluviatile sandstone rock units supports the establishment of the Abu Ballas and Maghrabi Formations to replace the uppermost part of the Six Hills and Sabaya Formations respectively in the area east of Long.27º. However, it does not support the total elimination of the Six Hills, Sabaya and Taref Formations or their replacement by other comparable lithostratigraphic units in the area west of Long. 27º.

Thus, the Six Hills Formation should be applied to include the fluviatile fine to coarse-grained, cross-bedded sandstones with channel sediments and which overly unconformably older Paleozoic sediments or Precambrian igneous rocks, and underlie either conformably the Abu Ballas Formation in the east or unconformably Sabaya Formation in the west, irrespective of the time duration of this Formation in different localities. Also, the Sabaya Formation should be applied for the fluviatile sandstone which is mainly large- scale tabular cross-bedded and which starts at base with an erosional surface overlain by a thick white kaolinitic paleosols sandstone, covering unconformably either the Six Hills in the west or the Abu Ballas in the East, and underlying unconformably the Taref Formation which represents the youngest member of the fluviatile sandstone sequence of the Nubia Groupin the WWD Province to the west of Long. 27^0 (Fig. 2).

The studies of Ouda et al. (2011, 2012)on the bedrock of different landforms in the Great Sand Sea including sandstone ridges, tracks between ridges, plateaus, domes, mesas, buttes, depressions, troughs and plains between latitudes 26º 30′ to 28º 30′ N and longitudes 25º 30′ to 27º E have shown that all bedrock of these new landforms belongs to the Sabaya Formation of Barthel and Boettcher (1978). The overlying Taref Formation is almost entirely eroded leaving remnants and elongated yardangs formed by differential erosion and wind abrasion. On this ground the author supports the validity of the main five units of Six Hills, Abu Ballas, Sabaya, Maghrabi and Taref Formations as constituting the Mesozoic lithostratigraphic divisions of the Nubia Group in the EWD Province (east of Long.27º). However, westward (west of Long. 27º) where fluviatile conditions continued for a long time, the Abu Ballas and Maghrabi Formations lose their identity, meanwhile the Six Hills , Sabaya and Taref Formations retain the same lithic characteristics for a relatively much younger time than in the east (Fig.1). Thus, all other Mesozoic formational names proposed for equivalent rock units in the Gilf El Kebir Plateau (Gilf Kebir Unit of Klitzsch et al. 1979, Burg Formation of the GSE, 1982) or in the southernmost parts of the Western Desert, (Abu Simbil Formation, Lake Naser Formation of Klitzsch, 1986) should be rejected.

5.1. Paleozoic Rock Units of the Nubia Group in the WWD Province:

In the WWD Province (west of Long. 27º), the Mesozoic sandstone sequence belonging to the Nubia Group is unconformably underlain in restricted areas near the Libyan borders by a predominantly fluviatile Paleozoic sandstone sequence which is strongly interrupted by erosional surfaces and partly interbedded by shallow -marine fossiliferous sandstone, clayey siltstone and/or shale of Late Silurian and Early Carboniferous age. The Paleozoic sediments are well exposed on the foot slopes and scarps to the west of the Gilf El Kebir Plateau and further south at the northeastern (Karkur Talh), eastern and southeastern (Karkur Murr) slopes of Gebel Uweinat (Klitzsch and Schandelmeier (1990). They include the following lithostratigraphic units arranged from top to bottom:

- The Lakia Formation (described originally from northern Sudan by Klitzsch and Lejal-Nicol, 1984): 250-300 m thick; fluviatile sandstone; known from the eastern slopes of G. Uweinat; no fossils have been recorded; given a supposedly Permo-Early Jurassic? age according to its stratigraphic position; overlain unconformably by the Six Hills Formation. The direction of transport of these sediments is oriented toward the south and southeast (Klitzsch and Lejal-Nicol, 1984), and the sediments were deposited after the eastern part of North Africa was uplifted by the Hercynian Event (Klitzsch and Schandelmeier, 1990).

- The Northern Wadi Malik Formation (Klitzsch and Wycisk ,1987): 30 to 60 m thick of fluvio-glacial sediments made up of boulders and blocks of older strata embedded in a matrix of clay , sand and conglomerate at north of Wadi Abdel Malik (klitzsch and Lejal-Nicol, 1984). The sediments are entirely replaced southward in the middle and southern part of Wadi Abdel Malik and its side wadis by fluviatile sandstone and conglomerate. Further southward, at the northeastern (Karkur Talh) and southeastern (Karkur Murr) slopes of G. Uweinat, the Formation is made up of 40-120 m thick of fluviatile sandstone interbedded with very regularly laminated siltstone overlying the Lower Carboniferous and showing a south- to southeastward direction of transport (Klitzsch and Schandelmeier, 1990). No fossil content has been recorded, but the top part of this formation at its type locality north of Wadi Abdel Malik is made up of parallel-bedded sandstone containing plant fossils of late Carboniferous age (klitzsch and Lejal-Nicol, 1984; Klitzsch and Schandelmeier, 1990). It is overlain unconformably by either the Six Hills Formation (Abu Ras Plateau and north Wadi Abdel Malik) or the Lakia Formation (eastern slopes of G. Uweinat).
- The Wadi Malik Formation (Klitzsch, 1979): 100-150 m thick, marine sandstone, siltstone and shale interbedded with fluviatile, deltaic and tidal sandstone; known at west and southwest of Wadi Abdel Malik and its side wadis, at the northeastern (Karkur Talh) and southeastern slopes (Karkur Murr) of G. Uweinat where it assumes 50-120 m thick. The marine horizons of this formation are rich in brachiopods, trace fossils, and starfish (Seilacher, 1984), but several continental strata are yielding frequent plant remains such as *Sigillaria* spp. and *Lepidodendron* spp.. The age of this Formation is given by Klitzsch and Lejal-Nicol (1984) as lower Carboniferous. It overlies unconformably either the Precambrian basement rocks (Karkur Murr) or the Tadrart formation (Wadi Abdel Malik, northeastern (Karkur Talh) and eastern G. Uweinat), and is overlain unconformably by the Northern Wadi Malik Formation. Issawi and Jux (1982) proposed the name Gilf Formation to the carboniferous sandstone with breccia and grit intercalations (100m thick) at the Gilf El Kebir, south Western Desert. The Gilf Formation being equivalentto both Wadi Malik and the overlying Northern Wadi Malik formations.
- The Tadrart Formation (Burollet, 1960): 80-100 m thick; fluviatile sandstone; known at the western edge of the Abu Ras Plateau and the northeastern slopes of G. Uweinat. The formation was originally described in southwestern and southeastern Libya as well as northeastern Chad. No index fossils have been recorded in Egypt. However, it has been given a supposedly Devonian age according to its stratigraphic position between the underlying Silurian Umm Ras Formation and the overlying lower Carboniferous Wadi Malik Formation (Hermina et al. 1989; Klitzsch and Schandelmeier, 1990).
- The Umm Ras Formation (Klitzsch and Lejal-Nicol, 1984): ~400 m thick fluviatile sandstone interbedded with a shallow marine sandstone and clayey siltstone. The sediments belonging to this formation extend in a narrow passage (Umm Ras passage) at the western foreland of the Gilf El Kebir Plateau, from the southern slopes of the Abu Ras Plateau to the lower slopes of the northeastern Gebel Uweinat. Frequent ichnofossils are recorded from the marine horizons but no index fossils are recorded. Actually, the stratigraphic value of these trace fossils is greatly reduced in the kufra Basin (Bellini and Massa (1980) by the fact that they are locally found throughout a rock unit and, elsewhere in other basins; they are found in younger sediments. The age of this Formation has been given by Klitzsch and Lejal-Nicol (1984) as Silurian based on the presence of *Harlania harlani* and *Cruziana acacensis,* an association which is generally found in the upper part of the Silurian Acacus Formation in the Kufra Basin in Libya. The Formation overlies the Precambrian basement rocks in Umm Ras passage along the Libyan border west of Abu Ras Plateau, or Karkur Talh Formation in the northeastern slopes of G. Uweinat where it assumes only 75m thick. It is unconformably overlain by Tadrart Formation.
- The Karkur Talh Formation (Klitzsch and Lejal-Nicol, 1984): 25m thick; fluviatile sandstone; only known from the northeastern slopes of G. Uweinat. According to Klitzsch and Schandelmeier (1990) the strata belonging to this Formation are highly burrowed by *Scolithos* sp. and its basal part contains *Cruziana* sp. of Ordivician ? age. However, as mentioned above, the assemblage of *Cruziana* is generally found in the upper part of the Silurian (not Ordivician) Acacus Formation in the Kufra Basin In Libya (Bellini and Massa (1980). The Formation overlies unconformably the Precambrian basement rocks.

5.2. Mesozoic Rock Units of the Nubia Groupin the WWD Province:

As previously mentioned, the Mesozoic sandstone sequence belonging to the Nubia Group in the WWD Province is represented only by the main three fluviatile rock units namely from older to younger, the Six Hills, the Sabaya and the Taref Formations. Neither Abu Ballas, nor Maghrabi Formation is recorded in this province.The Six Hills Formation of is 600-700 m thick in the Gif El Kebir Plateau, and 200-300 m thick in G. Uweinat. In the Abu Ras Plateau the Six Hills formation represents the top part of the plateau and is eroded over large areas (Klitzsch and Schandelmeier, 1990).The sediments belonging to this formation cover unconformably older sandstone Paleozoic strata belonging either to the Silurian (Umm Ras Formation, Klitzsch and Lejal-Nicol, 1984), or the Carboniferous (Wadi Malik Formation, Klitzsch, 1979 and Northern Wadi Malik Formation, Klitzsch and Lejal-Nicol, 1984) in Wadi Abdel Malik and its tributary wadis in the Abu Ras Plateau. Southward it extends to Gebel Kamil and the Sudanese border. Along the eastern slopes of G. Uweinat, the Six Hills Formation overlies unconformably 250-300 m thick of unfossiliferous fluviatile sandstone of supposedly Permo-Lower Jurassic? age (Lakia Formation).

The Six Hills Formation in the WWD Province is overlain directly by the Sabaya Formation which is made up mainly of fluviatile sandstone similar to those of the underlying Six Hills Formation, but both formations could be distinguished by a recognizable erosional surface characterized by a paleosol at the basal part of Sabaya Formation. The same erosional surface has been recognized at the base of Sabaya Formation at its type locality and wherever it overlies the Abu Ballas Formation east of Long.27º. In Wadi Qubba the Sabaya Formation is overlain bycontinental sandstone and paleosols equivalent to Taref sandstone (Klitzsch and Schandelmeier, 1990).

Eastward of the Gilf El Kebir Plateau toward the Kharga-Dakhla stretch, and southeastward (toward G. Kamel) the Paleozoic sediments are entirely missing, and the Lower Cretaceous sediments belonging to the Six Hills Formation overly unconformably the Precambrian basement rocks (Fig. 1). A vast flat plain of undulated Mesozoic sandstone bed rock with continuously decreased ground elevation (500 m to 400 m Above sea level) extends from the eastern slopes of the Gilf El Kebir Plateau toward the Kharga depression. The plain is dissected by low sandstone scarps made up of Six Hills and Sabaya Formations which are cropping out on this flat plain surface between the Gilf plateau and Long. 27º where they assume N-S, NE-SW and NW-SE trends (Issawi et al. 1999). Directly to the east of Long. 27º at Abu Ballas, the uppermost 60 m thick of the Six Hills Formation passes into near-shore, ferruginous clastic (silty sandstone, siltstone, shale and sandstone) belonging to the Abu Ballas Formation. The latter unit is unconformably overlain (with the formation of thick paleosol) by a fluvial sandstone more than 200 m thick belonging to Sabaya Formation. The sediments belonging to the three Early Cretaceous Formations (Six Hills, Abu Ballas and Sabaya) continue eastward toward Kharga until Long. 30ºwhere they constitute both the bedrock and outcrops of the vast plain. The Six Hills Formation reaches much further to the south toward G. Abu Bayan and the basement of Bir Tarfawi-Bir Safsaf area (Klitzsch and Schandelmeier, 1990).

6. The Nubia Sandstone in the Great Sand Sea

The Great Sand Sea (~72000 km^2 bounded in the south by the Gilf El Kebir Nubia Sandstone Plateau and in the north by Siwa Oasis) has long been described as being formed of many parallel longitudinal sand dunes which interlock, merge, and show in places an en echelon arrangement (e.g. Bagnold 1931,1941; Gifford et al. 1979). However, the data given by Ouda et al.(2011, 2012) indicate that the Great Sand Sea is essentially made up of a series of parallel longitudinalNubiaSandstoneridges that are structurally controlled, extending north northwest- south-southeast and covered by a thin veneer of free brown sands derived from disintegration and breakdown of the underlying Nubia Sandstone bed rock.

In the Great Sand Sea the Paleozoic rocks become only known from the subsurface where they overlain by thick Early Cretaceous sediments which extend upward until becoming exposed on the surface. To the north of Lat. 24º 30′ the Six Hills Formation becomes subsurface while Sabaya Formation becomes exposed on surface where it forms a series of longitudinalNubiaSandstoneridges running north northwest- south-southeast.The ridges are running parallel, straight and almost regularly spaced. They represent a series of bended (up-folded), cross-bedded to horizontally Nubia Sandstone layers belonging to the Sabaya Formation which later subjected to intense fracturing and a long-period of erosion.The sandstone ridges extend for a long distance ranging between 80 and 240 km and are uniformly separated by parallel tracks or corridors of varied width ranging between 500 m and 2500 m (Figs. 2, 3, 4 and 5).. The difference in ground elevation between the top of ridges and the floor of tracks are varying between 30 m and 70m, but averaging between 40 and 50 m (Fig. 2).

The sandstone ridges and intervening low-lying tracks are not overlain by younger consolidated deposits, but only covered by a thin veneer of free, brownish to yellowish sands originating from the disintegration and breakdown of the underlying Nubia Sandstone bedrock. The sand veneer attains a thickness of 3-5 cm, sometimes reaching up 10-15 cm, thus obscuring the original sandstone bedrock, but do not hinder the movement of cars over it (Fig. 3 A-B, Fig. 6 C-D). The Sabaya bedrock below the drifted sands is hard, white, highly porous quartz sandstone composed of rounded and translucent quartz grains which are well to moderately sorted, coarse to medium grained, partly kaolinitic and entirely barren of fauna Figs. 6 A-B).

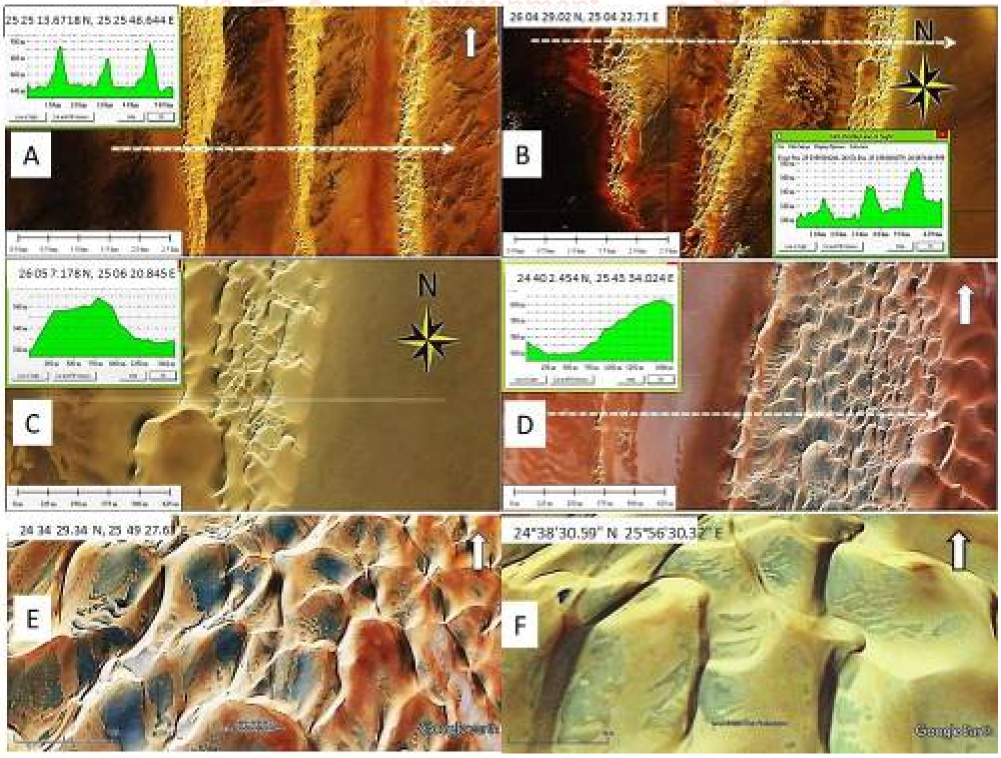

Fig. 2: A-D- SRTM Satellite images from World Imagery (A-C) and Google Map imagery (D) showing Longitudinal asymmetrical parallel Nubia Sandstone ridges with sharp steep slopes on one side and theater-like heads with flat floors on the other sidein the southern part of the Great Sand Sea. The ridges are strongly attacked by old river streams flowing from south to north during the wet periods of the Pleistocene. E-F- Satellite images from Google Earth Pro showing that the Nubia Sandstone ridges exhibit well preserved current three- dimensional ripple marks of linguoid shape that resulted from water currents. Note also that groundwater flow through and emerges from the cracked gaps between linguoid ripples in Figs. E and F.

Fig. 3: Longitudinal Nubia Sandstone ridges (black arrows) made up of Sabaya Formation extended northwest-southeast in the Great Sand Sea. Note the wide, flat and compact tracks which are covered by a thin veneer of loose, brown sands between the sandstone ridges so that cars can move fast and easy. Note the groundwater sapping process along bedding planes of the sandstone ridge in Fig. B

In the area between latitudes 26º Nand 28º N the sandstone ridges seem to have subjected to intense uplifting and faulting during the Oligocene leading to the development of two parallel sandstone mountain ranges; each one is made up of broad flat-topped plateau or dome (up to 180 m high and 60 km long) and wide flat depressions (63 km^2 to 1616 km^2 in area) running northeast-southwest in parallel lines which are oblique (~45^0) to the long axes of the pre-existing sandstone ridges (Ouda et al. 2011, 2012). The mountain ranges are formed as a result of intersection of two major fault systems; one is running north-northwest parallel to the long axes of the sandstone ridges while the other is oriented northeast parallel to the long axes of the depressions and plateaus. The major depressions represent down-faulted blocks sliding towards the northeast and southwest while the plateaus form uplifted flat-topped blocks between the depressions, thus constituting fault-block mountain ranges (horsts, Fig. 7 B-D; Fig. 8A and C). The bedrock of all these new landforms is white unfossiliferous highly permeable fluviatile quartz sandstone belonging to the Lower Cretaceous Sabaya Formation. The top and limbs of the sandstone plateaus as well as the flat depressions between have all a compact and hard surface due to saturation of the bedrock with groundwater, thus making car travel easy and fast (Fig.7 B and D; Fig. 8 B).

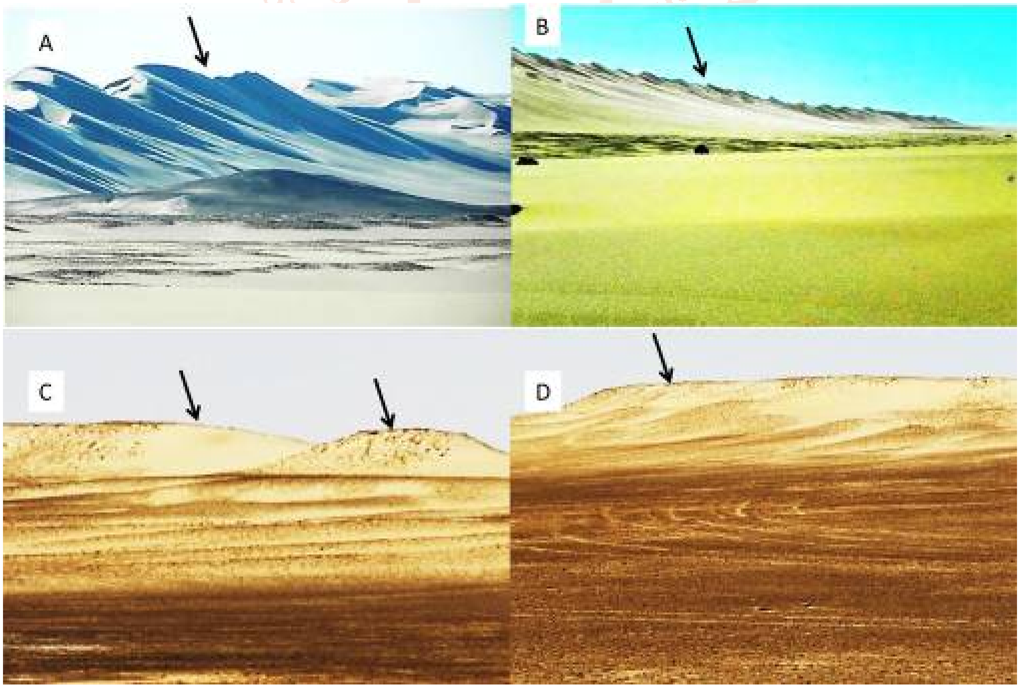

Fig.4: A and B: Longitudinal cross-bedded sandstone ridges of Sabaya Formation (black arrows) extending NW-SE in the middle part of the Great Sand Sea (between latitudes 27^0 and 28^0). C-D: -Interrupted Sabaya Sandstone ridges in the northern part of the Great Sand Sea (North of Lat. 28°). The ridges are well-bedded, short in length, narrow in width and less highly elevated compared to those southwards, and showing the phenomenon of groundwater sapping process which plays the main erosional agent of the bed rock in this area.

The lower limit of the Sabaya Formation is not exposed and therefore its total thickness below the surface is not definitely known. Unfortunately no wells have been drilled in the Great Sand Sea except of Ammonite -1 at the eastern rim (~80 km west of Abu Minqar) and Foram-1 at the northwestern rim (10 km west of the Libyan borders). In the Ammonite 1 the Mesozoic sequence of the Nubia Group (Six Hills, Abu Ballas, Sabaya, Maghrabi and Taref Formations) attains ~1170 m, overlying unconformably the Precambrian Basement complex and underlying 170 m thick of marine Campanian-Masstrichtian sediments. In Foram-1 the Mesozoic sequence (both Six Hills and Sabaya Formations) attains ~1200 m covering unconformably ~2300 m thick of Paleozoic sediments (Shrank, 1984).

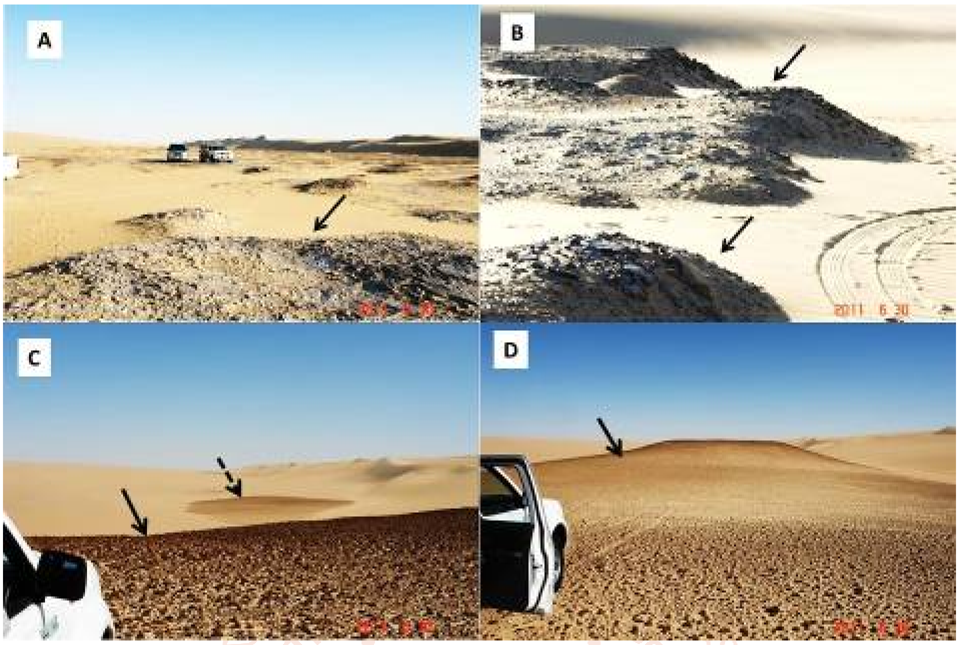

Fig. 5: A-B- Sabaya Sandstone exposures in the Great Sand Sea. Note the cars adjacent to the exposures in Fig. A. C-D- Cars running over the longitudinal Sabaya Sandstone ridge (continuous arrow). Note the groundwater seepage at the floor of the low-lying tracks between ridges (dotted arrow) . Note also the loose drifted sands which form a thin veneer covering the ridges and floor of tracks.

The Taref Formation is almost entirely eroded leaving remnants and elongated yardangs of bedded, highly jointed sandstone formed by differential erosion and wind abrasion in the flat depressions near the steep walls of the plateaus (Fig. 9). The Taref outcrops attain a maximum height of 6 meters and are made up of a thin (0.3-0.4 m thick) basal brown bed of clayey sandstone containing poorly sorted quartz grains mingled with brown rock debris of gravel size, and an upper thick-bedded white yellowish to greyish quartz sandstone made up of rounded, coarse to medium translucent quartz grains with erratic silica debris.

Fig. 6: A-B- Sandstone ridges of White quartz sandstone belonging to Sabaya Formation. The Formation is made up of white to translucent quartz sandstone, with rounded quartz grains well to moderately sorted, coarse to medium grained, partly kaolinitic and entirely barren of fauna. C-D- Sabaya Sandstone lying directly below a thin veneer (3-5 cm thick) of loose brown sand grains formed as a result of disintegration and breakdown of the underlying Sabaya Sandstone bedrock. The sands cover the floor of tracks between sandstone ridges, the flat tops and side-slopes of the plateaus, the bottom of the wide flat depressions and in the deflation hollows which result from differential erosion of the original Sabaya bed rock

A fluviatile porous sandstone comparable to the Taref Sandstone is also found unconformably underlying the Lower Eocene part of the open marine Esna Shale in the New Farafra Oasis, a new discovered depression by Ouda et al. (2011, 2012) lying between Ain Dalla west of Farafra and the Great Sand Sea. The investigation of planktonic foraminifera of the Esna Shale in this area indicates that the shales belong to Mahmiya Member of Aubry et al. (2007) of the Early Eocene (Ypresian) age. Southward, a similar stratigraphic relationship between the marine Dakhla Shale and the Taref Sandstone is recorded in the area lying between Abu Minqar at east and the Great Sand Sea at west. More southward on both sides of the Dakhla-Kharga road, the Taref sandstone becomes unconformably overlain by the shallow–water marine Quseir Formation.

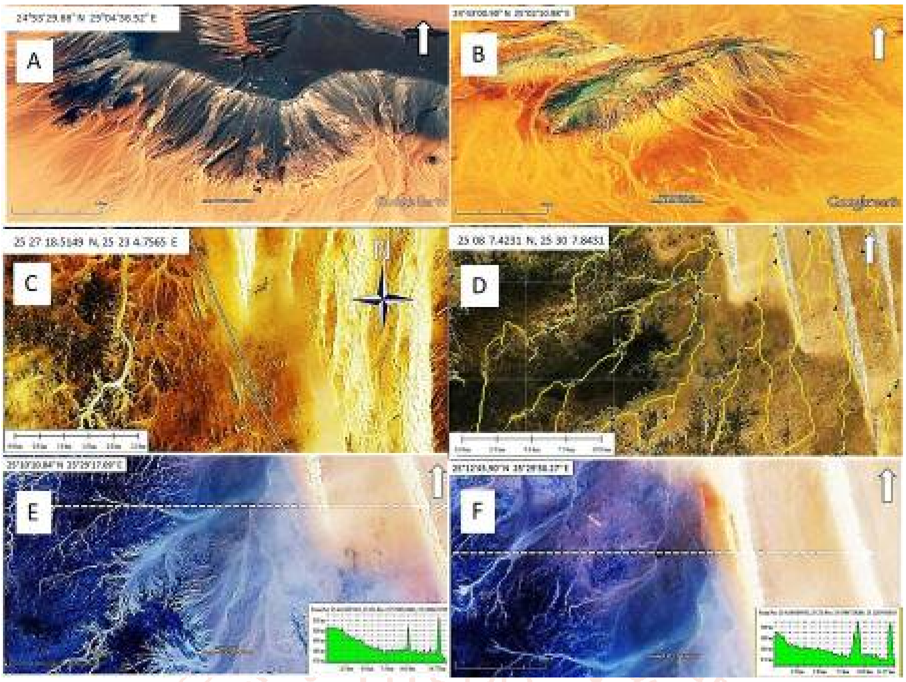

Fig. 7: A-B- Satellite images from Google Earth Pro showing groundwater sapping process acting through alcoves along the bedding planes in longitudinal sandstone ridges in the southern part of the Great Sand Sea. C-F- Satellite SRTM images processed by the Global Mapper showing overland flows over hillslopes along the Egyptian/Libyan borders (westward) attacking the Nubia Sandstone ridges (eastward

Beside the structurally formed landforms, there are two major flat sandy plains (1687-3030 km^2) along the Egyptian/Libyan borders (between latitudes 25^0 45′ and 27^0 45′) drained by old river systems which have led tosevere erosion and partial removal of the pre-existing sandstone ridges (Fig.10).This would indicate the influence of a long period of active erosion in the area occupied by the Great Sand Sea since the uppermost Cretaceous. The bedrock of the plains is made up of Sabaya Formation covered by a thin veneer of loose sands.Current ripple marks formed mainly by wind blowing over loose sand, with small alternating ridges and troughs that having straighter crests characterize the surface of the sand veneer all over the area.

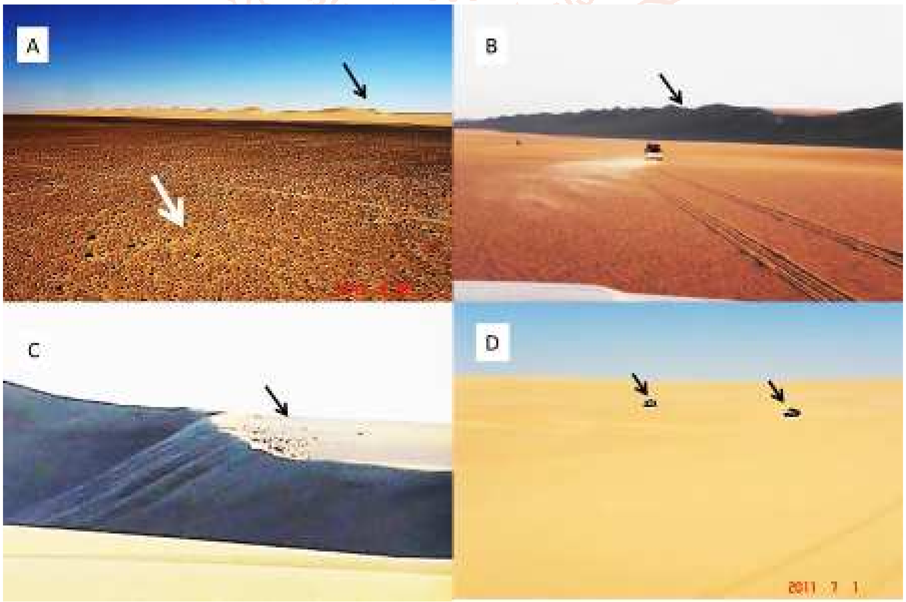

Fig. 8: A- Longitudinal Nubia Sandstone ridge (black arrow) made up of Sabaya Formation extended northwest-southeast in the Great Sand Sea. Note the wide wet tracks between the sandstone ridges due to groundwater seepage (white arrow). B- Flat-topped plateau (black arrow) made up of Sabaya Sandstone rising 180 m above floor and running northeast-southwest for 60 km. C- Enlarged photograph for the same plateau in B. D- Cars (black arrows) running easy over the compact and flat depression to the north of the sandstone plateau due to saturation of the underlying Sabaya bedrock by groundwater. Note the thin veneer of brown loose sands which obscure the underlying Sabaya bedrock.

Playa and fresh water lake deposits are seldom occurred in the Great Sand Sea due to the fact that the underlying bedrock is made up exclusively of the best aquifers of the Nubia Sandstone Group i.e. the highly porous Sabaya Formation which absorb the excess water before accumulation in low areas. However temporary accumulation of excess fresh water lake deposits in low areas to form shallow playa lakes seems to have occurredrarely and sporadically in the northern part of the Great Sand Sea. In this area well-eroded hummocks of no more one meter height, made up of thin horizontal beds of white carbonate (~60 cm thick) crowded by fresh water gastropods and overlain by a thin conglomeratic (~40cm thick) bed are intermittently recorded near the Libyan-Egyptian borders and the wide flat tracks between the Nubia sandstone ridges north of Lat. 28º (Fig. 11A-B).

Fig.9: A and C: Plateau of Nubia Sandstone (Sabaya Formation, black arrows) with flat top and showing in part cross-bedding limbs extended northeast-southwest in the Great Sand Sea. B- Longitudinal sandstone ridges made up of Sabaya Formation extended northwest-southeast and showing compact and hard top surfaces and limbs so that cars can cross the ridge easy

Northward of Latitude 28^0 25′ and west of Long, 27^0 the sandstone ridges decrease in length to 23-35 km until becoming very short and intensively interrupted south of Siwa-Oasis. The width of the tracks increases generally in this area due to connection or branching of the sandstone ridges meanwhile the ridges are becoming shorter. The Nubia Sandstone bedrock of the floor of the tracks between sandstone ridges is composed of quartz sandstone, brown in color due to disseminated iron oxides , but the quartz grains are still well sorted and having rounded edges. The area shows evidence of attack by the northeastern distributaries of the old river delta of Wadi Balatah in northeastern Libya, thus leading to the destruction or distortion of the Sandstone ridges and the development of wide intertwined or branched plains (Figs 4C-D). The surface floor in some tracks between ridges becomes wet during winter seasons so that plants become more common and almost situated in parallel arrangement around the exposed bed rock, thus suggestive of near-surface groundwater seepage.

Fig. 10: A-D- Small yardangs of bedded, highly jointed sandstone up to ~6 meters height belonging to Taref Formation are sporadically exposed over the Sabaya bedrock in the flat depressions near the steep walls of the plateaus. These outcrops are made up of a thin (0.3-0.4 m thick) basal brown bed of clayey sandstone containing poorly sorted quartz grains mingled with brown rock debris of gravel size, and an upper thick-bedded white yellowish to greyish quartz sandstone made up of rounded, coarse to medium quartz grains with erratic silica debris.

Further northward of Lat. 28º 30′, The desert plants become much more dense and structurally controlled, being almost arranged in rows along the sides of the tracks (Fig. 11D). The floor of the tracks become well exposed, fully made up of eroded and washed Nubia Sandstone which in turn becomes discontinuously covered by wedges and thin sheets of hard grey shiny unfossiliferous limestone (Fig. 11 C) belonging to the lower part of the Middle Miocene Marmarica Formation of Said (1962). The limestone sheets show a progressive increase in both thickness and areal distribution northward towards Siwa where they change into fossiliferous limestone rich in echinoides belonging to the middle part of Marmarica Formation at the vicinity of Siwa Oasis.

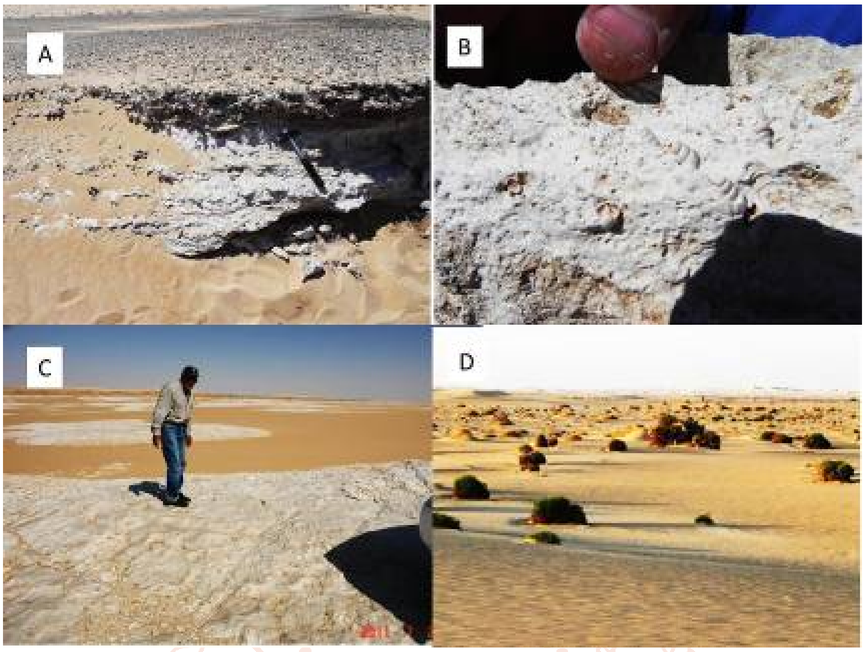

Fig. 11: A-B- Well-eroded hummocks of no more one meter height, made up of thin horizontal beds of white carbonate (~60 cm thick) crowded by fresh water gastropods (B) and overlain by a thin conglomeratic (~40cm thick) representing temporary accumulation of excess fresh water lake deposits in low-lying depressions in the Great Sand Sea north. C- Wedges and thin sheets of hard grey shiny unfossiliferous limestone belonging to the lower part of the Middle Miocene Marmarica Formation overlying unconformably the Nubia Sandstone bedrock (Sabaya Formation) in the northernmost part of the Great Sand Sea to the north of Lat. 28^0 30. D- Desert plants become much dense and structurally controlled, being almost arranged in rows along the sides of the tracks at the southern limit of Siwa Oasis.

Thus, the new data from the Great Sand Sea necessitate the modification of the map of the Nubia Sandstone Aquifer System in Egypt which previously presented by CEDARE (2002) and compiled by Bakhbakhi (2006). The Nubia Sandstone which is exposed on the surface of the western part of the Western Desert (west of Long. 27^0) should be extended northward up to the southern limit of Siwa Oasis (Fig. 12).

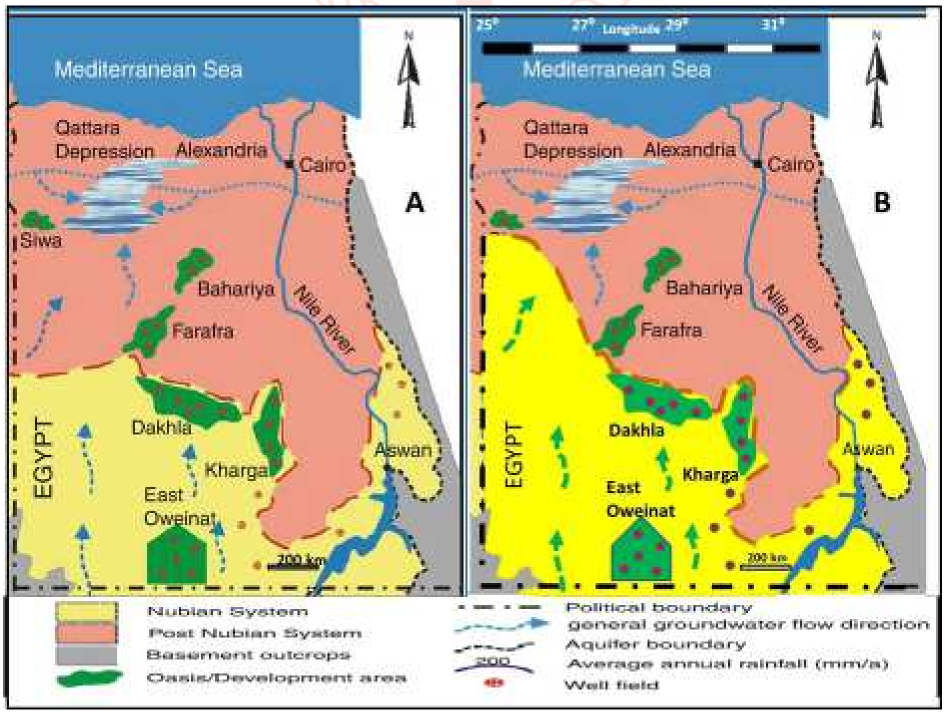

Fig.12: A- Regional surface exposures of the Nubia Sandstone in Egypt, after CEDARE (2002) and Bakhbakhi (2006). B- The same map, after being modified according to the results of the present work.

7. Conclusion

The author supports the continued usage of the historical name of the Nubia Sandstone or Nubia Group as previously proposed by many workers since more than 80 years in order to express the natural relations of a number of associated sandstone formations. These formations are made up predominantly of thick continental Paleozoic-Mesozoic sandstones which were transported and deposited from streams of old river systems that partly flowed in freshwater lakes in regional continental basins, and which were discontinuously interrupted by periods of uplifting and erosion, and intermittently influenced, in places, by marginal marine episodes and periods of soil formation.

The interruptions of the sandstone sequence by episodes of non- deposition and intense erosion, or intergradation of another rock unit particularly in areas where intermittent pulses of marine transgression accompanied the accumulation of fluviatile sandstone during the same time, are good reasons supporting the recognition of a number of rock units of lower rank (Formation) within the main sequence of the Nubia Group. However, they are not reasons for restriction or elimination of the Nubia Group (or Nubia Sandstone) which has been deeply entrenched in the Egyptian, Libyan, Sudanese and Chad lithostratigraphy. The time duration of the entire sequence of the Nubia Group or the time span exhibited by the different rock members of this Group play no part in differentiating or determining the boundaries of the lithostratigraphic unitswhatever their rank.The predominant continental history of the sandstone sequence belonging to this group came to an end during the Santonian where permanent marine environment prevailed during Campanian-Ypresian in southern Egypt.

In the eastern part of the Western Desert (east of Long.27^0) the Nubia Sandstone sequence is made up of three thick predominantly fluviatile Mesozoic sandstone units namely from older to younger: Six Hills, Sabaya and Taref formations, intercalated with two thin near-shore clastic units namely from older to younger: Abu Ballas and Maghrabi formations. The sediments of this group range in age from the Lower cretaceous (Berriasian) to the lower part of the Upper Cretaceous (Cenomanian-Turonian). They overlap unconformably the Precambrian basement rocks and covered by a fully marine sequence related to the climax of the Campanian-Ypresian transgression (i.e. Quseir Formation-Duwi Phosphate - Dakhla Shale - Tarawan Chalk - Esna Shale-Thebes Limestone).

In the western part of the Western Desert, west of Long. 27^0 and south of Lat. 28º 30, the Nubia Group is made up of a Paleozoic fluviatile sandstone sequence which is interrupted with shallow marine horizons of claystone, shale and sandstone, and overlain unconformably by a predominantly fluviatile Mesozoic sandstone sequence represented by Six Hills, Sabaya and Taref formations. Neither Abu Ballas, nor Maghrabi Formation is recorded in this province.This means that accumulation of the material assigned to the Nubia Group has begun much earlier and ended slightly younger in the west than in the east of Long. 27º, and consequently the different members of this group could be represented anywhere by either relatively short or long stratigraphic interval. The Paleozoic lithostratigraphic units in this province include from top to bottom, Lakia,Northern Wadi Malik, Wadi Malik, Tadrart, Umm Ras, and Karkur Talh formations.

One of the most interesting conclusions is that the Great Sand Sea which occupies the western part of the Western Desert between the Gilf El Kebir Plateau (at south) and the Siwa Oasis (at north) is not consisting of Pleistocene-Recent sand dunes as previously described and wrongly mapped in the geologic map of Egypt. It is essentially made up of a series of parallel longitudinalNubiaSandstoneridges that are structurally controlled and extending north northwest-south-southeast. The ridges extend for a long distance ranging between 80 and 240 km and have a height ranging between 30 and 70 m above surface floor. They represent a series of bended (up-folded), cross-bedded to horizontal Nubia Sandstone layers belonging to the younger members of the Cretaceous Nubia Sandstone Group (Sabaya Formation and partly Taref Formation) separated by low-lying flat tracks (500- 2500 m wide)and later subjected to intense fracturing and long-period erosion. The sandstone ridges are highly jointed, and intensively attacked by groundwater sapping process. They become twisted and corrupted near the Egyptian/Libyan as a result of invasion of old (Pleistocene) river systems. The ridges and tracks between them are covered by a thin veneer of free, brownish to yellowish sands originating from the disintegration and breakdown of the Nubia Sandstone bedrock. The sand veneer attains a thickness of 3-5 cm, sometimes reaching up 10-15 cm, thus obscuring the original sandstone bedrock, but do not hinder the movement of cars over it.

The area of the Great Sand Sea exhibits a long history of predominantly continental sandstone accumulation and continuous subsiding followed by a long period of active erosion since the uppermost Cretaceous. This is indicated by the great thickness of the Paleozoic-Mesozoic sequence of the Nubia Group which reaches up 3500 m in the subsurface of the Great Sand Sea. In the area between latitudes 26º Nand 28º N the sandstone ridges were subjected to intense uplifting and faulting during the Oligocene leading to the development of two sandstone mountain ranges, each one is made up of broad flat-topped plateaus or domes (180 m high and 60 km long) and wide flat depressions (63 km^2 to 1616 km^2. in area) running northeast-southwest in parallel lines which are oblique (~45^0) to the long axes of the pre-existing sandstone ridges. The vast depressions represent down-faulted blocks sliding towards the northeast and extend for many kilometers long and wide while the plateaus form uplifted flat-topped blocks between the depressions, thus being different from the previously known depressions in the Western Desert. The bedrock of all these new landforms belongs to the Sabaya Formation. The Taref Formation is almost entirely eroded leaving remnants and elongated yardangs (up to 6 meters high) of bedded, highly jointed sandstone.Beside the structurally formed landforms, there are two major flat sandy plains (1687-3030 km^2) along the Egyptian/Libyan borders (between latitudes 25^0 45′ and 27^0 45′) drained by old river systems which strongly affecting and removing the pre-existing sandstone ridges.

Northward of Latitude 28^0 25′ the Nubia Sandstone ridges decrease in length to 23-35 km until becoming very short and intensively interrupt south of Siwa-Oasis. The width of the tracks increases generally in this area due to connection or branching of the sandstone ridges, meanwhile the ridges are becoming shorter. Further northward of Lat. 28º 30′, the Nubia Sandstone bedrock becomes discontinuously covered by wedges and thin sheets of hard grey shiny unfossiliferous limestone belonging to the lower part of the Middle Miocene

Marmarica Formation. The limestone sheets show a progressive increase in both thickness and areal distribution northward towards Siwa Oasis. On this basis the author recommends modifying the geological map of Egypt in line with the field reality, which is that the Nubian sandstone covers the entire surface of the area known as the Great Sand Sea and which lies to the west of Long. 27^0 between the Gilf Kebir in the south and the Siwa Oasis in the north.

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