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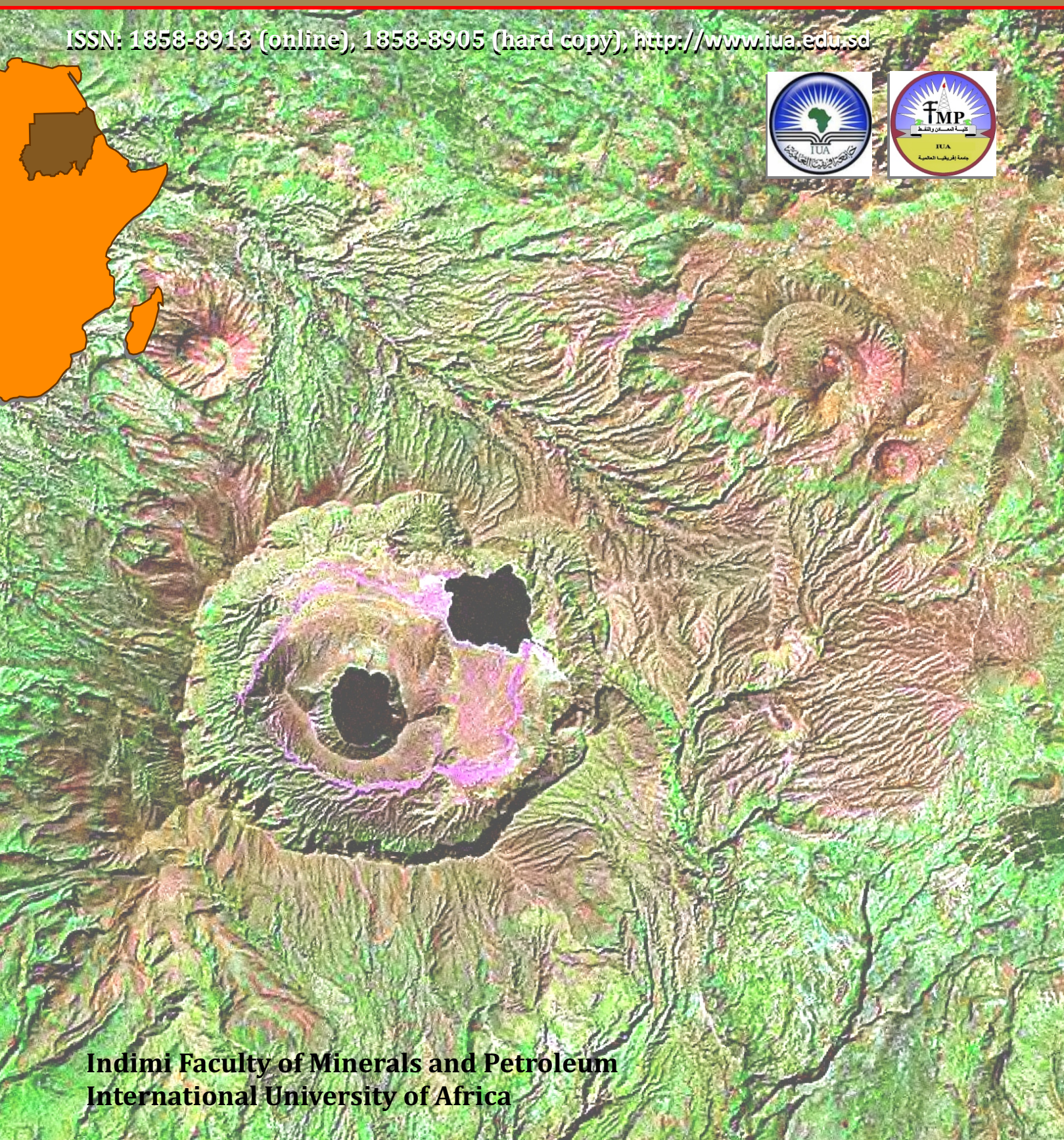

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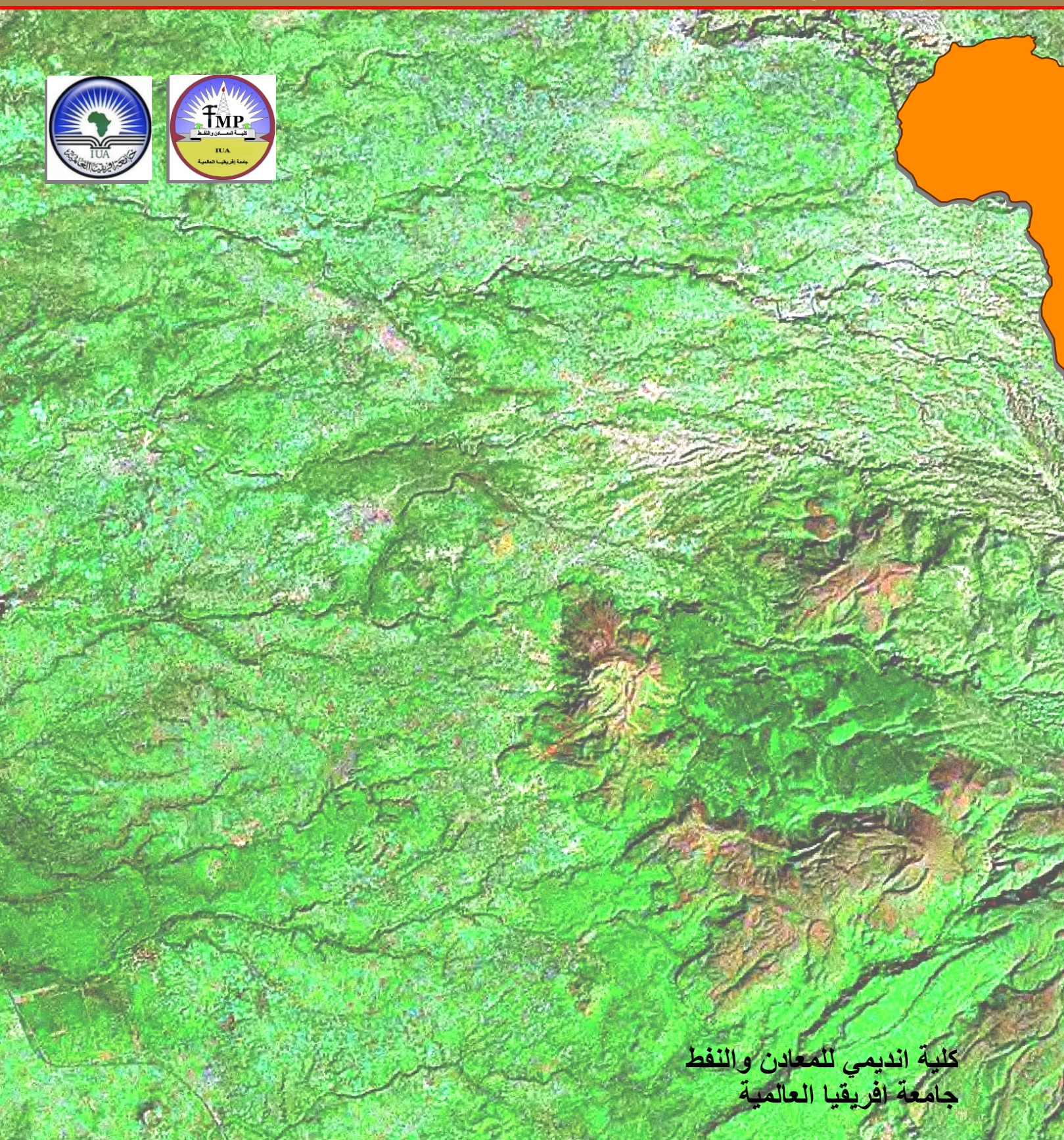

كلية انديمي للمعادن والنفط
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Paleographic Development During the Deposition of the Clastic Sediments around Wadi Halfa and Argeen Areas Northern Sudan

Elamein A. M.[1], Nafi. M.[2] and Ali O. E.[2]

[1]Department of Petroleum Geology, Faculty of Earth Sciences and Mining, University of Dongola, Dongola, Sudan

[2]Indimi Faculty of Minerals and Petroleum, International University of Africa, Khartoum, Sudan

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Abstract

The study was carried out on the clastic sections around Wadi Halfa and Argeen areas, Northern Sudan. The objective of the study is to infer the paleogeographic situation during the deposition of these sediments. Stragraphic investigations classified these sediments into two stratigraphic units: Late Carboniferous Gilf Kebir Formation and Permotriassic - Early Jurassic Lakia Formation. Based on sedimentological and stragraphic studies these two stratigraphic units are equivalent to Wadi Halfa Oolitic Ironstone Formation. New findings of marine trace fossils in the sediments of the study area indicate that the Late Carboniferous period is characterized by high sea level invading the study area from the north. This situation allowed the deposition of thin layers of sandstones, claystones and oolitic ironstones of shallow marine environments intercalating with thick deposits of fluvial origin. The reactivation of the many E-W faults dissected the study area during Late Carboniferous; created negative relief areas filled by continental and shallow marine sediments belonging to Wadi Halfa Oolitic ironstone Formation. The new discovery of Paleozoic strata around Wadi Halfa and Argeen areas marks an extreme change in the previous thinking on Paleozoic section of Sudan.

Keywords: Gilf Kebir Formation, Lakia Formation, paleogeography, Wadi Halfa Oolitic Ironstone Formation.

1. Introduction

The study area is located in Wadi - Halfa and Argeen areas, extending east and west of the River Nile. It is bounded by the latitudes N 21° 25’ 53.4 & 21° 59' 50.8″ and longitudes E 30° 49' 23.1 ″ & 31° 54'2.2 ″; covering an area of approximately 5,472 Km2 (Fig.1). The area is very easy to access through the paved highway road from Khartoum to Wadi Halfa via Dongola and Elselem, or form Port Sudan via Atbara and Merowe to Elselem - Wadi Halfa. Also it can be reached by airplane from Khartoum. Moreover, the area is accessible through railways connecting Port Sudan – Atbara - Wadi Halfa, Khartoum – Atbara - Wadi Halfa and with boat from Aswan (Egypt) to Wadi Halfa (Fig.1).

2. Regional Geology

The geological column for the study area is relatively simple (Fig. 2), the oldest units belongs to what is generally referred to as the basement complex rocks, most of which are Precambrian. The basement rocks are unconformably overlain by Paleozoic, Mesozoic, and Cenozoic sediments of continental and marine environments. Based on sedimentological and stratigraphic studies Elamein (2015) classified the clastic section of the study area into two main stratigraphic units Late Carboniferous Gilf Kebir Formation following (Issawi and jux,1982) and Permotriassic-Early Jurassic Lakia Formation following Klitzsch and Lejal-Nicol (1984). Nafi et al. (2015) renamed the Late Carboniferous-Permotriassic-Early Jurassic strata in the study area as Wadi Halfa Oolitic Ironstone Formation.

The Gilf Kebir Formation is composed mainly of trough crossed bedded micaceous sandstone facies, oolitic ironstone facies, paleosole beds and contains plant and ichno fossils. These clastic sediments seem to have been deposited in shallow marine to fluvial environment. Lakia Formation consists of trough cross bedded pebbly kaolinitic sandstone intercalated with some horizon of paleosols and contains silicified tree trunks and plant remains.

Fig. 1. Location map of the study area.

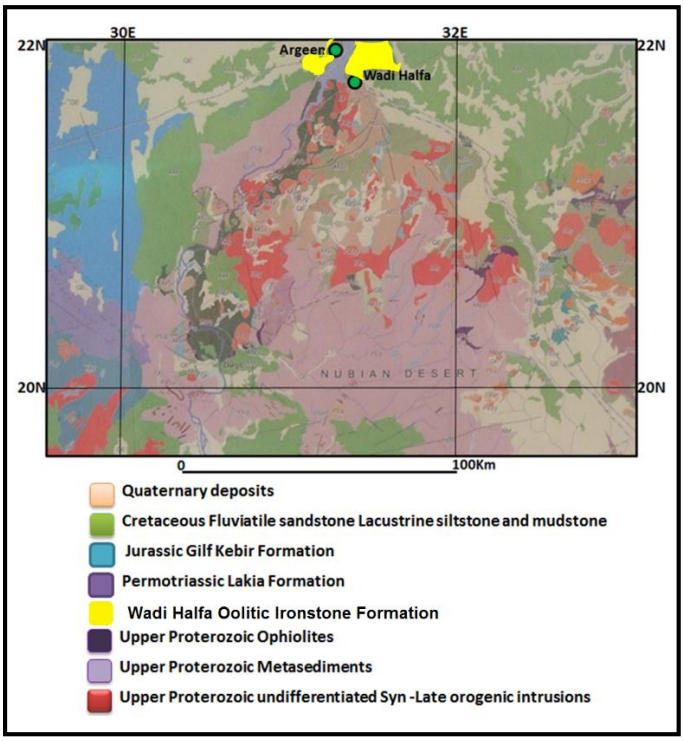


Fig. 2. Geological map of the study area (modified from geological map of the Sudan 2004).

3. Problem Statement

Information on the geology of the study area is until recently, relatively scarce due to its remote location in the far northern Sudan. According to Semtner and Klitzsch (1994) this area was either regionally high extending from Sudan through Egypt to the northern edge of Gondwana during the Early Paleozoic, or they were eroded and transported to the south Lakia Formation in Sudan. Klitzsch and Wycisk, 1987; Klitzsch and Squyers, 1990 concluded that the sediments of the study area belong to fluvial and lacustrine deposits equivalent to Wadi Hower Formation of Cretaceous age. In fact, the above mentioned statements are not true, since the Paleozoic sediments have been recorded from south east of Aswan, south Egypt (Issawi and Osman, 1996). Moreover, recent work in the northern Sudan, such as the study area, depicted the presence of marine and continental Paleozoic sediments of Late Carboniferous to Permotriassic-Early Jurassic age named Wadi Halfa Oolitic Ironstone Formation (Nafi et al., 2015). The expected outcome of this study might change the paleogeographic picture during Paleozoic – Early Mesozoic in Northern Sudan.

4. Methodology

The aim of this study is to reconstruct the paleogeographic situation during the deposition of the Late Carboniferous – Permotriassic-Early Jurassic clastic sediments around Wadi Halfa and Argeen area, Northern Sudan. The study involved field investigation in terms of lithofacies analysis using vertical profiles method. Each profile has been photographed, examined, and described in terms of all lithofacies aspects. These include detailed description of lithological composition, fossil content, texture, sedimentary structures, facies thickness and paleocurrent direction.

5. Results

In this study thirteen sedimentary sections (7 around Wadi Halfa and 6 around Argeen) have been examined (Fig. 3). Fifteen lithofacies were defined on the basis of lithological composition, fossil content, texture, sedimentary structures, facies thickness (Table 1). Based on the vertical profiles (Figs. 4 a & b) the clastic sediments of the study area can be divided into three lithofacies associations: Lithofacies association (A) of fluvial origin, lithofacies association (B) represent shallow marine environments and lithofacies association (C) belong to fluvio - glacial environments.

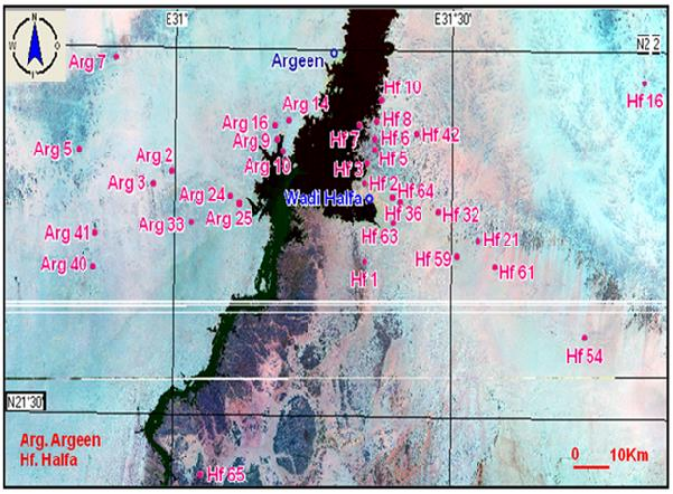
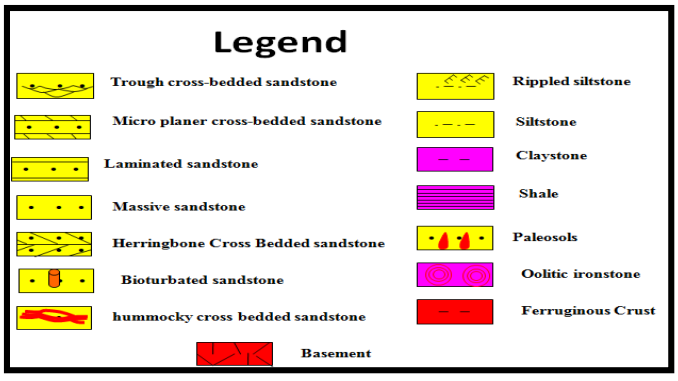


Fig. 3. Satellite image showing the locations of the studied vertical sedimentary profiles.

Table 1. Lithofacies types, abundances, characteristics and corresponding depositional environments

Facies code	Lithofacies type	Sedimentary structure	Total thickness	Total %	Total sand and mud	Sand / mud ratio	Depositional environments
Gm	Gravel	Massive	4.1	0.7	515.1m >90%	15.6:1	Continental sediments of fluvial origin formed by braided rivers and composed of sand bars, floodplains and overbank fine deposits
Gt	Gravel	Trough cross bedding	4	0.7			
St	M/C sandstone	Trough cross bedding	440	76.2			
Sp	M/C sandstone	Planar cross bedding	30	5.2			
Sh	M/C sandstone	Horizontally bedding	18	3.1			
Sm	F/M sandstone	Massive sandstone	18	3.1			
Fr	F/M sandstone	Root structure	1	0.2			
Fl	Mud + clay	Lamination	16	2.8	33m <10%		
Fm	Clay	Massive	17	2.8			
Pa	Paleosole	-	8	1.4			Non depositional period
Foi	Oolitic ironstone	-	10.5	1.8			Shallow marine deposits
Sr	F/ M sandstone	Ripple cross bedding	3	0.5			
Shm	Bioturbated sandstone	Bioturbation	5.5	1			
Fd	Diamictites	-	2	0.3			Glacial sediments



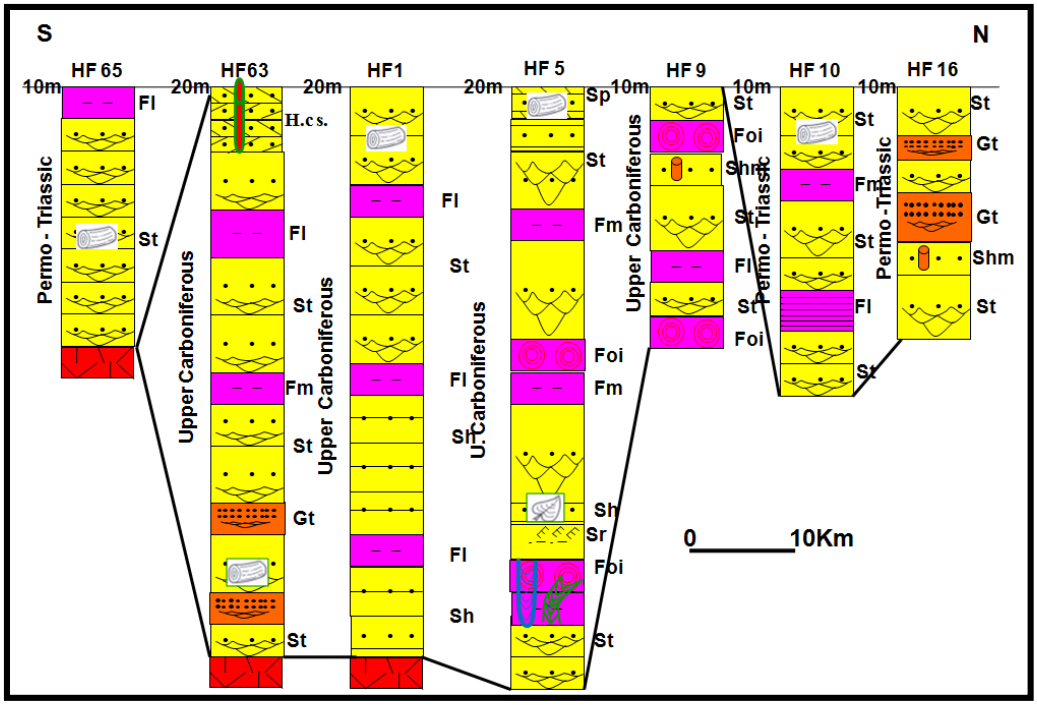


Fig. 4 (a) N-S Litho-and chronostratigraphic correlation profile of the outcropping sediments around Wadi Halfa area.

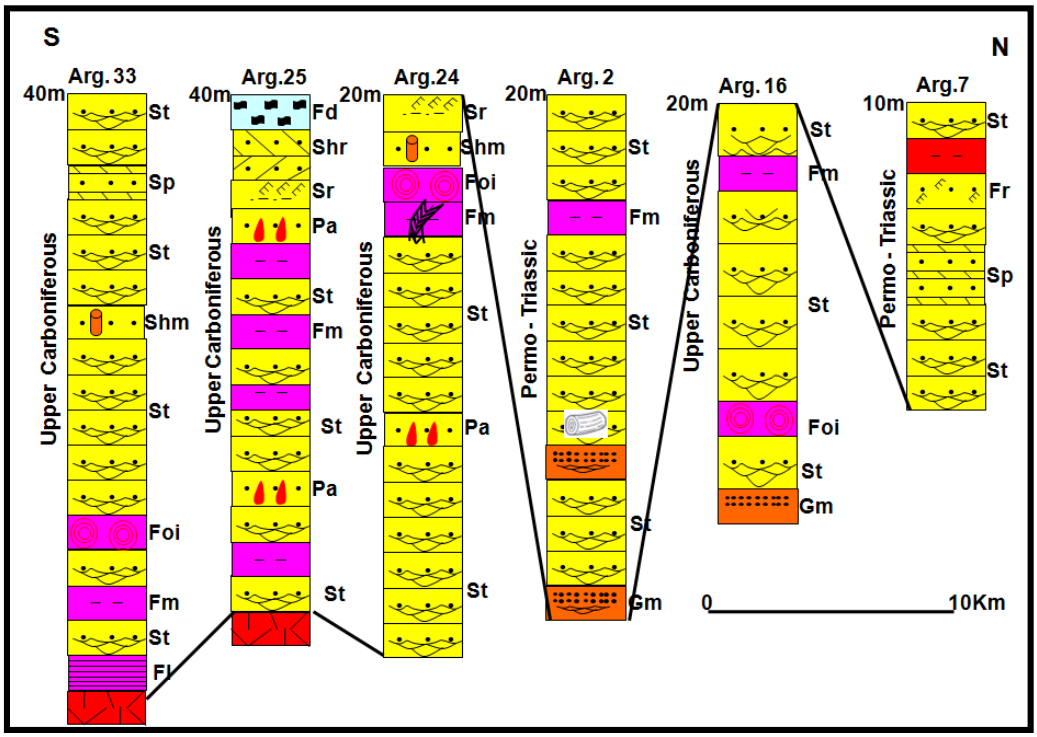


Fig. 4. (b). NW-SE Litho-and chronostratigraphic correlation profile for the outcropping sediments around Argeen area.

6. Fossils Content

During the field work interesting plant and trace fossils were found in Wadi Halfa and Argeen areas. The continental origin of the Late Carboniferous sediments in the study area is indicating by the presence of *Paleoweichselia* aff. *Defrancei* sp. *Calamites* sp., aff. *Sigillaria* sp., *Rhodea*, aff. *Lotzenensis* sp., *Walchia* sp., *Lepidodendron imprint*, and large silicified tree trunks (Plates 1 & 2). Nearshore Late Carboniferous sediments are indicated by the presence of the following trace fossils: *Planolites* sp., *Rhizocorallium* sp., *Skolithos* sp., *Thalassinoides* sp. and indeterminate *worm burrows* (Plate 3).

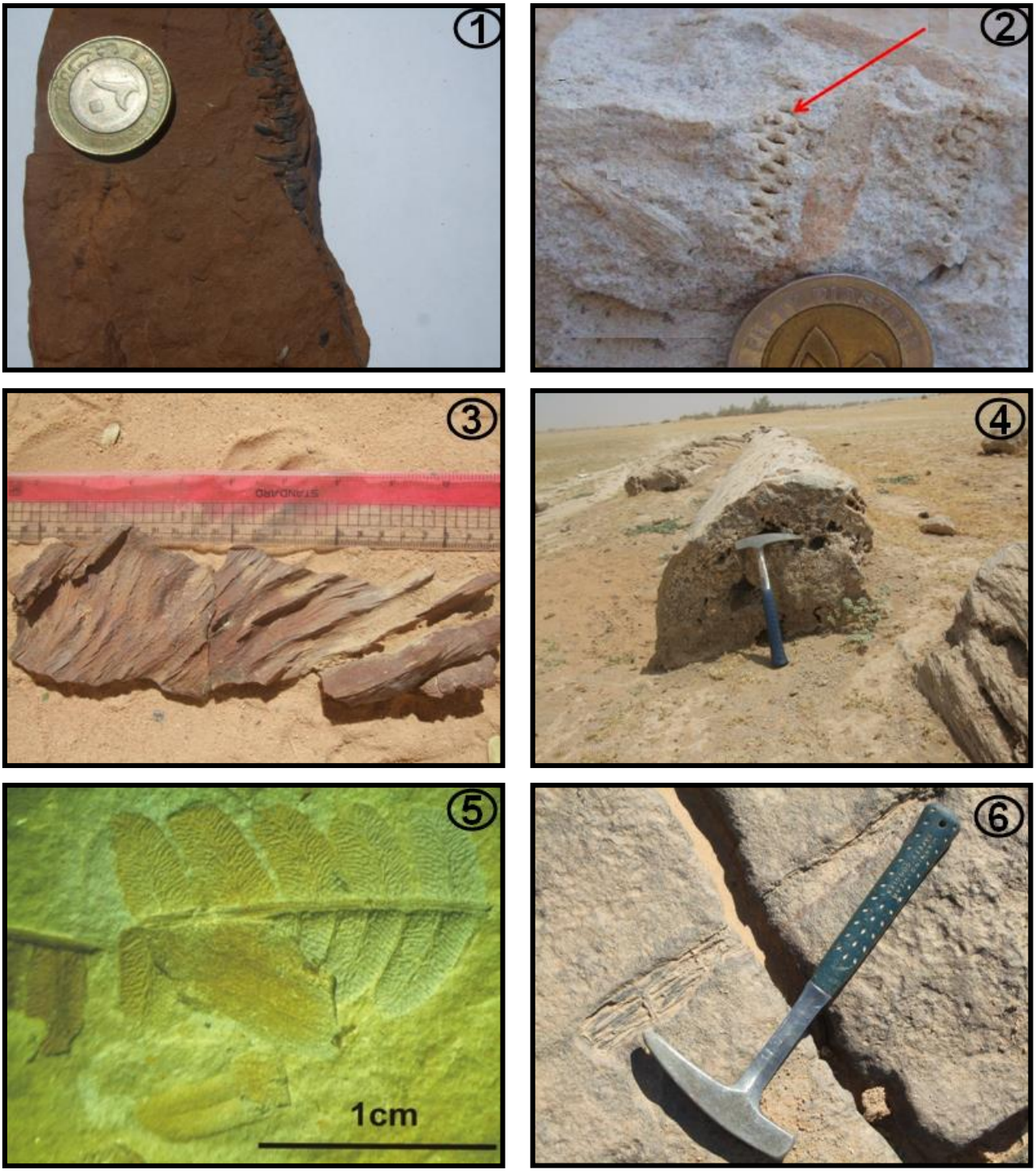


Plate (1):

1. ***Walchia* sp.,** Late Carboniferous terrestrial environment, Argeen area, North Sudan
2. ***Walchia* sp**., Late Carboniferous, Gilf Kebir Formation Wadi Halfa area.
3. ***Lepidodendron imprints*** Late Carboniferous, Gilf Kebir Formation Wadi Halfa area.
4. **Large silicified tree trunk**, Permo-Triassic, Lakia Formation Argeen area, North Sudan
5. ***Paleoweichselia* aff. *Defrancei* sp.** Late Carboniferous, Gilf Kebir Formation, Wadi Halfa area, North Sudan
6. ***Calamites* sp**., late Carboniferous), Gilf Kebir Formation, Wadi Halfa area, North Sudan

Plate (2):

1 & 2. ***Aff. Sigillaria* sp.,** Late Carboniferous, Gilf Kebir Formation, Wadi Halfa area,
3**. *Calamites* sp.**, Late Carboniferous, Gilf Kebir Formation, Wadi Halfa area,
4. ***Rhodea* aff. *Lotzenensis* sp.** Late Carboniferous, Gilf Kebir Formation, Wadi Halfa area
5. ***Rhodea* aff. *Lotzenensis* sp.** Late Carboniferous, Gilf Kebir Formation, Argeen area, North Sudan
6. ***Paleoweichselia* aff. *Defrancei* sp.** Late Carboniferous, Gilf Kebir Formation, Wadi Halfa area.

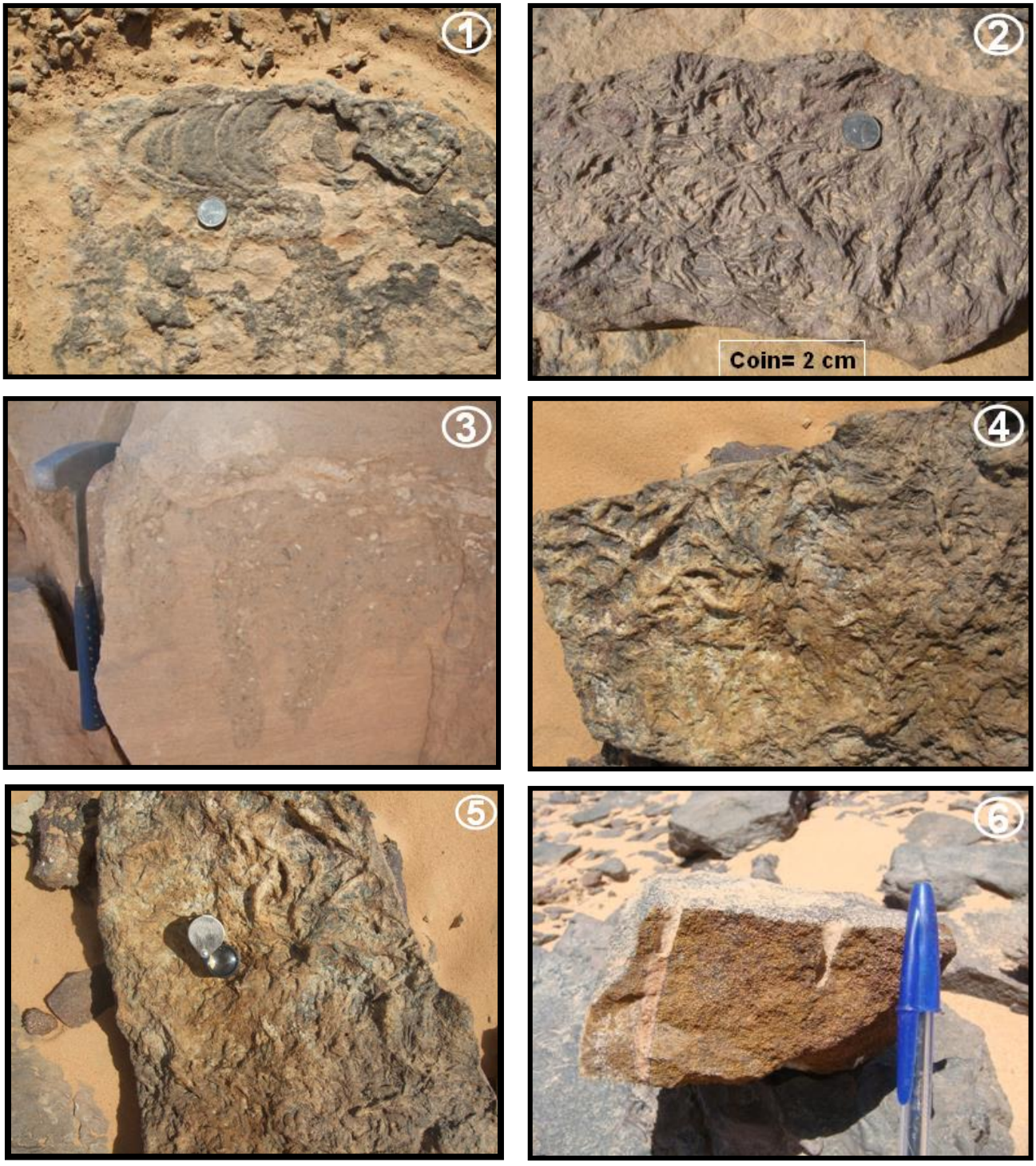


Plate (3):

1. ***Rhizocorallium* sp.** 2. ***Planolites* sp.**, shallow marine environment ,Late Carboniferous, Gilf Kebir Formation, Wadi Halfa area, North Sudan. 3. ***Skolithos* sp.**, represents nearshore marine environment, Late Carboniferous, Gilf Kebir Formation Wadi Halfa area, North Sudan. 4. ***Indeterminate worm burrows***, ,Late Carboniferous, Gilf Kebir Formation shallow marine environment, Wadi Halfa area North Sudan. 5. ***Planolites* sp.** shallow marine environment ,Late Carboniferous, Gilf Kebir Formation Argeen area. 6. Oolitic Ironstone contains ***Skolithos* sp.**, represents nearshore marine environment, Late Carboniferous, Wadi Halfa area, North Sudan

7. Discussion and Interpretation of the Results

Published sedimentological studies in northern Sudan (eg. Klitzsch and Wycisk, 1987; Klitzsch and Squyers, 1990; Barazi, 1989; Semtner, 1993; Wycisk et al., 1990; Nafi et al.,2009; Nafi et al., 2011 and Nafi et al.,2015). Klitzsch and Squyers (1990) concluded that during Paleozoic a regional high extended from northern Sudan via Egypt to northern edge of Gondwana and trending NNW – SSE to almost N- S. This regional high controlled the deposition of shallow marine facies which thought to be restricted in northwestern and northeastern parts of Sudan (Fig. 5).

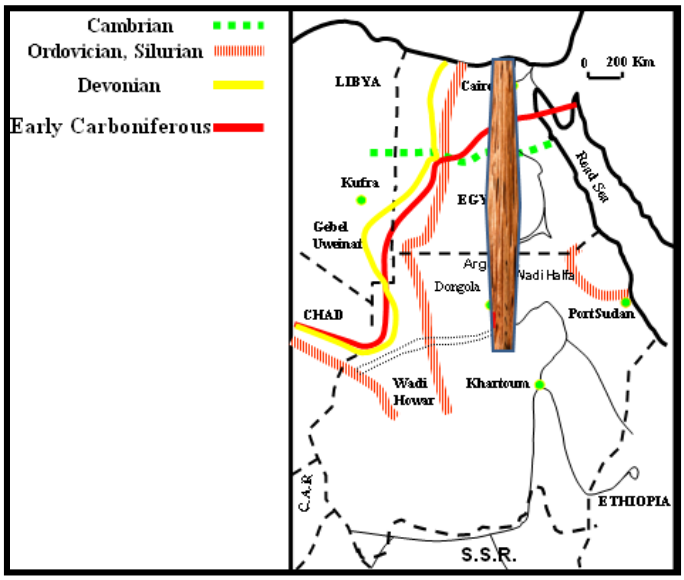


Fig. 5. Paleozoic regional high extended from northern Sudan via Egypt to northern edge of Gondwana after (Klitzsch and Squyers, (1990); Nafi et al., 2009; Nafi et al., 2011)

Klitzsch and Wycisk (1987) summarized the Paleogeographic developments during Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permo-Triassic times in Egypt and northern Sudan (Fig. 6). They showed that the Cambrian transgression was confined only in northern Egypt but not further to the south, while during Ordovician and Silurian times the sea transgressed from western direction from Egypt through Jebel Uweinat southward to Wadi Hower in northern Sudan. The sea also transgressed from northeastern and reached northwest Port Sudan in eastern Sudan (Klitzsch and Wycisk, 1987). In Devonian and Carboniferous times, the sea transgressed to northwestern areas of Egypt and extended southwards to cover part of northwestern Sudan. During Permo-Triassic period the transgression is confined only in north Egypt.

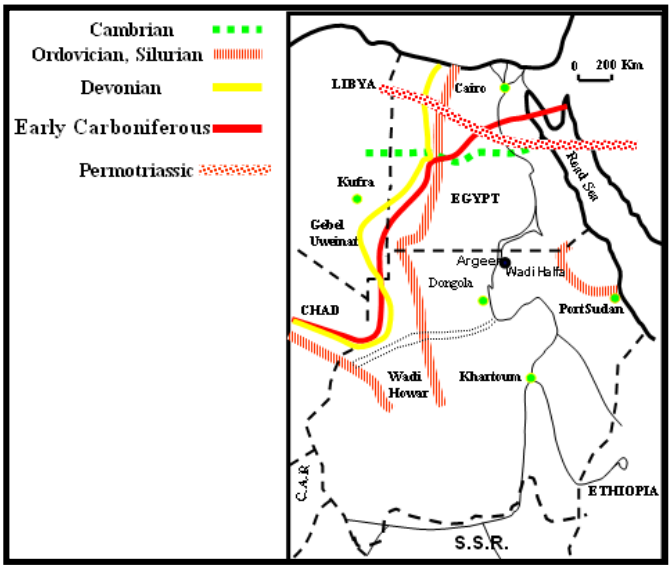


Fig. 6. Maximum sea transgression during Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permo-Triassic times after (Klitzsch and Wycisk, 1987)

Figure (7) shows the Paleogeographic situation in Egypt and northern Sudan during the Jurassic to Paleogene (Klitzsch, and Squyers, 1990). The Aptian-Albian sea (Early Cretaceous) transgressed into the area around Abu Simble (Egypt) and Wadi Halfa and probably further to the south (Klitzsch and Wycisk, 1987).

During the Cenomanian time (Late Cretaceous), the sea transgressed from Sirte Basin in Libya eastward into northern Egypt and from there southwards to the Sudanese-Egyptian border, but did not extend as far southward as the Aptian Sea (Klitzsch and Wycisk, 1987). The Campanian-Maastrichtian to Early Eocene sea entered large parts of Aswan-Kharga (Egypt) high as far southward as Gebel Abyad Plateau in Sudan and extended further south to Hamrat El Wuz area of northern Kordofan (Barazi, 1989; Klitzsch and Wycisk, 1987; Barazi and Fiedler-Volmer, 1993).

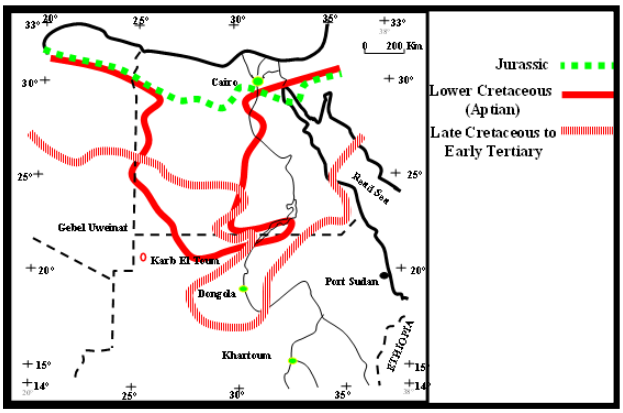


Fig. 7. The Paleogeographic map during Jurassic to Paleogene (Klitzsch, and Squyers, 1990)

Semtner and Klitzsch (1994) stated that, no Paleozoic strata are known from eastern Egypt east of the river Nile and from northern Sudan, due to the North – South trending high which extended from Sudan through Egypt to northern edge of Gondwana during the early Paleozoic. This led the assumption that sea transgression was only from NE and NW directions (Fig. 5). But the above mentioned statement is not actually true for the following reasons:

1. Ahmed et al., (1993); Issawi and Osman, (1996) and Issawi, (2000) recorded Paleozoic sediments south east of Aswan. The typical section at Wadi Gabgaba (south east of Aswan) includes the following units: Gilf Formation (Carboniferous), Wadi Malik Formation (Devonian), Naques and Gabgaba Formations (Early Silurian – Late Ordovician) and Cambrian Araba Formation. Accordingly, paleogeographic map depicting the maximum extension of Paleozoic – Mesozoic transgression has been reconstructed for Egypt (Fig. 8).

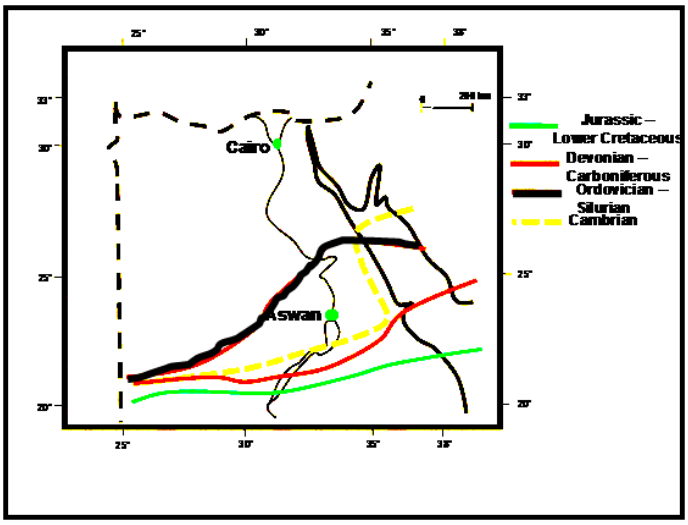


Fig. 8. Maximum extension of Paleozoic-Mesozoic transgression (Issawi and Osman, 1996)

2. Nafi et al. 2009, 2011, 2015 and the current study described occurrence of new Paleozoic strata around Wadi Halfa and Argeen areas. The typical section is located North Wadi Halfa and subdivided into Late Carboniferous Gilf Kebir Formation and Permo-Triassic Lakia Formation which is equivalent to Wadi Halfa Oolitic Ironstone Formation. The Late Carboniferous Gilf Kebir Formation is composed mainly of trough cross bedded micaceous sandstone facies, oolitic ironstone facies and paleosols beds, and contains ichnofossils (Plate 3); and also common plant fossils (Plate 1&2). The Permo-Triassic-Early Jurassic Lakia Formation consists of trough cross bedded pebbly kaolinitic sandstone intercalated with some horizon of paleosols and contains silicified wood and plant remains.

Based on the above mentioned points and the new findings of marine trace fossils (Plate 3) and the plant fossils (Plate 1&2); it is possible to assume that the Late Carboniferous is characterized by high sea level invading the study area from the north through Egypt (Fig. 9).

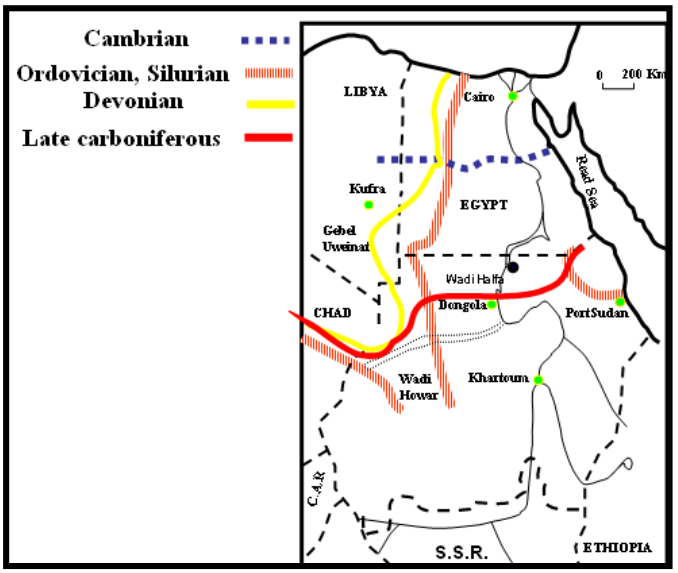


Fig. 9. Paleogeographic map showing the Maximum transgression during the Late Carboniferous time

The structural pattern in NE Africa plate during Paleozoic-Mesozoic shows that the African continent was in a state of extension from the Early Mesozoic until the recent time. This began with the breaking of Gondwana in the Permo-Triassic and resulting in African continental margins and several of intra-continental rift basins. These basins are located mainly in older (Late Proterozoic) shear zones (Janssen et. al., 1993). In the Late Carboniferous, the collision of Gondwana with North Continent initiated on ENE structures by re-opening of pre-existing zone, and the rising magma caused the uplift in Jebel Uweinat area. During this period extensive basins were developed and filled gradually with fluvial sandstone and conglomerate of Permo-triassic-Early Jurassic age (Lakia Formation). The structural regime controlling sedimentation and basin differentiation since the Late Carboniferous continued until Early to Middle Jurassic (Schandelmeier et. al. 1987). Uplift of south east Egypt started in post Carboniferous times and reached its maximum during the Turonian when south Egypt was a positive high land (Issawi and Osman, 1996). The major uplift which occurred during this period resulted in marine regression through a long period of time over south Egypt. The reactivation of the many E-W faults dissected the study area during Late Carboniferous, created negative areas filled by continental sediments belonging to Permo-Triassic-Early Jurassic Lakia Formation which overlies strata of Late Carboniferous Gilf Kebir Formation. These sediments composed of sandstones, siltstones, and claystones locally contain rootlet structures indicating paleosols

development. These facies association are intercalated with thicker paleosols at the top of the rock succession, and consist of large silicified tree trunks in different parts of the section including the basal part. These fluvial sediments unconformably overlying the Late Carboniferous Gilf Kebir Formation, and are consisting of sequences formed by braided rivers. These facies had been changed laterally northwards into meandering rivers of low sinuosity and thin layers of paleosole are present at the top of succession. Moreover, not far from the SW corner of the study area Dr. Nafi, University of Dongola found an interesting plant fossil of Permo-Triassic to Early Jurassic age *(Pterophyllum nubiense*) at the top of Jebel Toshka, northern Sudan (Pers. Comm.; Fig.10). Following Klitzsch and Lejal-Nicol (1984) these sediments are assigned to Lakia Formation (Fig.11).

Fig. 10. *Pterophyllum nubiense.*, Permo-Triassic- Early Jurassic Lakia Formation Jebel Toshka, Northern Sudan (This photo is published after a kind permission from Dr. Nafi, University of Dongola).

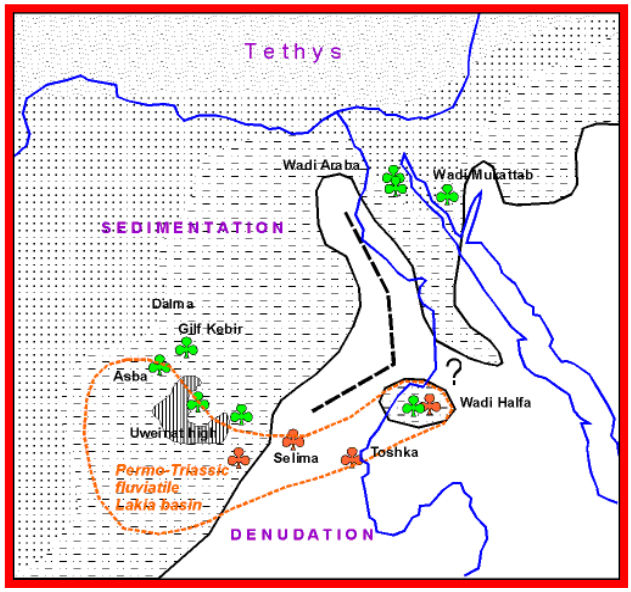


Fig. 11. The proposed Permo-Triassic paleogeographic situation including the study area (after Brügge, 2009).

8. Conclusions

1. The study was carried out on the clastic section around Wadi - Halfa and Argeen areas, Northern Sudan; to deduce the paleogeographic situation during the deposition of these sediments.

2. The sediments of the study area were classified into two stratigraphic units; Gilf Kebir and Lakia Formations and are equivalent to Wadi Halfa Oolitic Ironstone Formation.

3. The most interesting marine trace fossils found in the sediments of the study area indicate that the Late Carboniferous period is characterized by high sea level invading the study area from the north. This situation allowed deposition of thin layers of sandstones, claystones and oolitic ironstones suggesting shallow marine environments intercalated with thick deposits of fluvial origin (Gilf Kebir Formation).

4. The reactivation of the many E-W faults dissected the study area during Late Carboniferous, created negative areas filled by continental sediments belonging to Permo-Triassic-Early Jurassic Lakia Formation.

5. Since Carboniferous through Permo-Triassic the studied area was built up by large extent sheet – like sandstone units formed by vertical and lateral stacking of fluvial sandstone bodies as well as by amalgamation of fluvial sequences from mainly braided to low –sinuosity rivers and sandy nearshore deposits.

6. The new discovery of Paleozoic strata around Wadi Halfa and Argeen areas marks an extreme change in the previous thinking on Paleozoic section of Sudan.

7. The outcome of this study might change the paleogeographic picture during Paleozoic – Early Mesozoic in Northern Sudan.

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