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Plate tectonics and cratonal geology in Northeast Africa (Egypt, Sudan)

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With 7 figures.

Zusammenfassung

Die Klärung der stratigraphischen Stellung der Sedimentserien Nubiens hat zusammen mit den Ergebnissen sedimentologischer, tektonischer und petrologischer Untersuchungen Einblicke in die Entwicklung dieses kratonalen Gebietes zur Folge, die bisher nicht möglich waren.

Die bekannten globaltektonischen Großereignisse haben danach seit dem frühen Paläozoikum auf dem Ostsahara Kraton die Verteilung von Abtragungs- und Ablagerungsgebieten entscheidend beeinflußt und waren dort von bruchtektonischen Vorgängen und magmatischen Ereignissen begleitet.

Danach bestand im Paläozoikum bis ins Karbon ein WSW-ENE gerichtetes Dehnungsrelief mit daraus resultierender Anordnung entsprechend NNW-SSE gerichteter Großschollen. Die Kollision Gondwanas mit den Nordkontinenten hatte im Karbon Aufwölbung von Teilen des Ostsahara Kratons entlang einer Ost-West Achse zur Folge, begleitet von Ost-West gerichteten Bruchsystemen und nachfolgend von der Intrusion intermediärer Magmatite.

Eine Folge der Aufwölbung war die völlige Umkehr der Entwässerungssysteme und entsprechende Erosion vorher mit paläozoischen Sedimenten bedeckter Bereiche vor allem Mittel- und Südägyptens. Lokale Vergletscherung im späten Karbon und Karroo-ähnliche Sedimentationsbedingungen bis in den Unterjura waren im Nordsudan eine weitere Folge.

Mit dem Auseinanderbrechen des Superkontinentes Pangea während des Jura stellte sich die bereits im Paläozoikum übliche Nordneigung der Ostsaharatafel wieder ein, neue bruchtektonische Elemente entwickelten sich, und es kam zu erneuter Umkehr der Haupt-Entwässerungsrichtung und damit zur Annäherung an die heutige Situation. Differenzierter Widerstand gegen die Nordrift der Ostsaharaplatte führte schließlich zur Abtrennung Arabiens und damit zur Entwicklung des Grabensystems Rotes Meer – Akaba – Suez.

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Abstract

The stratigraphical interpretation of the strata of Nubia allows for the first time – in connection with structural, petrological and sedimentological investigations – to reconstruct the geological development of this cratonal area. After cratonization during the PanAfrican event, extensional trends in WSW-ENE direction caused a structural relief, striking NNW-SSE. The collision between Gondwana and the northern continents during the Carboniferous resulted in the uplifting of large parts of the northeast African Plate and was accompanied by more or less East-West striking faults and magmatic intrusions. Erosion of Paleozoic sediments in middle and southern Egypt and reversal of the main drainage direction was the consequence. This caused deposition of Karroo-type strata in northern Sudan, including glacial deposits at the base along the Sudanes Egyptian border.

The breaking apart of Pangea during Jurassic time led to a northward tilt of NE-Africa again and consequently, the main drainage system began to follow its original northward directions. New structural elements developed, partly following older trends. Differing resistence against the northward drift of northeast Africa including Arabia led to the separation of Arabia from Africa and to the formation of the Red Sea – Gulf of Suez – Gulf of Akaba-Graben system. All major structural events were accompanied by magmatic activity.

Résumé

L'établissement de la stratigraphie de la série sédimentaire de Nubie et des régions voisines, joint aux données récentes sédimentologiques, tectoniques et pétrologiques, permet aujourd'hui de reconstituer l'histoire de ce domaine cratonique, chose qui était jusqu'ici impossible.

Après la cratonisation du Sahara occidental à la fin du cycle panafricain, les événements géodynamiques (tectonique cassante et magmatisme) ont déterminé dans cette région la répartition des aires d'érosion et de sédimentation.

Ainsi au Paléozoïque s'installe une tendance à l'extension dans le sens WSW-ENE qui perdura jusqu'au Carbonifère avec pour conséquence un relief structural d'orientation NNW-SSE. La collision du Gondwana avec les continents septentrionaux au cours du Carbonifère a provoqué le soulèvement d'une grande partie de l'Est saharien, accompagné d'un système de cassures E-W et d'intrusions magmatiques.

Ce soulèvement a eu pour conséquence une inversion complète du système de drainage et l'érosion des sédiments paléozoïques en Egypte moyenne et méridionale. Une autre conséquence a été, dans le Nord du Soudan, l'établissement de glaciers locaux et le dépôt de sédiments de type Karroo.

La dislocation de la Pangée au Jurassique a été accompagnée d'un nouveau basculement vers le Nord du Sahara oriental, avec nouvelle inversion du système de drainage. Finalement, la résistance inégale rencontrée dans sa dérive vers le Nord par la plaque nord-est africaine amena la séparation de l'Arabie avec formation du système des grabens Mer Rouge – Akaba – Suez.

Краткое содержание

На основании данных седиментологических, тектонических и петрологических исследований удалось установить стратиграфию седиментарной серии Нубии, что привело к новым, до сих пор неизвестным, взглядам на развитие этой кратоновой области.
Известные глобально-тектонические большие события имели решающее влияние на кратон восточной Сахары начиная с раннего палеозоя, именно на распределение областей сноса и отложения, и сопровождались, как разрывно-тектоническими процессами, так и магматизмом.
После этого, в палеозое до карбона появился рельеф растяжения, простирающийся в WSW-ENE, и соответствующее (NNW-SSE) расположение больших глыб. Коллизия Гондваны с северными материками в карбоне создала выпячивание частей кратона восточной Сахары вдоль восточно-западной оси, что сопровождалось появлением системы разрывов, простирающихся на E-W и последующей интрузией средних магматитов.
В результате выпячивания произошло полное преобразование системы стоков и соответствующая эрозия среднего и южного Египта, покрытого палеозойскими осадочными породами. Результатом этого были локальное образование глетчеров в позднем карбоне и условия осадконакопления, похожие на таковые периода формации Карру, существовавшие на севере Судана еще и в нижней Юре.
При разломе сверхматерика Пангеи в юрском периоде появилось уже обычное в палеозое наклонение восточной плиты Сахары к северу, появились также новые элементы тектоники разломов, и повторное изменение главного направления стока вод, очень близкое к сегодняшнему. Припятствия северному дрейфу восточной плиты Сахары привели, под конец, к отделению Арабии и развитию системы грабенов Красного моря, Акабы, Суэца.

Introduction

For several years, geoscientists of the two universities of Berlin (West) are engaged in a special research project in Egypt and Sudan. This project is sponsored by German Research Foundation and carried out in cooperation with the General Petroleum Company of Egypt (groundwater division), the Geological Survey of Egypt, the Geological and Mineral Resources Department of Sudan and colleagues of universities in Egypt and Sudan (Asyut, Cairo, Khartoum).

The aim of this project is the reconstruction of the geological development and the groundwater situation of the Eastern Sahara, including paleoclimatic studies and conceptions on possibilities and limits of groundwater use.

It was in the course of basic geological field- and laboratory works that important relations between global tectonic events on one hand and the development of cratonal areas of NE Africa on the other, were found. Thus, the typical development of cratonal areas in structural, sedimentological and paleogeographical respect and the dependence of these developments on platetectonical events became a primary scientific aspect of the project. The project also aims to contribute to the success of IGCP Project 210, »Continental Sediments of Africa«.

The most important key to the understanding of the geology of the Eastern Sahara is the understanding of its stratigraphy. This is the classical area of the so-called Nubian Sandstone, which had the reputation of being barren. Far from really being unfossiliferous, these strata can be subdivided into formations of Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permotriassic to Early Jurassic, Late Jurassic to Early Cretaceous, Middle and Upper Cretaceous age. One of the difficulties to interpret the age of certain units results from the fact that conditions of sedimentation and re-sedimentation have been repeated under similar paleogeographical and climatical circumstances several times within earth's history. Consequently, similarities of facies and partly also of paleontological remains between strata of different age are frequent. Moreover, much of the stratigraphy has to be done on the basis of ichnofossils and plant remains. We have, however, reached a reasonable status of knowledge on the stratigraphy of Nubia and surrounding areas in Egypt. It was important to have the help of several paleontologists to reach this aim: K.-W. BARTHEL, M. GRÖSCHKE & W. HERRMANN-DEGEN (invertebrates), A. LEJAL-NICOL (plants), E. SCHRANK (palynomorphs) and A. SEILACHER (ichnofossils). Stratigraphical results from Nubia have recently been published and summarized (KLITZSCH & LEJAL-NICOL 1984). Other important contributions are from N. BARAZI (1985), R. BOETTCHER (1982), W. DOMINIK (1985), F. HENDRIKS (1985, 1986), P. LUGER (1985), S. SCHAAL (1984), E. SCHRANK (1982, 1983) and P. WYCISK (1986).

Petrological investigations and age-dating of magmatic intrusions related to the different post-Precambrian events are carried out by a team led by G. FRANZ & H. SCHANDELMEIER. This group is also investigating the structural situation in Precambrian time and its influence on the later structural development (BERNAU et al., in press, SCHANDELMEIER 1986). H. W. LINKE (1986) worked on the structural development of the northern Red Sea and the Gulf of Suez area. A large number of articles on research in Nubia has been published in volume 50 of »Berliner Geowissenschaftliche Abhandlungen« (KLITZSCH et al. 1984).

Major Structural Events since the Early Paleozoics

Early Paleozoics to Middle Carboniferous

The major structural event of the Late Precambrian (Pan-African) must have come to an end sometime before the beginning of the Cambrian. In the Um Bogma area on Sinai and in Wadi Qena in the Eastern Desert of Egypt, well preserved trilobite tracks (and in Um Bogma also trilobites) indicate an Early Lower Cambrian age (personal communication SEILACHER) of strata overlying the basement. In both areas, the Cambrian strata were deposited over a very strong unconformity cutting through metasediments and magmatic intrusions, which in some areas in the Eastern Desert of Egypt and in the Red Sea Hills of Sudan are thought to be of Cambrian age. At least for the areas north of Hurghada and for Sinai, it seems to be certain that the latest PanAfrican movements or magmatic intrusions ended long before Cambrian time. Due to these observations we have serious doubts that any of the Cambrian ages given to Pan-African movements or intrusions in northeast Africa are correct. Before Early Cambrian time, much of the PanAfrican was more or less eroded down to a peneplain surface, at least north of 27° northern latitude.

Unfortunately, reconstruction of structural development during the Paleozoics is difficult in northern Sudan and Egypt due to the absence of strata in large areas representing these times. We can, however, recognize similarities with the development in Libya and northern Chad, where the structural development is less difficult (KLITZSCH 1970): it is very likely that there was an extensive trough striking NNW-SSE and an uplift east of it striking parallel. The trough reaches from northern Darfur (see Fig. 1) to the central part of the Kufra Basin and from there possibly further towards the southern edge of the Syrte Basin. Evidence for these postulations is: along Gebel Tageru (south of Wadi Howar in northern Kordofan), we found shallow marine strata of Silurian age (*Harlania harlani* DESIO, *Cruziana accacensis* SEILACHER) overlain by Devonian to Carboniferous strata mainly of fluvial origin. The Silurian beds are the southernmost occurrences of marine Silurian strata found until now in this part of Africa. Their position at the western edge of a NNW trending uplift or high (between northeastern Darfur and Uweinat) indicates an uplift-trough or horst-graben relationship between the two areas. Both structural units trend into an area, for which NNW-SSE trending reliefs have been proven. Geophysical investigations (personal communication, H. BURKHARDT), however, prove that the differentiation between uplift or horst and trough or graben along Wadi Howar is only in the order of some ten to maximum some hundred meters. The Paleozoic Darfur-Kufra Trough or graben is certainly not a rift structure. But it had enough subsidence to allow the Silurian transgression to reach furthern south than in other areas of eastern Africa.

The Darfur to Uweinat Paleozoic uplift or horst striking NNW and parallel to the Darfur-Kufra Trough, is free of Paleozoic strata as far north as the southwestern rim of the Uweinat High: these more northern areas were evidently in a lower position of the generally northward dipping plate and there, parts of the Paleozoic uplifts were covered by a thin sheet of Paleozoic sediments (Ordovician, Silurian, Devonian, Carboniferous, see KLITZSCH & LEJAL-NICOL 1984). Further north, at Gebel Gardeba, Paleozoic strata covered (and still cover) the whole high, but from subsurface evidence it is obvious that the Gebel Gardeba area and even areas further to the NNW within the Syrte Basin were also part of a large Paleozoic high.

East of this Paleozoic Uplift, which could be called the Darfur-Uweinat-Gardeba Uplift, are several structural lows (Fig. 1). Their development unfortunately cannot be reconstructed to a satisfactory degree: while the Abiad Basin is only a very shallow basin or trough filled with Middle Cretaceous to Early Tertiary strata, the Misaha Trough contains several hundred meters of sediments, which are mainly or exclusively of Late Jurassic to Middle Cretaceous age in the northern part or this trough, in the South, these strata are underlain by 200 to 300 meters of

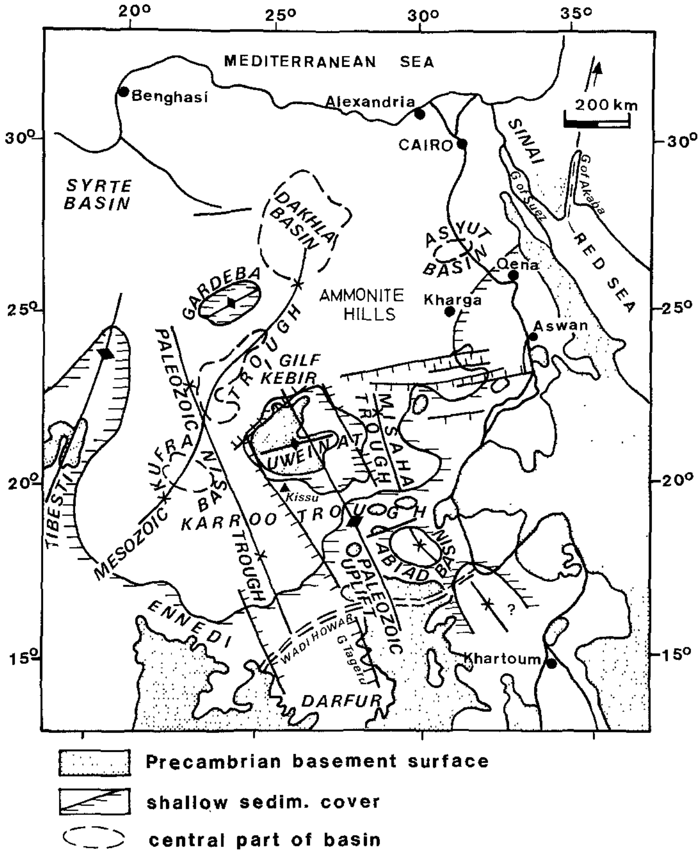


Fig. 1. Map shows major structural elements in southern Egypt, northern Sudan and bordering areas in Libya and Chad. For development of Red Sea – Gulf of Suez area see Figures 5 and 6.

Permotriassic to Lower Jurassic sediments. Thus, it is obvious that the present situation does not prove a Paleozoic age of the Misaha-Abiad Lows. But they might well be placed in areas which were in trough or graben position during the Paleozoics, and were later included in regional uplifting and erosion. The prolongation of the Misaha axes towards NNW leads to the central parts of the Dakhla Basin, which had by far the strongest subsidence during the Paleozoics (about 3000 meters). The prolongation of the Abiad axes towards SSE (towards Khartoum) leads into areas of possibly stronger subsidence during the Cretaceous. Paleozoic strata have not been proven there and are probably absent at the surface. Presence of Paleozoic sediments in more central and deeper parts of this area of subsidence is possible.

In Libya and northern Chad an extension in ENE-WSW direction, resulting in the formation of NNW-SSE striking graben and horst structures is typical for Cambrian and Ordovician time (KLITZSCH 1970). Later, during the Silurian and Devonian, the horsts became the central part of uplifts and the grabens became elongated troughs. Differentiation between high and low structures was relatively high during the Silurian and the Lower Devonian and later lost intensity. It is at least likely that the observations we have from southern Egypt and northern Sudan indicate a similar development.

Magmatic data related to Early Paleozoic tectonics are known from bordering areas in Chad; the Silurian strata at the eastern part of the Ennedi Mountains are full basaltic sills and basaltic flows, similar observations are known from the edges of the NNW-SSE trending southern part of the Murzuk Basin in southern Libya and northeastern Niger.

Late Carboniferous to Early Jurassic

The youngest strata deposited before the strong Carboniferous event are of Viséan age. We found plenty of excellent preserved plant remains of Gondwana characteristics and Viséan age from several places in northern Sudan (southeast of Gebel Kissu), southern Egypt (Gebel Uweinat, Wadi Abd el Malik at the Abu Ras Plateau) and further northwest also at Wadi Dakhal in the Eastern Desert and at the Um Bogma and the Wadi Feiruan areas on Sinai.

After the Viséan almost all of southern and middle Egypt was uplifted and a large part of northeast Africa – probably including most of Sinai and northern parts of Arabia – was tilted southward. Consequently, Paleozoic (and older) strata were removed from a large part of Egypt and transported southward towards the present Wadi Howar area and southwestward towards the southern parts of the Kufra Basin. This uplifting and tilting was accompanied by East-West striking faults, which were locally intruded by intermediate magmatites of Permian to Triassic age (SCHANDELMEIER 1986). Remains of the east-west striking high make up the so-called Uweinat Uplift (or Uweinat-Aswan Uplift), but originally this high extended much further north. South of this high, a shallow east-west trending basin developed, which was mainly filled with Late Carboniferous to Lower Jurassic strata (see Fig. 2).

The collision between Gondwana and parts of the northern continents evidently resulted in a complete re-orientation of structural trends. Many of the fractures or main lineations active at this time were deep-seated or deep-reaching fractures of ages older than the Paleozoics. But it became obvious that the new stressfield caused by the collision of the Gondwana continent with continents north of it mobilized structural patterns, which were passive during most of the Paleozoics. And vice versa, structural elements important during most of Paleozoics lost their function, like the NNW-SSE troughs and uplifts, which were now included in Eastwest or ENE-WSW trending highs and lows (see above and Fig. 1).

The major consequence of the new structural situation was that middle and southern Egypt and all areas south of there came under purely continental conditions. No transgression reached these areas anymore until this structural situation came to an end. Meanwhile, conditions prevailed which were similar to the Karroo in eastern and southern Africa.

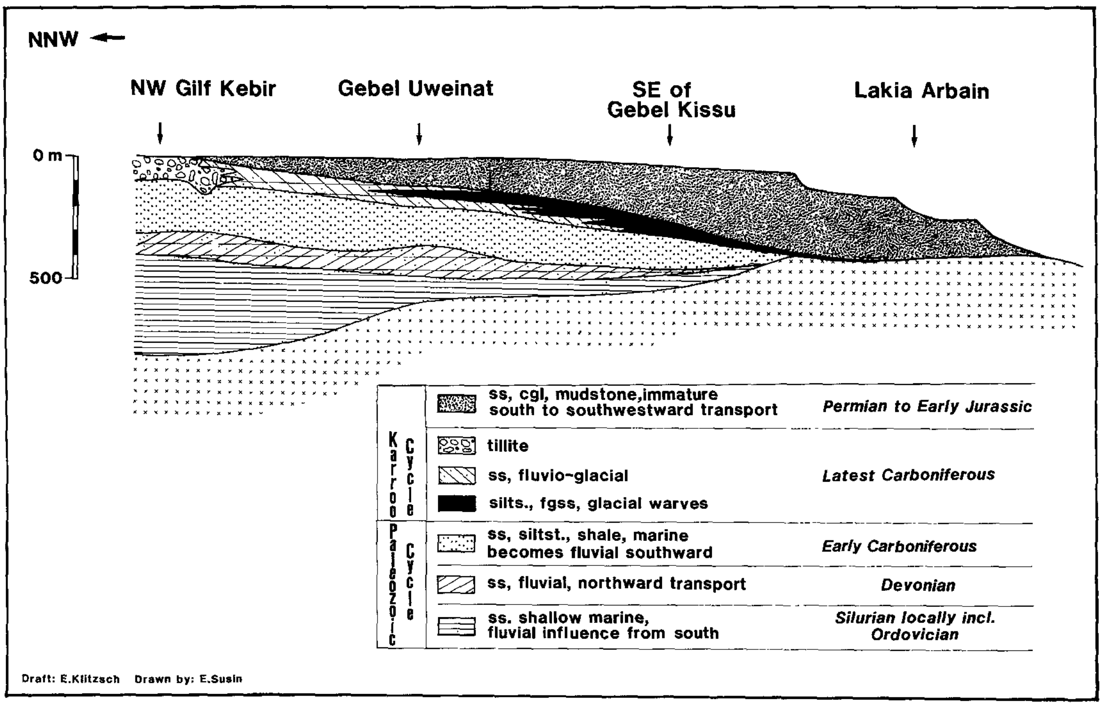


Fig. 2. Schematic section from Abu Ras Plateau (NW Gilf Kebir) to the Lakia Arbain escarpment showing the situation of this area towards the end of Jurassic time. Further east Paleozoic strata were totally eroded (see also Figure 4).

Late Jurassic to Late Cretaceous or Early Tertiary

The disintegration of Pangea, which began during the Jurassic and continued throughout Cretaceous time was the next structural event of importance for the structural as well as for the paleogeographical situation of northeast Africa. The old northward tilt became active again, resulting in a northward structural dip and consequently the south-northward drainage developed again, which had influenced the main direction of continental transport (northward) and the marine transgressions (southward) already during most of the Paleozoic era. At the same time, the old NNW-SSE striking structural elements at least partly and locally became active again: the Uweinat-Aswan Uplift was interrupted by the NNW-SSE striking Misaha Trough. Further south, the Abiad Basin and a probably deeper graben structure developed between the eastern end of Wadi Howar and the Khartoum area. The major part of the Dakhla Basin had subsiding tendency again. The area east of Kharga, the so-called Upper Nile Basin between Kharga and Aswan as well as the southern Wadi Qena and the Red Sea areas, however, remained in a relatively high position, with north- to northwestward dip. While several Cretaceous and Early Tertiary transgressions went southward, possibly through the Misaha Trough at least to the Abiad Basin, the area east of Kharga (Kharga-Aswan-Red Sea High) remained an area of erosion until the late Cenomanian. It later was covered by the sea during a short interval in Coniacian to Santonian time and again in Campanian, Maastrichtian and Paleocene to Early Eocene time (see Fig. 3 and 4).

It seems that in most of northeast Africa during Late Jurassic to Late Cretaceous or Early Tertiary time, rejuvenation of old Paleozoic and older structural elements prevailed and that the structural elements active during the Late Carboniferous to Early Jurassic episode came out of order or were included in new developments. In the areas close to the northern edge of the plate, however, another development began to be active, which reached the areas further

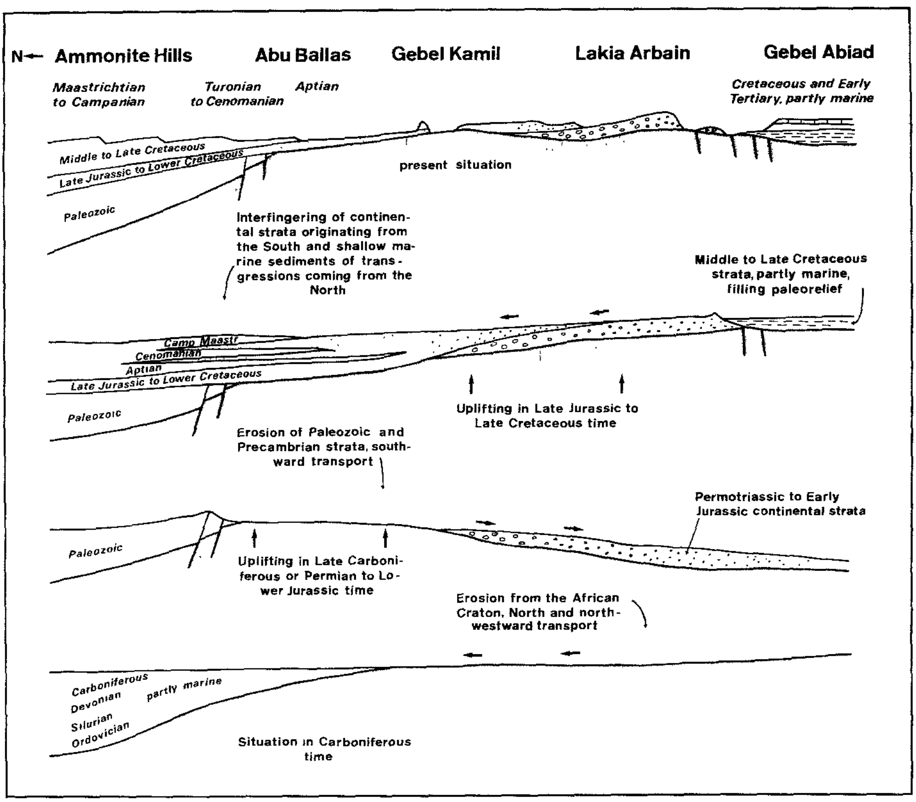


Fig. 3. Schematic sections from Dakhla Basin north of Ammonite Hills southward to the Abiad Basin in Sudan, showing the consequences of epirogenic vertical movements for the distribution and facies of strata in a cratonal area.

south (southern Egypt, Sudan) or southeast (Red Sea) not or at least not generally before the Eocene: in northern Sinai and between there and the Bahariya area, gentle but extensive anticlinal structures developed after the Cenomanian and during the Late Cretaceous, indicating resistence against north- to northwestward movement of this part of the African plate (see also SALEM 1976). Magmatic intrusions (mainly basalt) of Jurassic and Cretaceous ages are known from several areas in northeast Africa.

Latest Development

The collision between the African/Arabian plate and its northern foreland reached its first peak during the Eocene: along the western edge of the northern Red Sea and the Gulf of Suez area, Riedel shear systems developed (see Fig. 6). The Riedel shears are characterized by more intensive block faulting, and their strike is different than the Gulf of Suez – Red Sea Graben. The areas affected by Riedel shears later were partly included in the graben, but before the graben opened, a system of intensive and large strikeslip faults developed towards the end of the Eocene and during Oligocene time. Now Sinai and Arabia began to separate from the African plate along this NNW trending fault system. This separation was accompanied in Oligocene and Miocene time by slightly rotational movements around a pivot point situated somewhere in the northeastern part of Sinai or directly east of there (see also H.-W. LINKE 1986). As a result of this rotational movement, the Red Sea Graben began to open, Sinai was moved slightly south to southeastward and later, when faults developed along the Akaba trend in Late Miocene and Pliocene time, Sinai was separated from Arabia and the latter moved northward. Now the Red Sea Graben opened to its present width, representing an early stage of seafloor spreading.

The main reason for this separation must have been the difference in resistence, which the African-Arabian plate met in the North. While Africa was hindered to proceed at the same speed as Arabia, the resulting stress field first caused the formation of Riedel shears, later the development of a large strike slip fault system and afterwards a graben. Because this constellation and a turning movement did not compensate the differences in drift potential, a second graben developed (Akaba) along a strike slip fault and now Arabia went northward leaving the Sinai microplate and the Gulf of Suez Graben together with Africa behind.

The beginning of separation in the Gulf of Suez – Red Sea area was accompanied in Eocene time by intrusions much further west along structural trends also striking NNW (Gebel Kissu, Gebel Uweinat, MARHOLZ 1965). Later movements were accompanied by the well known basaltic intrusions in the Gulf of Suez – Red Sea area.

It certainly is of great interest to include the northern edge of northeast Africa in this structural analysis. Unfortunately, the data available until present are not sufficient to allow a conclusive analysis. Because of the Syrte Graben System in northern Libya and similar features in northern Egypt, it might still be realistic to postulate a slight westward movement of the northeastern part of the African plate during Middle or Late Cretaceous time (KLITZSCH 1970).

The Sedimentary Cycles

Description and paleontological evidence on the strata of Nubia and bordering areas has recently been published (KLITZSCH & LEJAL-NICOL 1984). An up-to-date stratigraphic chart of large parts of this area is enclosed (Fig. 7). In this publication, only a short account on the strata is given, mainly to show the interaction between sedimentological cycles and structural movements in cratonal areas. Furthermore, it is important to point out the value of stratigraphical work for the reconstruction of the development of these areas. In the case of the Eastern Sahara, an up-to-date interpretation was not possible until recently, because strata ranging in age from Cambrian to Tertiary was grouped over large areas under only one (useless) term.

Lower Cycle or Paleozoic Cycle

After the cratonization of northeast Africa in the PanAfrican event and before Gondwana collided with the northern continents during the Carboniferous, erosion and deposition were controlled by the general north- to northwestward dip of the plate. Local differentiation was caused by the development of NNW trending troughs and uplifts, but the principal rule was that fluvial transport and deposition of continental sediments took place north to northwestward. Most indications from cross-bedding all over northern Sudan and Egypt within Paleozoic strata until the Viséan more or less follow this pattern. The same was observed during fieldwork in the sixties in northern Chad and southern Libya. Whenever sealevel fluctuations allowed southward transgressions, continental sedimentation (or the formation of soils or erosion) was interrupted by marine deposition. Times of marine transgressions in northeast Africa were the Lower Cambrian (known only north of 27 °N), the Lower and/or Middle Ordovician, the Lower Silurian and the Lower Carboniferous. All these transgressions flooded a shallow to very shallow shelf and consequently, most deposits of these times consist of interbedded sequences of shallow marine to nearshore sediments and deltaic to fluvial sandstone. Differentiation between deeper marine and nearshore sedimentation, as it is characteristic for the sediments of several Paleozoic transgressions in the central and western Sahara is very rare. The biofacies of most sediments suggest deposition in cold climate.

Middle Cycle or Karroo Cycle

The typical interfingering of continental sediments deriving from southern directions and marine sediments caused by southward transgressions came to an end when the collision between Gondwana and plates of the northern continents caused uplifting or updoming of large parts of northeast Africa. In Late Carboniferous time, the drastic change of the paleogeographical situation resulted in the development of a new type of sedimentary cycle: in most areas of middle and southern Egypt, the Paleozoic strata were eroded and transported south- and southwestward. Along the western edge of this area of total erosion of Paleozoic strata, where the original situation is more or less preserved (between the western part of Gilf Kebir and the western and southwestern part of the Uweinat High, see Fig. 2), the Viséan is overlain by tillite, interfingering southward with fluvio-glacial sediments. Further south at Gebel Uweinat, the fluvio-glacial sandstone and conglomerate is interbedded with finegrained sandstone and siltstone, which has the characteristics of varves (glacial lake deposits). Further south, SE of Kebel Kissu in Sudan, the Viséan is overlain by several ten meters of sediments, consisting in most places almost exclusively of varves. From the distribution of these sediments overlying the Viséan, it became obvious that they were already deposited after southward tilt had become effective.

These glacial sediments must be more or less an equivalent of the Dwyca of the South- and Eastafrican Karroo. At Wadi Abd el Malik in the Abu Ras Plateau of the western Gilf Kebir, the glacial sediments are overlain by fluvial sandstone containing flora of Stefanian age (personal communication. A. LEJAL-NICOL). At Gebel Uweinat as well as south and southeast of Gebel Kissu, the glacial strata are followed by very immature clastics, mainly made of arcose, conglomerate and – more frequent the further south it occurs – sandstone. Intercalations of paleosols and mudstone indicate periods of non-deposition or low energy transport situations within these braided river deposits. Parts of the sequence are full of silicified trees and the top of the formation contains a rich flora of most likely Lower Jurassic age (KLITZSCH & LEJAL-NICOL 1984). The whole sequence is up to several hundred meters thick, it is best exposed along the Lakia Arbain-Lakia Umran escarpment and it must be of Permian to Early Jurassic age. Similar sediments occur north of the Murdi Depression and from there westward all along the inner part of the southern edge of the Kufra Basin.

The changes of facies and grain size, but more obviously the directions of transport measured at many places all over northern Sudan, indicate without doubt that the sediments of this Karroo-type cycle were mainly transported south- and southwestward and that they were the result of erosion which took place over large areas in Egypt between the Late Carboniferous and the Early Jurassic (see also WYCISK 1984, 1986). Different from the Lower and from the Upper Sedimentary Cycle, this Middle Cycle is purely continental without marine transgressions.

The Upper Cycle or Nubian Cycle and the Latest Development

If any of the strata in Nubia could still be named »Nubian« or »Nubia«, it would be the strata following the Karroo-type sediments. After Pangea began to disintegrate and the northern dip of northeast Africa became effective again, a situation returned which was very similar to the Lower or Paleozoic Cycle: again transgression came from northern directions (the first one during the Aptian in Lower Cretaceous time), and their sediments interfingered with fluvial strata which were deposited in the course of northward prograding river systems. As in Paleozoic time, the more western areas have been transgressed earlier than the more eastern ones, indicating that the dip of the plate was more northwestward or north-northwestward than straight northward. While the area between Kharga and the much later developing Red Sea Graben remained continental until the Turonian, areas further west and southwest had already been reached by shallow transgressions during Aptian and Cenomanian times.

The interfingering of fluvial to deltaic sediments being transported northward with marine sediments of southward transgressions can be studied best along excellent exposures between the Aswan area and Qena and from there northward along Wadi Qena. This area is of importance for the stratigraphical interpretation of the upper part of the Upper (or Nubian) Sedimentary Cycle, because there several of

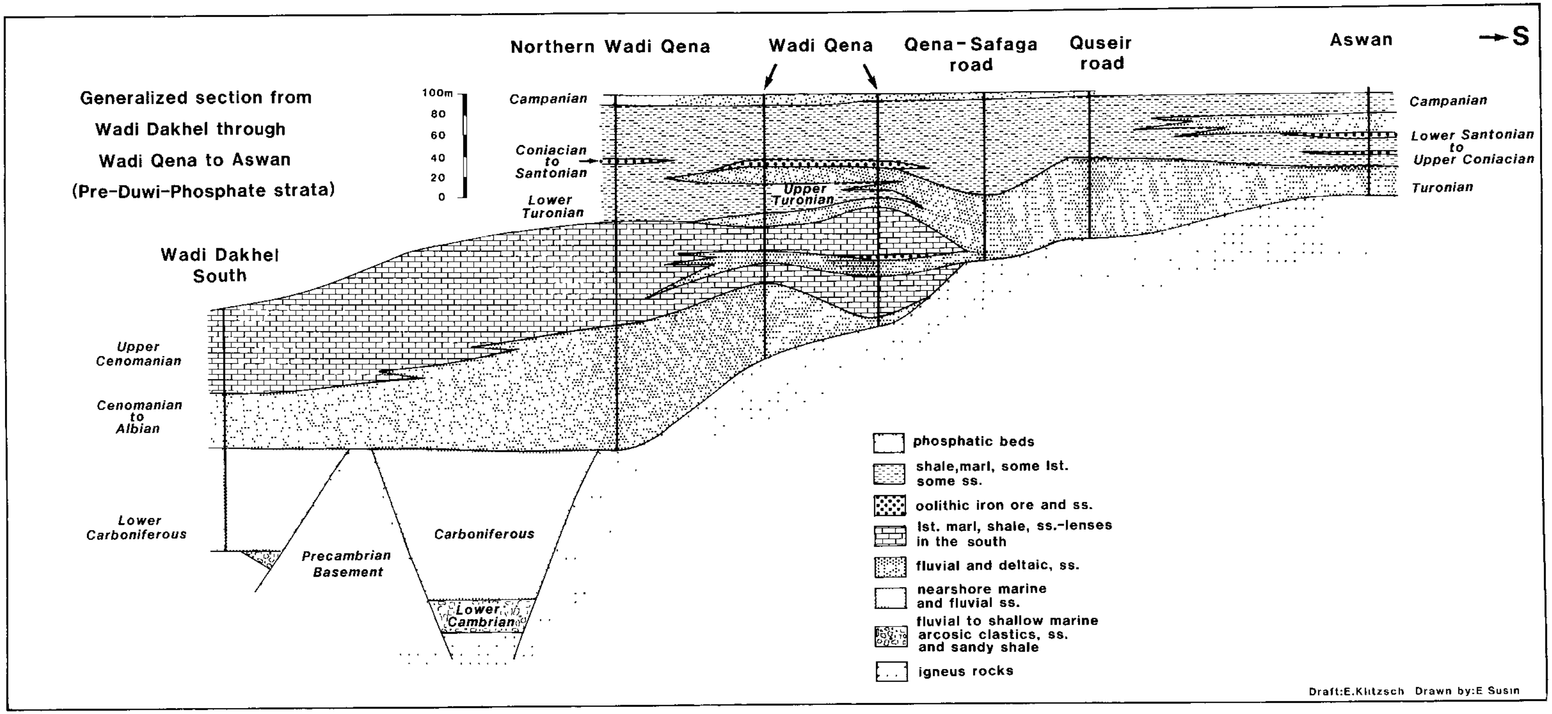


Fig. 4. Schematic section from Wadi Dakhel through Wadi Qena to Aswan, showing the typical interfingering of continental strata of Cretaceous age with strata of marine Cretaceous transgressions coming from the north. Further west transgressions began already during the Aptian.

the fluvio-continental formations interfinger with ammonite-bearing marine beds (for interpretations see Fig. 4). The marine Cenomanian beds (Galala Formation) interfingering with fluvial sandstone at Wadi Qena (Fig. 4) contain among others ammonites like *Angulites mermeti* (COQUAND), *Metengonoceras dumpli* (CRAGIN) and *Neolobites brancai* ECK. The overlying beds of Turonian age are most likely the equivalent of the Taref Sandstone of the Western Desert. At central Wadi Qena the middle part of this mainly fluvial sandstone formation consists of shale and marl, containing among others *Coilopoceras* cf. *multicostatum* LEWY and *Coilopoceras requienanium* (D'ORBIGNY). Northwest towards northern Wadi Qena, this Um Omieyed Formation (equivalent of Taref Sandstone Formation) becomes fully marine. The overlying Hawashia Formation at central Wadi Qena contains among others *Metatissotica* cf. *thomasi* (PERON) and is of Coniacian to Santonian age. Further south at Aswan, its equivalent is most likely the iron oolite bearing Timsah Formation: it contains among others *Inoceramus (Platyceramus) cycloides* WEGNER and *Inoceramus (Volviceramus) balli* NEWTON. Our previous terminology (KLITZSCH & LEJAL-NICOL 1984) of the Aswan area had to be revised (see Fig. 7) because of the new stratigraphic data and also because some older literature was previously not known to us, for example Z. R. EL-NAGGAR (1970). The new fauna of the Aswan area and of Wadi Qena was found during fieldwork of Herrmann-Degen, Klitzsch and Seilacher in 1984 and identified by Gröschke and Herrmann-Degen. More complete results will be published in the new edition of »The Geology of Egypt« by R. Said & C. H. Squyres in 1987. The fauna from Wadi Qena is mainly from an east-west striking wadi along 27° 34'.

The Upper (Nubian) Sedimentary Cycle represents several transgressions and regressions. The transgressions are reflected in normally rapidly southward extending marine environment, characte-

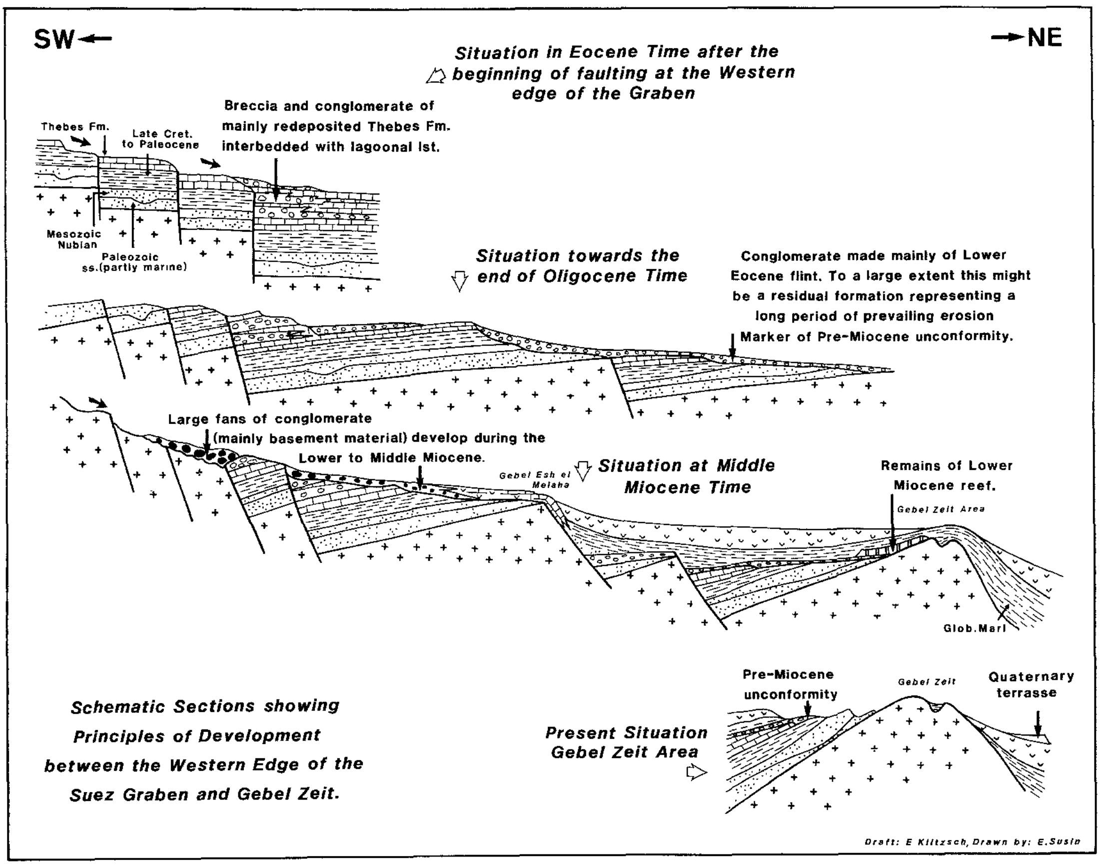
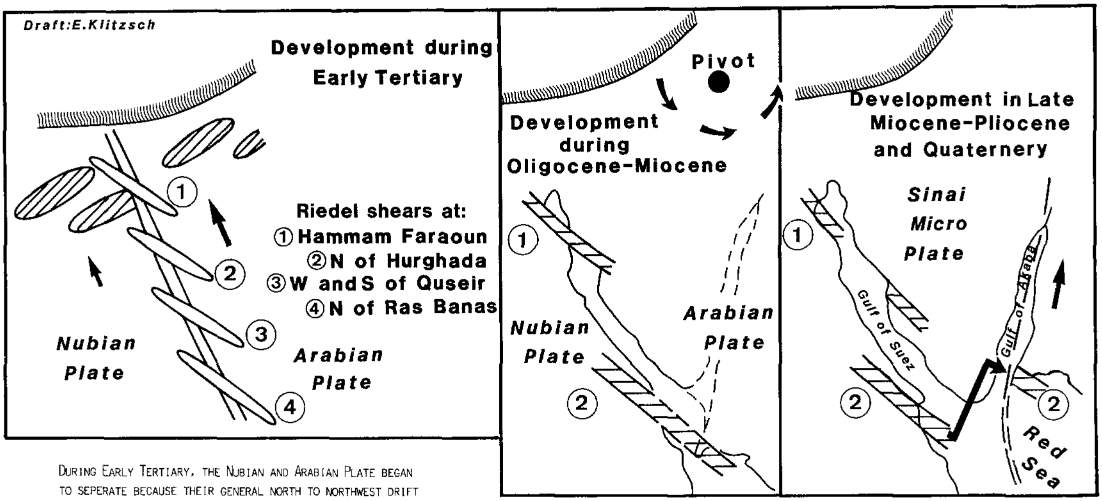


Fig. 5. Development of block-faulting between the western edge of the Suez Graben and Gebel Zeit, partly after discussions with PHILOBBOS and ZANKL.



During Early Tertiary, the Nubian and Arabian Plate began to seperate because their general north to northwest drift met strong resistance at the northwestern foreland of the plate. Consequently, systems of Riedel shears developed in relatively equal distances of approx. 200 kilometers along the early fault systems of the later Red Sea - Gulf of Suez Graben. The areas effected by Riedel shears show a more complicated structural development than the relatively simple structures, which developed parallel to the Red Sea - Gulf of Suez Graben. The northern edge of the Nubian and Arabian Plate also is characterized by the formation of large anticlinal structures (Cretaceous and Early Tertiary).

During Oligocene and Miocene, the Arabian Plate began to turn anti-clockwise because of the continuing resistance at the northwestern foreland. The Sinai area moved south to southeast and at the Gulf of Suez area, a graben opened. In the extreme south the Afar Triangle developed and the Arabian Plate there moved east- to northeastward.

Beginning in Late Miocene time, the Arabian Plate moved northward along the Akaba Fault, Sinai remained more or less in its position and became a microplate and the Red Sea Graben slowly opened to its present extent.

Fig. 6. Schematic maps showing different stages of structural development of the Red Sea – Gulf of Suez – Gulf of Akaba Graben System. Partly after LINKE (1986).

rized by shale, silt- and sandstone (Aptian, Late Cenomanian in the Western Desert) or by marl and limestone (Late Cenomanian in the Eastern Desert, parts of Maastrichtian and Early Tertiary) or by oolithic sedimentation (Coniacian) or by phosphate beds (Campanian).

The development of the Gulf of Suez – Red Sea Graben was accompanied by its own sedimentological characteristics. Typical for the graben edges was the redeposition of older strata in chaotic masses during Eocene and Oligocene time and large fans during the Miocene (see Fig. 5). Towards the backside of antithetic blocks, these fans interfinger in most areas with back reef or sabkha typ strata, while the seaward side of the blocks and their crust was normally overgrown by reefal sediments. The deeper graben blocks were filled with fine clastic material and (mainly during the Middle Miocene) by evaporitic sediments.

At the same time, the areas west and east of the graben system underwent strong erosion. While the western graben shoulder was uplifted, Early Tertiary, Cretaceous and older strata were eroded and the large escarpment developed, which forms much of the landscape between the Galala Plateau in the north and the Aswan area in the south, and which borders on the so-called Upper Nile Basin to the east.

Discussion on Stratigraphy in Nubia

In this and in previous articles of our group a total revision of the strata called »Nubia(n) Sandstone« or »Nubia(n) Formation« has been carried out. In May 1985, Rushdi Said gave a lecture in Berlin on »sealevel fluctuations in Egypt since Paleozoic time«. In this lecture he had to deal with the entire strata revised by our teams during the last years. The term »Nubia(n) Formation« or »Nubia(n) Sandstone« was not needed once, it was totally ignored by him, because he thought ther was no use for it. We considered this as one of the best compliments for our work. On fig. 7, an up to date stratigraphical interpretation is given, which needs some interpretation (see also KLITZSCH & LEJAL-NICOL 1984 and other recent references). The stratigraphical interpretation of the different formations is of differing value: the Early Paleozoic formations are mainly dated by the use of marine trace fossils in comparison to earlier and secured results from Libya and northern Chad.

The Devonian in Egypt and Sudan is not dated, Devonian age is given because of the situation of this fluvial strata within the stratigraphic column in comparison with similar strata in Libya (Tadrart Sandstone). The Early Carboniferous strata are well dated with Gondwana flora.

The lowest part of the Karroo-type sediments is dated with flora of latest Carboniferous age; different from the Viséan flora, these plants belong to the community of flora of the northern continents. The age of the uppermost beds of the Karroo-type strata is less secure; here, the given Early Jurassic age based on flora has to be considered as a tentative age. Subdivision of the strata above the basal glacial formation has not been carried out. The age of this Lakia Formation is Permian and Triassic to probably Early Jurassic. Triassic time is proven by the presence of silicified wood of Triassic age and by other plant remains.

The Late Jurassic to Early Cretaceous sediments underlying strata of the Aptian transgression are dated with ferns. The Aptian fauna is not very significant, but the Aptian age of these strata (Abu Ballas Formation, BOETTCHER 1982) is strongly backed by palynological data (SCHRANK 1982, 1983). The next time unit for which we have definite ages is the Cenomanian (ammonites at Bahariya and in Wadi Qena). The best area to correlate Cenomanian and younger marine strata with the mainly continental sediments of the same age further south is the area of Wadi Qena: their Cenomanian, Turonian, Coniacian to Santonian and Campanian age is proven with ammonites for strata which partly or totally interfinger with or are replaced by fluvio-continental strata south and southeastward (see Fig. 4). In the central parts of Wadi Qena it is clear that for example the equivalents of the Taref Sandstone are of Turonian age and the equivalents of the Sabaya Formation (formerly Desert Rose Beds) are of Albian to Cenomanian age (GRÖSCHKE, personal communication)*. Because of these findings, we had to correct our previous interpretation of strata in the Aswan area (see Fig. 4 and 7 and compare with Fig. 2 in KLITZSCH & LEJAL-NICOL 1984).

Other authors recently also investigated the strata of this Eastern Desert area (WARD & MCDONALD 1979, BHATTACHARYYA 1980, JUX & ISSAWI 1982, ZAGHLOUL and others, 1983, SULTAN 1985). While the first authors gave very useful interpretations of the environment but neglected to date the different Cretaceous formations of the Eastern Desert, JUX & ISSAWI (partly based on ZAGHLOUL 1983) gave a misleading interpretation of the stratigraphy. These authors placed the Aswan strata in the Paleozoics and correlated it over many hundreds of kilometers with relatively well established strata of Paleozoic age in the Gilf Kebir – Abu Ras area. The age of the strata at Aswan, however, is Cretaceous as already postulated by ATTIA (1955). The marine iron oolithe bearing beds contain different species of *Inoceramus* of Coniacian to Santonian age. The underlying sandstone further north at Wadi Qena is interfingering with marine beds containing ammonites of Turonian age. SULTAN (1985) published palynological investigations which also prove Coniacian to Santonian age for the iron oolithe bearing beds east of Aswan.

To conclude the discussion on stratigraphy in Nubia or on stratigraphy of the former Nubia(n) Sandstone Formation, it can be stated that we tried to fulfill the old aim postulated already by ZITTEL (1883) and later by POMEYROL (1968), to break these strata down into mapable and recognizable units. It should be relatively easy to complete this work also in those areas of northeast Africa, where stratigraphical interpretation and subdivision is still not carried out to a satisfactory degree. It is, however, proven that future geologists can use stratigraphical subdivisions, which allow the reconstruction of structural and paleogeographical development also in those areas of northeast Africa, which are not at all or not totally controlled by marine sediments. Our subdivision has already been used for the geological maps 1:500 000 of Egypt, which is published by Continental Oil Company in cooperation with the Egyptian General Petroleum Corporation in 1986/87 (KLITZSCH, LIST & PÖHLMANN 1986).

*) At present, these problems are under investigation by a mixed team of Asyut University and Technical University of Berlin.

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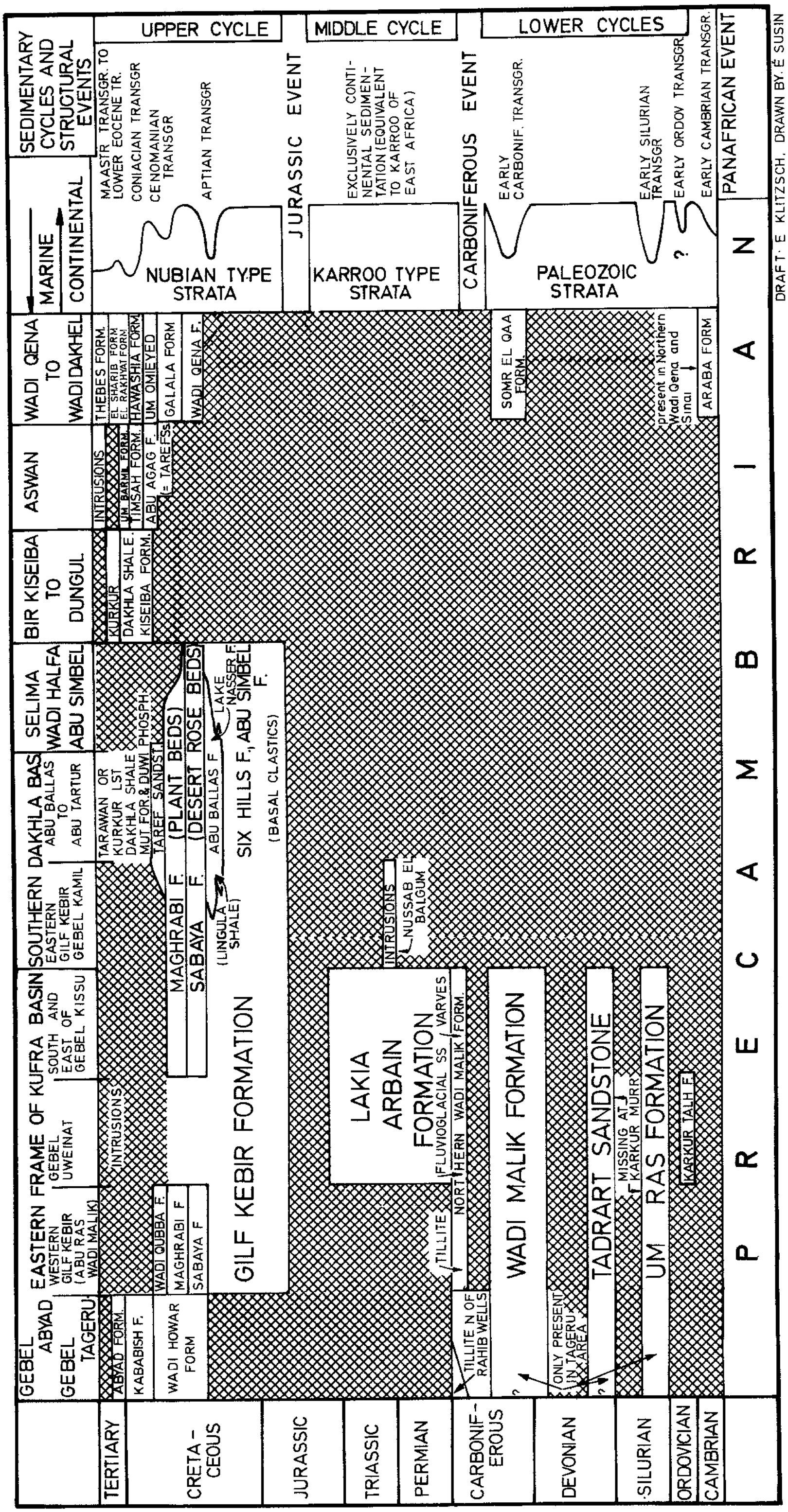

Fig. 7. Correlation chart showing present subdivision of strata in Nubia and bordering areas (modified after KLITZSCH & LEJAL-NICOL 1984).

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