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Late Cretaceous and Early Tertiary Stratigraphy in the Great Sand Sea and its SE Margins (Farafra and Dakhla Oases), SW Desert, Egypt

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With 18 Text Figures

Kurzfassung

Ausgangspunkt für die gegenwärtigen Untersuchungen ist das Standard-Profil der Dakhla Oase, das sich aus Mut Formation (neu; ex "Variegated Shales"), Dakhla Fm. (mit El-Hindaw Schichtglied [ex "Phosphate"], Qûr-el-Malik SG. [neu], Dakhla Shale SG.), sowie Tarawan Fm. zusammensetzt. Die Kreide/Tertiär-Grenze bildet über weite Strecken der Bir-Abu-Munqar Horizont (neu), in dem auslaufendes Maastricht und Teile des Dan kondensiert sind. Der phosphoritführende Horizont liegt im oberen Drittel des Profils.

Nach W gegen die Große Sandsee nimmt der Sandanteil in den genannten Einheiten zu. Das Qûr-el-Malik SG. verschwindet dort und in den hangenden Partien der Dakhla Fm. erscheinen das fossil- und kalksandstein-reiche Ammonite Hills SG. (neu) und darüber das oolithführende Peak Hill SG. (neu). Die Kreide/Tertiär-Grenze verläuft im oberen Teil des Ammonite Hills SG. (Verschwinden von *Libycoceras ismaelis* [Zittel] und *Exogyra overwegi* [v. Buch]).

Gegen E geht das Peak Hill SG. der Dakhla Fm. in kleine Korallen-Riffe und schließlich in den Tarawan 'Chalk' über.

Die Tarawan Fm., die die Dakhla Fm. in der Region zwischen Dakhla und Bir-Abu-Munqar mit Hiatus überlagert, verzahnt mit dieser in der Farafra Depression und ersetzt sie schließlich im N gänzlich. Diese Verzahnung reicht weit in den SW, wo ein letzter Ausläufer in der Ammonite I Bohrung erfaßt wurde. Im untersuchten Gebiet stellt die Tarawan Fm. die karbonatische Schwellenfazies dar, die auf dem Rücken des Bahariya-Arch besonders mächtig ist.

Gegen Ende oder nach der Tarawan Ablagerung kommt es im Abschnitt zwischen NW Dakhla und Farafra zu einem lokalen Uplift mit anschließender Relief-Umkehr und Verfüllung der entstandenen Depression mit mächtigen groben Sandsteinen und einer Abdeckung durch Süßwasser- bzw. 'intertidal'-Kalke mit Land- und Süßwasser-Schnecken. Z. T. sind die fossilen Schuttablagerungen der Uplifts noch erhalten. Aus Analogie-Schlüssen müssen die Depressionsfüllungen vorerst zum Unteroligozän gerechnet werden.

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While the manuscript was in press, Prof. Dr. K. Werner Barthel deceased unexpectedly. This is the last study completed by this imaginative scientist and dedicated teacher.

Die Tarawan Fm. geht in der Farafra Region gegen oben in die Mergel und Tone der Esna Fm. über. Dieser Wechsel enthält verschieden lange Hiatus. Gegen NW (Ain-Dalla) erscheint anstelle der Esna Fm., die Karbonatfolge der Ain-Dalla Fm. (neu), während beide Fm. nach N zu durch Tarawan Fm. ersetzt werden, wie dies bereits früher mit der Dakhla Fm. der Fall war. Im SW des El-Qûss-Abu-Said finden sich im Übergangsbereich von Tarawan zu Esna Fm. karbonatische Rutschungen und kleine Korallen-Riffe. Z. T. taucht dort auch die Schlamm-Bank-Fazies mit der Auster *Ilymatogyra osiris* (ZITTEL) auf.

Die Ain-Maqfi-Region im NE der Farafra Depression zeigt die Beziehungen zwischen der kalkig-kieseligen bis sandigen Hefhuf Fm. und der Tarawan Fm. Die Hefhuf Fm. übernimmt dort offenbar die Campan-Anteile der Tarawan Fm.

Farafra Fm., ein bioklastischer Kalk, bildet eine Steilstufe über Esna- und Ain-Dalla Fm.

Die Datierungen erfolgten anhand von Ammoniten und besonders mit Hilfe planktonischer Foraminiferen.

Abstract

The starting point of our studies is the reference section of Dakhla Oasis. It exposes Mut Formation (new; ex 'Variegated Shales'), Dakhla Fm. (comprising El-Hindaw Mb. (new; ex 'Phosphate'), Qûr-el-Malik Mb. (new), and Dakhla Shale Mb.), and Tarawan Fm. The Cretaceous/Tertiary boundary is recognizable over considerable distances as Bir-Abu-Munqar Horizon (new) which is encountered in the upper third of the sections. Latest Maastrichtian and Early Danian are condensed in this striking level, rich in phosphorite.

Sand content increases in all of the units mentioned as one moves westward into the Great Sand Sea. While the Qûr-el-Malik Mb. pinches out, the higher parts of the Dakhla Shale Mb. are replaced by the Ammonite Hills and Peak Hill Mbs. (both new). The first abounds in fossils and carbonatic sandstones, the second is characterized by its oolite content. The Cretaceous/Tertiary boundary lies within the upper Ammonite Hills Mb. (absence of *Libycoceras ismaelis* [ZITTEL] and *Exogyra overwegi* [V. BUCH]).

Peak Hill Mb. of Dakhla Fm. correlates with small coral reefs in the E and, still further E, with Tarawan Fm.

Tarawan Fm. covers Dakhla Fm. in the stretch between Dakhla and Bir-Abu-Munqar. In Farafra depression Tarawan and Dakhla Fms. intercalate. The latter is entirely replaced by the first in N Farafra. Intercalations extend into the Sand Sea where a last extension of Tarawan Fm. is found in the Ammonite I well. In the area of investigation Tarawan Fm. is the shallow marine swell carbonate strongly developed on Bahariya-Arch.

At the close of Tarawan deposition or shortly thereafter, the area between NW Dakhla and Bir-Abu-Munqar was uplifted, eroded and underwent subsequent relief reversal. The resulting depression was filled with coarse sands that finally were covered by freshwater and intertidal limestones. Both sediments contain terrestric and freshwater gastropods. From analogies with similar sediments further N, we assume the infill to be of Lower Oligocene age.

In Farafra depression the transitional beds between Tarawan and Esna Fms. hide various hiatus. Toward the NW (Ain-Dalla) the Esna marls and clays are replaced by the bedded chalky limestones of Ain-Dalla Fm. (new). Both formations turn into Tarawan Fm. as one proceeds in northern direction. SW of El-Qûss-Abu-Said, the transitional beds between Tarawan and Esna Fms. consist of limestones with slumps, erosional features and small coral reefs. In this area a mud-bank facies marked by *Ilymatogyra osiris* (ZITTEL) is locally developed.

The Ain-Maqfi region of NE Farafra depression exposes the interrelations between the cherty limestones of Hefhuf Fm. Hefhuf Fm. here apparently is the Campanian equivalent of lower Tarawan Fm.

Farafra Fm., a bioclastic carbonate of Late Ilerdian age, forms a cliff above Esna and Ain-Dalla Fms.

Dating was done by ammonites and, in the majority of cases, by planctonic foraminifera.

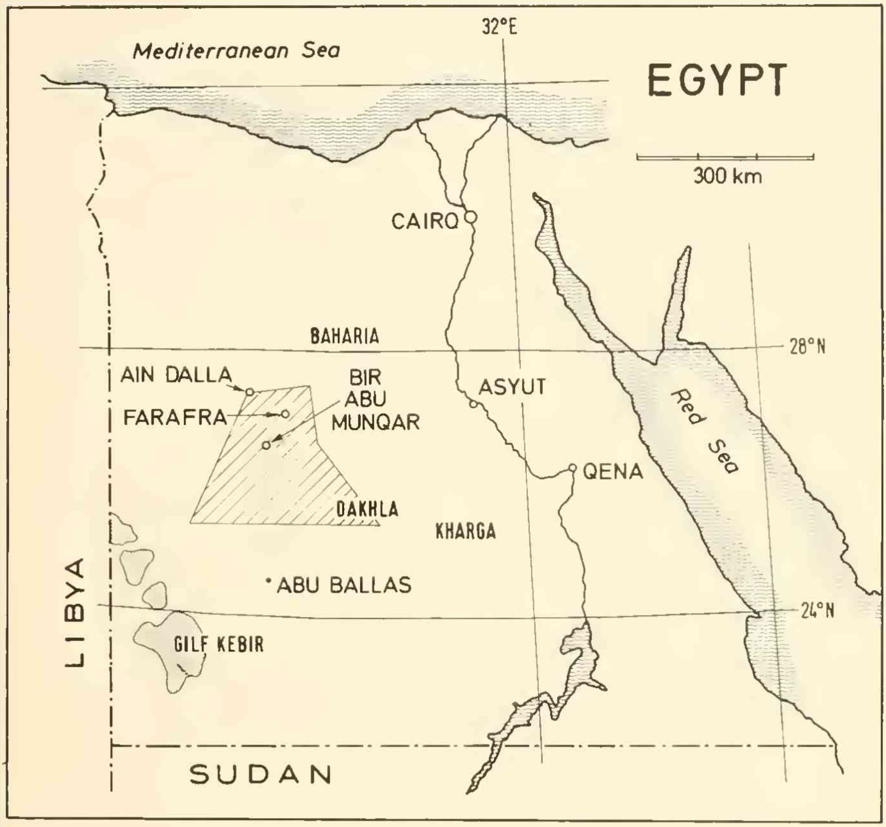

Fig. 1: Geographic outlines of Egypt. Area of investigations hatched.

Introduction

Up to present more detailed stratigraphic knowledge of the SW Desert of Egypt was largely restricted to the oases and areas adjacent to the Nile Valley. The only expedition that brought major geological results from western regions was organized by G. Rohlfs in 1873/74. K. A. v. Zittel, member of the expedition and renowned paleontologist, succeeded to establish the general stratigraphy of the area, still in use today in literature (Zittel 1880, 1883). The rich faunae found by Zittel were later described by Quaas and Wanner (1902), and others.

Since 1977 members of the Technical University and the Free University of Berlin are engaged in geological and paleontological studies in the Western Desert. First results deal with the stratigraphy of the socalled "Nubian Series" (BARTHEL & BÖTTCHER, 1978; KLITSCH, HARMS & LEJAL-NICOL, 1979). KLITZSCH & LIST edited a preliminary geological map (1:500000), based on the remote sensing and ground observations.

During a 1979 expedition to the Great Sand Sea it became clear that the existing stratigraphy needed revision and that stratigraphy in the area was much more complex than assumed.

The 1980 expedition therefore was planned to gain at least an outline of the stratigraphy in the SE Sand Sea and of its eastern fringes. The area of investigation covered more than 20000 km^2. The southern limit follows 25°30′ N (latitude of Mut; major settlement of Dakhla Oasis). 27°30′ N delimits the area in the N, with Ain-Dalla as a wellknown location. A line between Qasr-el-Farafra and Mut marks the eastern boundary, while in the W it runs from the intersection 26°30′ E/25°30′ N to a point 30 kms W of Ain-Dalla.

In large-scale structural terms the territory under surveillance covers most of the "Dakhla Basin". This basement depression (Fig. 5) has been outlined by BEALL & SQUYRES (1980). It is bordered on three sides by Asyut and Nubian platforms in the E and S, and by a spur of the Gilf-el-Kebir in the W. The basin opens to the N, the passage being restricted by the Bahariya-Arch.

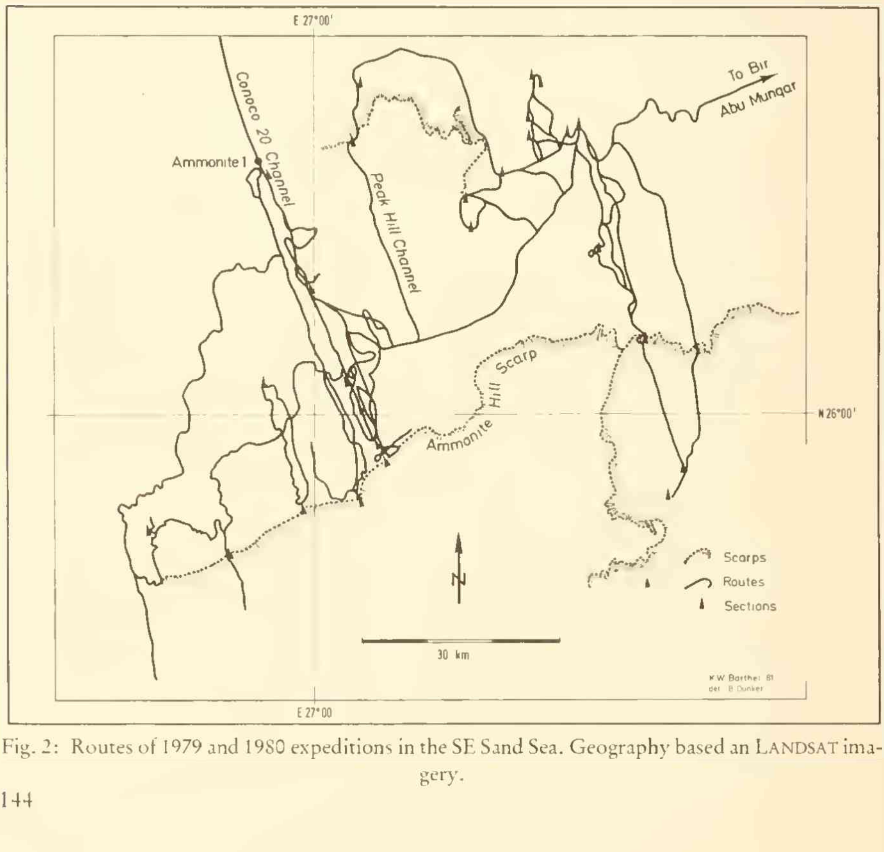

Fig. 2: Routes of 1979 and 1980 expeditions in the SE Sand Sea. Geography based an LANDSAT imagery.

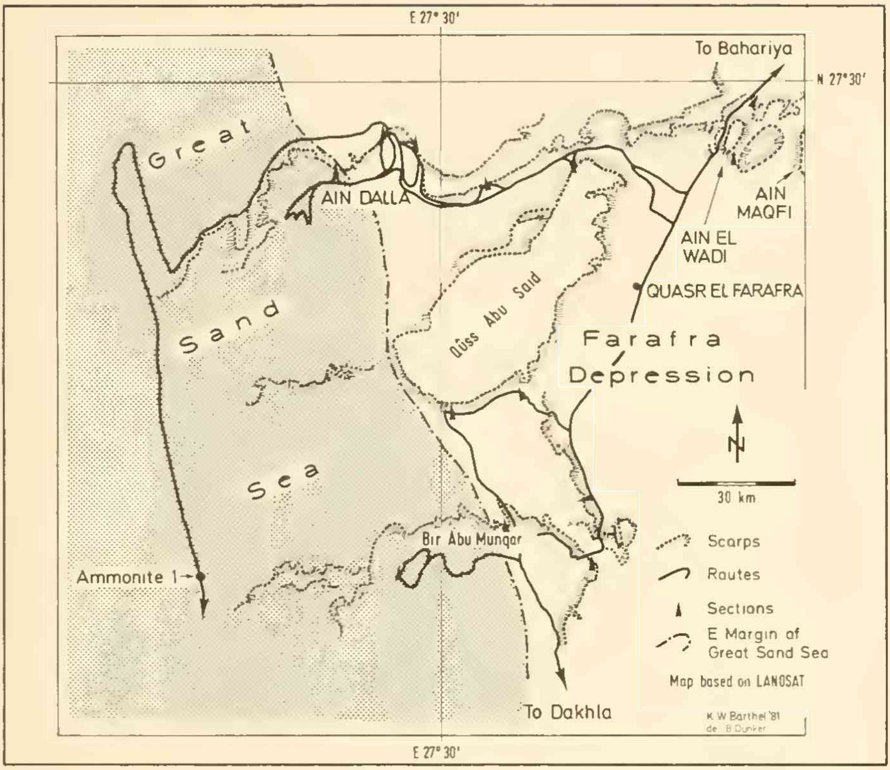

Fig. 3: Routes of 1980 expedition to El-Qûss-Abu-Said – Farafra – Ain-Dalla region.

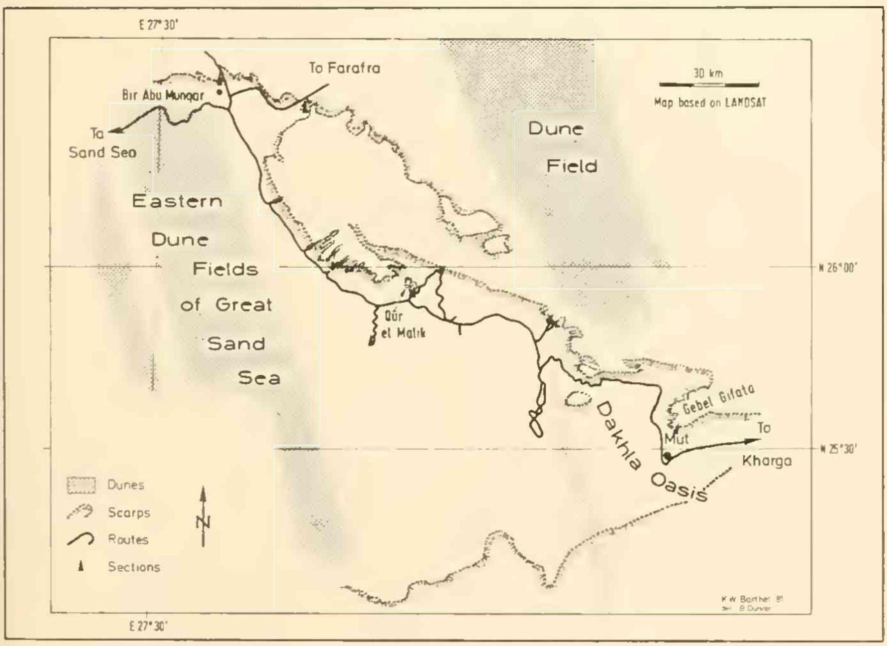

Fig. 4: Routes of 1980 expedition to Dakhla – Bir-Abu-Munqar area.

Topography and Tectonics

The southeastern part of the Great Sand Sea is coined by a series of minor and major escarpments following an ENE/WSW trend. In general the beds dip 1° or less in northern direction. The northern regions lie about 250 ms above sea level, while in the S an average altitude between 450 and 550 ms is reached.

Much of the area under discussion is obscured by vast sheets of sand and the characteristic longitudinal dunes extending in NNW/SSE direction, often continuing for more than 100 kms. Dunes and sand render stratigraphical work difficult. In addition, the low regional dip, in connection with rather quick facies changes, causes problems in following beds for some distance.

Dakhla Basin Basement Surface

Simplified after Beall & Squyres, 1980

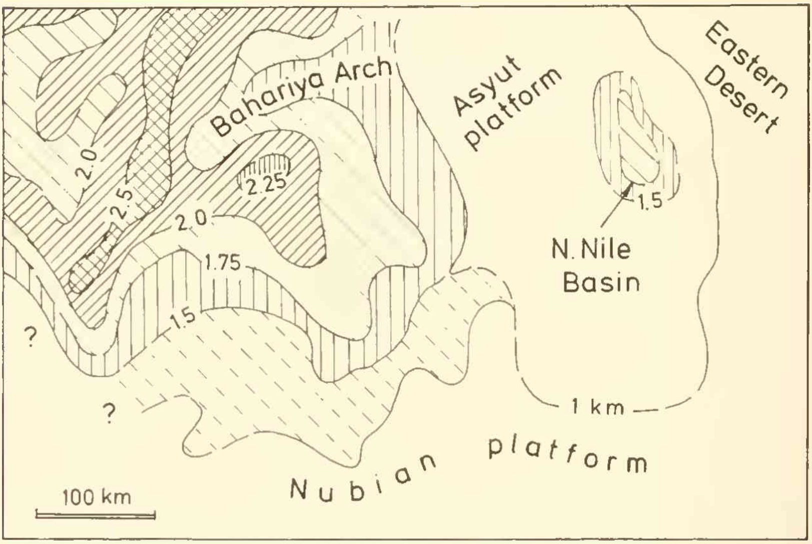

Fig. 5: Dakhla Basin: basement structures after BEALL & SQUYRES. Note eastern margin of complex Gilf-el-Kebir spur.

Another factor complicating matters is the gentle large-scale warping and local updoming of strata, accompanied by faulting. Single faults never amount to major throws. The observed maximum of throw is about 10 ms, whereas throws from 0,3 to 3 ms are common. Most fault zones thus are the summation of many small faults.

The fault patterns exhibits two predominant trends, near 60 and near 300 degrees. A lesser number of faults prefer directions around N/S and E/W.

In the E the southeastern Sand Sea is bordered by several depressions. These are the Farafra (35 ms; NE), Ain-Dalla (98 ms; W), Bir-Abu-Munqar (123 ms; S), and Dakhla depressions (ca. 200 ms; SE). All are more or less completely rimmed by scarps.

Farafra, Ain-Dalla and Bir-Abu-Munqar depressions are separated by the central plateau of El-Qûss-Abu-Said (340 ms).

The fault system in the depressions is essentially the same as given for the SE Sand Sea. In the Dakhla Oasis the more important structures show an E/W trend.

Previous works

In the Sand Sea works are restricted to those of ZITTEL, QUAAS and WANNER, mentioned above. The micropaleontological material was treated by P. DE LA HARPE (1883) and C. SCHWAGER (1883).

BEADNELL (1901a) contributed by recognizing a gap between Tarawan Fm. and Esna Fm. At the same time he notes intercalations of clay in the Tarawan Fm. near the transition to Esna Fm. in the Farafra area (pl. III and pp. 32/33). He also records disappearance of the Tarawan Fm. on the way to Ain-Dalla ("Ain-Iddaila") and the tapering out of Esna Fm. toward W and N. It is also evident that BEADNELL was aware of additional rock types in Ain-el-Wadi and Ain-Maqfi (= Hefhuf Fm. and Bahariya Fm.).

BEADNELL (1901b) gives a review of ZITTEL's reconnaissance in Dakhla Oasis and mentions the hiatus between Tarawan and Esna Fms. He noticed corals in the Tarawan Fm. on the scarp N Qasr-el-Dakhla and was aware of a "soft chalky bed" following on the "Phosphate" as well as in the Gebel-Gifata section. BEADNELL also stated the economic importance of the phosphorite bearing beds later called "Phosphate".

BALL & BEADNELL (1903) outline the geology of Bahariya Oasis. They lithologically separated Hefhuf and Bahariya Fms. without naming them. The Tarawan Fm. is found, in places, to cover the Hefhuf. Both are thought to be an equivalent of Dakhla and Tarawan Fms. in the S. A considerable hiatus between Late Cretaceous and Mid-Eocene is recognized.

BLANCKENHORN (1921) in his "Geology of Egypt" reviews the facies interchanges in the Kharga-Dakhla-Farafra region. He lists the 'Phosphate' and the *overwegi*-beds under his chapter on the Campanian. This is correct for the 'Phosphate' and the lowermost part of Dakhla Fm. but not for the main body of Dakhla Fm. (which BLANCKENHORN refers to as an equivalent of his Lower Esna Shales).

LeROY (1953) was the first to undertake detailed micropaleontological studies on a section in the Western Desert. The Ain-Magfi section was subdivided in four units. These rest on Maastrichtian Tarawan Fm. Units IV to I (Esna Fm. = IV-II; Farafra Fm. = I) are considered to be of Lower Eocene age (= Late Paleocene). Hiatus are recorded between Tarawan Fm. and unit IV, and between units IV and III (= Ain-Maqfi horizon).

L. HOTTINGER (1960, 226) selected some alveolinid neotypes from Farafra Fm. on Qûss-Abu-Said. On p. 28 he refers to alveolinids from the El-Kharafish (Charaschaff) scarp NE Qasr-el-Dakhla.

HOTTINGER & SCHAUB (1960) introduce new substages for the Early Tertiary. They also mention (p. 464) the Farafra faunae (see HOTTINGER 1960).

After 1960 literature on the oases augments considerably. We here give but short abstracts of the more pertaining ones. In some cases we add a short comment [ ].

HERMINA, GHOBRIAL & ISSAWI (1961) took numerous sections betwen Abu-Tartur plateau and NW of Gebel-Edmonstone. They correlate various horizons by "zones" marked mostly by pelecypod species. Various ages are assigned to the plateau-forming chalk, depending on various geographic positions, becoming younger on proceeding to the W. [At present more exact stratigraphic data can be given by micropaleontological means only, since the genus *Libycoceras* has to be revised and other ammonite faunae are restricted to the lower position of the section.]

R. SAID (1961) states that in "Farafra dome" the Danian is missing and the chalk is Maastrichtian in age. He indicates a "reefal" limestone [which we would rather define "shallow water limestone"] in the Esna shale.

SAID & KERDANI (1961) studied the foraminiferal fauna of the Ain-Maqfi section in detail, dating the Tarawan Fm. to Maastrichtian and the Esna Fm. to Upper Paleocene. The covering Farafra Limestone is found to be Ypresian in age. Within the lower Esna Fm. a shallow-water limestone horizon is termed "Maqfi Limestone". A hiatus between Tarawan and Esna Fms. leads the authors to assume a "Farafra swell" during the Upper Paleocene.

R. SAID (1962), in his 'Geology of Egypt', brings excellent general descriptions of the oases with simplified sections and reliable micro-paleontological datings.

AWAD & GHOBRIAL (1966), in their stratigraphic paper on Kharga Oasis, create several new rock units: Abu-Bayan sandstone for part of the "Nubian Series", as well as "Mawhoub", Beris (= Baris), and Kharga members for Dakhla Fm. They apply a "zonal" stratigraphy of facially bound invertebrates. [To us it seems in the reference area, these terms are unnecessary. There would be nothing left for the namegiving unit, which we here retain as Dakhla Shale Mb. (see p. 154.]

HERMINA (1968) deals with the eastern side of the Abu-Tartur plateau and describes 16 sections. His stratigraphy apparently depends on facies-linked fossils, mostly pelecypods, once more used as "zones". Abu-Tartur Fm. is created for shallow water limestones characterized by burrows and by *Ilymatogyra osiris*. [Correlation should be restricted to stratigraphically significant fossils, i. e. in their absence or, if still unknown, lithostratigraphy has to be relied on, and this is what the author actually did. *Ilymatogyra* limestones seem to be indicative of swell or shallow areas. In this case the swell between Dakhla and northern Nile Basins was an apt place for this depositional environment.]

ABBASS & HABIB (1969) summarized the geological knowledge for Late Cretaceous – Lower Tertiary stratigraphy between Dakhla Oasis and the Nile Valley. ABBASS & HABIB utilize and extend "Mawhoub" Fm. of AWAD & GHOBRIAL (lower part of the Dakhla Shale). [In the area studied R. SAID's 1961 term "Dakhla Shale" is fully adequate as there is no basis for lithologic distinction of the various shales in the section.].

HERMINA & ISSAWI (1971) present an outline of formations in southern Egypt for the Upper Cretaceous and Early Tertiary. Dungul, Garra, and Kurkur Fms. are supposed to reach as far N as the Abu-Tartur plateau. [In view of the frequent diachronies of facies observed, we were unable to apply the stratigraphic table of these authors.]

YOUSSEF & ABDEL-AZIZ (1971) introduce the term "Farafra Chalk" for Tarawan Fm. in the Farafra depression. "Farafra Chalk" is supposed to range through Maastrichtian to Danian. [In Farafra depression the Tarawan Fm. entirely replaces the Dakhla in the N, whereas in the S the Dakhla considerably thickens. So up N both "Tarawan" and "Farafra" chalks join, whereas toward the S the Dakhla Fm. thickens and so does the "upper" Tarawan Fm.]

ISSAWI (1972) reviews the Upper Cretaceous – Lower Tertiary stratigraphy of Central and Southern Egypt. He discusses the origins of different facies in separate basins. The equivalence of Tarawan Fm. in Farafra with Dakhla Fm. in the S is correctly interpreted. The paper brings a wealth of observations. [Some of the correlations could not be confirmed with our ammonite finds.]

BARAKAT & ABDEL HAMID (1974) discussed in Farafra Oasis two chalks, Esna Shale and Farafra limestone. The chalk in the S extends down to 160 ms subsurface. This may be followed by another 60 ms of chalk on the surface, thus giving a total measurement for the chalk of 220 ms. The subsurface chalk rests on a dolomite bed of 10 ms. The dolomite is thought to be a possible equivalent of Ain-Wadi Fm. (OMARA, HEMIDA & SANAD, 1970) resp. the Hefhuf Fm. of EL AKKAD & ISSAWI (1963). Below the dolomite sandstones and marls of "Nubian group" follow with a thickness of 640 ms. [The interpretation of BARAKAT & ABDEL HAMID agrees well with our findings. The "Nubian group" should best be compared with the Bahariya 1 well (SAID, 1962, p. 302) which reached the basement. The Late Cretaceous – Early Tertiary sediments indicate shallow water conditions, expected to be found on the Bahariya-Arch. Both chalks, since interfingering with Dakhla clays, and joining entirely in the N, should be joined in Tarawan Fm.]

E. M. EL SHAZLY et al. (1976) published a remote sensing based study of Kharga – Dakhla Oases. Among other new formations they apply "El-Mahariq Fm." and "Kharga-Dakhla Phosphate Fm." to rock units also concerning the present work.

HOTTINGER (1977, 55/56) proposes to discard "*Operculina libyca*" because it encloses several valid species: *O. ornata* HOTTINGER, *O. subgranulosa* D'ORBIGNY, *O. canalifera* D'ARCHIAC, and possibly others.

CAUS, HOTTINGER & TAMBAREAU (1980) refer to and figure *Daviesina ruida* (SCHWAGER) from Farafra Fm.

This short review is by far not complete but is thought to encompass at least some of the more important papers. Further literature may be extracted from the list prepared by R. SAID, M. F. MICKHAIL, A. O. MANSOUR & A. N. ELIAS (1975): Bibliography of Geology and Related Sciences Concerning Egypt for the Period 1960–1973, published by Geol. Survey of Egypt and Mining Authority (Cairo).

Stratigraphic units

The rock sequences treated in this paper rest on the socalled "Nubian Series". This hard-to-tackle complex has been successfully subdivided (KLITZSCH et al. 1979, BARTHEL & BÖTTCHER 1978). The units from bottom to top are: Six Hills Fm. – Abu-Ballas Fm. – Sabaya Fm. – Maghrabi Fm.[1]) – Taref Fm. – Mut Fm.

The Tertiary stages used in this paper are those of HOTTINGER & SCHAUB (1960) and v. HILLEBRANDT (1974).

Mut Formation ("Qûsseir Formation", "Variegated Shales")

Figs. 6, 17

This rock unit has been correlated with the Qûsseir Variegated Shales near the Red Sea. The general term Variegated Shales is used by various authors for the youngest sediments of the "Nubian Series".

Since at present correlation of the "Variegated Shales" from the Western Desert to the Red Sea can not be achieved in a satisfactory way. EL SHAZLY et al. introduced "El-Mahariq Fm." for the "Dakhla-Kharga Variegated Shales". Unfortunately these authors gave only a very general description and did not define a reference section precisely enough to give their new formations sound legal standing.

It thus became necessary to name and define these conspicuous sediments in an area readily accessible and well exposed:

Mut Formation

Name: Mut is one of the major villages of Dakhla Oasis.

Reference area: The lowest scarps along the road from Mut to El-Rashda. Mut itself (28°57′ E, 25°35′ N) is built on Mut Fm.

Definition: Vermilion to brick-red clays. This color may vary to gray and green near leaching horizons.

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[1]) Since the geographic term "Kharga" is lithostratigraphically preoccupied (AWAD & GHOBRIAL, 1966) we here propose Maghrabi Fm. to substitute "Kharga Fm." (BARTHEL & BÖTTCHER 1978, p. 155). The credit for the new term again goes to KLITZSCH as in the original denomination. It should be noted that the longitude (in L. c.) of the reference area, due to an error, must be corrected to 30°07′ E. Maghrabi is the region SE of Abu-Tartur plateau (HERMINA 1968).

Near the top of the formation but also within it, sandstones may occur rather frequently. The local distribution of the sandstones is easily to be explained: They are ancient river channel-fills that weather out and then show no apparent relations to the clays in the vicinity.

Proceeding W, toward the Sand Sea, sandstones more and more become dominant, as we were able to check in interdunal channels N of Abu-Ballas.

Mut Fm. rests on sandstones of Taref Fm. According to numerous well logs between Mut and Gebel-Edmonstone the thickness averages range from 80–100 ms (ABBASS & HABIB 1969; HERMINA et al. 1961).

The depositional environment of Mut Fm. was possibly fluvial to brackish and restricted marine. This is indicated by the presence of glauconite in variegated shales and sands below El-Hindaw Fm. in the Ammonite I well (p. 152). KENAWY et al. (1976) report arenaceous foraminifera from Duwi Fm. near the Red Sea, which may be an equivalent of Mut Fm.

Since the superimposed El-Hindaw Mb. and even the basal beds of Dakhla Shale Mb. are of Late Campanian age (cf. p. 154), we may assume that Mut Fm. has been deposited in Mid- to Early Campanian times.

Dakhla Formation

Figs. 6–11, 13–17

This formation is a well-known unit in Egyptian stratigraphy. The name was coined after Dakhla Oasis by R. SAID in 1961. R. SAID gave a general outline of distribution and sediments. Up till now there exists no published modern report on paleontological data of a complete sequence in the reference area.

One of us (W. H.-D.) will study Dakhla Fm. and its interrelations with topping formations in detail. Therefore we here present but an outline.

The reference area and section were chosen in the scarp NE of El-Rashda, at the prominent Gebel-Gifata. Due to conditions of exposure the reference section is a compound one. Its base lies at the NW outskirts of El-Hindaw. From there the section runs N in small canyons, ascending to a low plateau, finally reaching the slopes of Gebel-Gifata.

Dakhla Fm., in the reference section, from base to top is characterized by three predominant sediments: "El-Hindaw" Mb., lateral tongues of Qûr-el-Malik Mb. and Dakhla Shale Mb. The complete section measures 310 ms.

A complete section of Dakhla Fm. has been penetrated by the Ammonite I well (26°24'27''N, 26°51'32''E). Conoco kindly permitted to give a brief review of this part of the well report. The interpretation is ours. The top 54 ms consist of clays, siltstones and oolites (surface observation!). The age for this portion ranges from Danian (?) to Mid Ilerdian, according to the foraminiferal species cited. Below this we should expect carbonatic sandstones of the Ammonite Hill Mb (p. 157). The report, however, mentions approximately 20 ms of white to gray limestones with clay intercalations. Then, down to about 240 ms, follow sandstones, silty clays with siltstones representing part of the Ammonite Hill Mb. and the Dakhla Shale Mb. The age determined for this sequence is Maastrichtian. A subjacent glauconitic clay- sand- and siltstone unit of nearly 50 ms, with phosphorite and vertebrate fragments, is the equivalent of the El-Hindaw Mb. (p. 152). The beds below this Dakhla Fm. section may be the northern extension of Mut Fm. (p. 149), presence of glauconite suggesting marine influence.

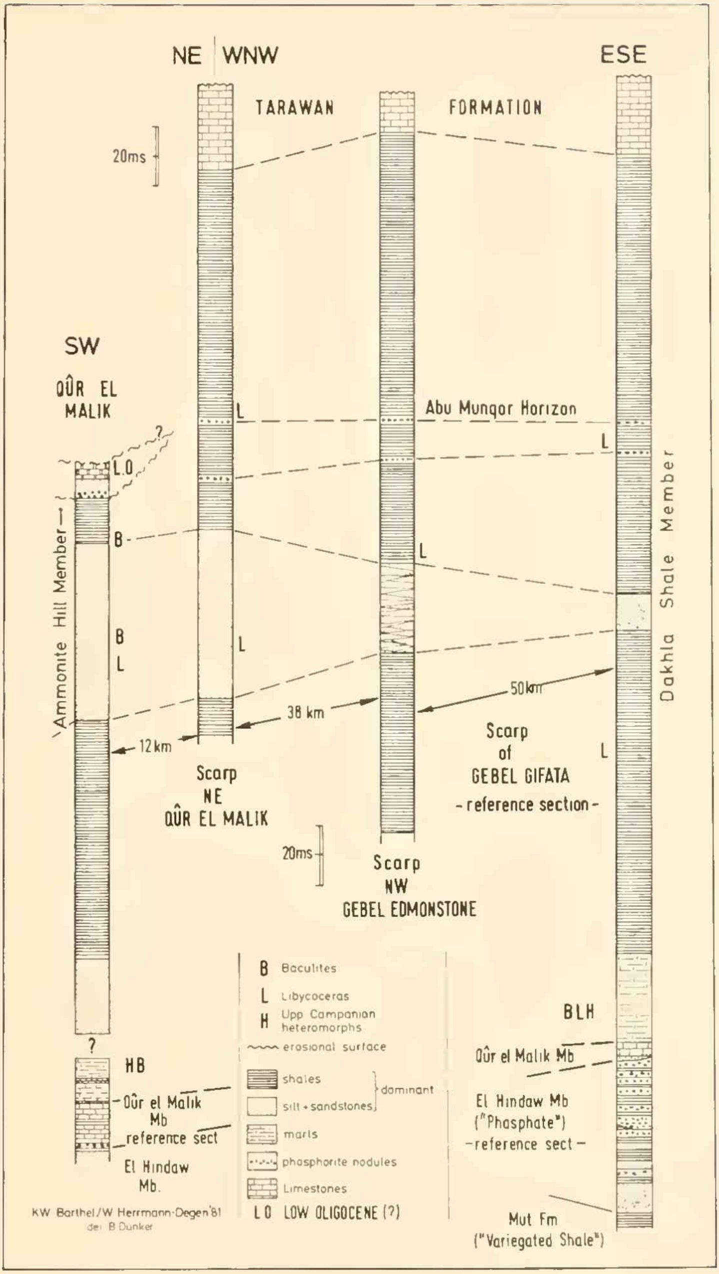

Fig. 6: Series of sections between Qûr-el-Malik and Gebel-Gifata near Mut, Dakhla Oasis. Sections are much simplified. Within "Dakhla Formation" stippling indicates predominance of sand and siltstones, while clay signature stands for preponderance of clays.

El-Hindaw Member of Dakhla Formation (Phosphate)

Figs. 6, 17

This member has been correlated with "Duwi Fm." cropping out near the Red Sea (R. SAID 1962, p. 310; YOUSSEF, 1957). In the Nile Valley EL NAGGAR (1966) refers to "Sibaîa phosphate formation". Since it is adviceable to have a reference locality that permits close range correlation in the Western Desert itself, we select the lower part of the main Dakhla section. This is best exposed near El-Hindaw Oasis.

El-Hindaw Member (E.H.M.)

Name: After the village of El-Hindaw, about 7 kms SW El-Rashda, near Mut, Dakhla Oasis.

Reference area: The low scarps and canyons immediately NW of the palm gardens of El-Hindaw, 28°58′E and 25°34′30″.

Definition: At the base whitish sandstones intercalate with greenish to reddish clays. The main body of the member consists of an alternation of grayish clays with beds of sandstone (0,30–2 ms). Some sandstone beds abund with glauconite and phosphorite pebbles. Other sandstones are crowded with fossils, especially oysters, mostly preserved as cores. Sandstones and clays vary more or less in thickness. One striking horizon of finely laminated carbonate exposes on bedding planes an unusual assembly of fish remains. The top of the E.H.M. consists of several ms of buff sandstone, enclosing channel-fills of reddish sandstone. Channel-fills may even join to form a sheet on the surface of the buff sandstone. Channelling continues into the lower part of the topping Qûr-el-Malik Mb. The thickness of E.H.M. in the reference area is 48 ms.

Beside the invertebrates mentioned, the phosphorite horizons procure vertebrate remains, especially shark teeth, fragments of turtle plates, and vertebrae of fishes and reptiles.

The E.H.M. holds out toward Kharga Oasis in the facies described.

In the W sandstones become dominant. At about 25°30′ N and 27° E, variegated continental sandstones intercalate with but thin clay beds associated with phosphorite and shark teeth.

The age must be deduced as early Late to Middle Campanian since the overlying Qûr-el-Malik Mb. can be dated to Late Campanian.

The general term "Phosphate" refers to the locally high content in phosphorite pebbles. Phosphorites are mined at the SE edge of the Abu-Tartur plateau, between Dakhla and Kharga Oases.

In the Ammonite I well E.H.M. is of equal thickness as in the reference area (cf. p. 150).

Qûr-el-Malik Member of Dakhla Formation

Figs. 6, 7, 16, 17

Above the El-Hindaw Mb., in the reference region, follows white limestone and chalk. This sediment extends, as LANDSAT photographs show, far into the eastern margin of the Sand Sea (Fig. 7).

This striking sediment has been observed as early as 1883 by ZITTEL and also by BEADNELL (1901).

Qûr-el-Malik Member (QEMM)

Name: After the Qûr-el-Malik mesa, 4 kms N of the Dakhla-Farafra road.

Reference area: 14 kms SE Qûr-el-Malik and 10 kms S of Dakhla-Farafra road (28°7′ E; 25°48′ N to 25°52′30′′N).

Definition: Whitish soft limestones and chalk-like sediments, resting on a phosphorite bearing clastic base (El-Hindaw Mb.). The deposition of carbonate is interrupted by 1–2 ms of reddish siltstone. The upper carbonate sequence ends also with a siltstone (0,3 ms). The total thickness in the reference area may amount to 14 ms.

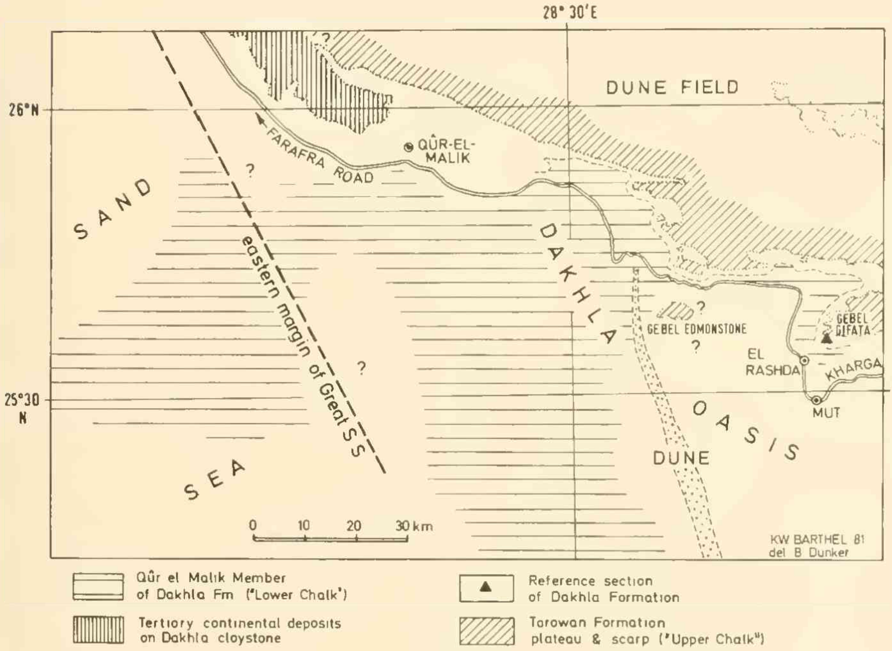

Fig. 7: Distribution of Qûr-el-Malik Member of Dakhla Fm. Compiled from ground observations and LANDSAT imagery.

QEMM is overlain by the marls and clays of the Dakhla Shale Mb. which, near the base, holds an ammonite fauna of Upper Campanian age.

Prof. D. HERM (Munich) kindly checked some of our micro-samples from the QEMM and all were found to be of Upper Campanian age, in the Mut area as well as in the Qûr-el-Malik region. He considers presence of *Globotruncana fornicata globulocamerata* EL NAGGAR and of members of the *Globotruncana mariai* GANDOLFI group, of the *Globotruncana stephensoni* PESSAGNO group, of the *Globotruncana bulloides* VOGLER group, as well as absence of typical Maastrichtian *Rugoglobigerina* and heterohelicids as indicative of Uppermost Campanian.

Our present knowledge does not permit correlation of QEMM with any of the chalk deposits further N.

The "Isocardia chargensis limestone" of ABBASS & HABIB (1969) is included in the member. Fig. 2 of these authors illustrates the distribution of this horizon, on basis of aerial interpretation executed by Geofisika Company.

In the Gebel-Gilata region the QEMM is much reduced (ca. 5 ms).

QEMM has not been recorded in Ammonite I well (cf. p. 150).

Dakhla Shale Member of Dakhla Formation

Figs. 6, 10, 16, 17

This is the name-bearing member of the formation as expressed by R. SAID in 1961 and 1962. AWAD & GHOBRIAL subdivided the sequence without reference to the formational name (see p. 150). Their "Mawhoub" Mb. stands for the lower part. ABBASS & HABIB (1969) discern a "conglomerate" as the upper limit of the "Mawhoub" Mb. Since in the reference section and NW of it clays and marls are predominant, we rather consider them as an unit. It might be helpful later to single out restricted horizons.

Dakhla Shale Member (D.S.M.)

Name: see Dakhla Formation (p. 150)

Reference area: As given for Dakhla Formation. R. SAID 1962, 69: "... to the north of Mut".

Definition: At the base the member is almost chalky in appearance, continuing upward with alternating bands of marls and clays. From the marly bands we extracted, at the reference section and in the Qûr-el-Malik area, a heteromorph ammonite-fauna that fully corresponds to LEWY's (1967, 1969) Late Campanian faunae:

Nostoceras cf. *helicinum* (SHUMARD), *N.* cf. *pauper* (WHITFIELD), *Solenoceras* cf. *reesidei* STEPHENSON, *Exiteloceras unciforme* LEWY, *Baculites* sp., *Libycoceras* sp.

The foraminiferal fauna, after D. HERM (cf. p. 155) is in accord with this.

Thus the age for the base of the D.S.M. has to be corrected to **Uppermost Campanian.**

Above the ammonite level follow blackish to greenish clays with occasional marls on intercalations of brownish siltstone beds. This is where *Exogyra overwegi* (v. BUCH) is locally frequent.

Referring to the original description of ZITTEL (1883) it is this part of the section which he called "*overwegi*-beds". It must be noted that the "*overwegi*-beds" occur rather low in the D.S.M.

The section continues with about 100 ms of gray to greenish clays with some bands of phosphorite bearing glauconitic sandstone. Further NW resistant marls replace part of the clays.

Two tiers of carbonatic sandstone with some ms of clay sandwiched in between form an excellent marker horizon. The lower sandstone is crowded with "*Cardita*" *libyca*, the upper one with shell debris and both terminate with sandy phosphoritic-glauconitic and iron-oolitic deposits. *Libycoceras* was extracted from the lower bed.

The marker tiers are the reduced eastern equivalents of the Ammonite Hill Mb., while one or both phosphoritic deposits correspond to the conglomeratic bands of ABBASS & HABIB (1969) in the Gebel-Edmonstone region. Since this marker horizon can be followed over quite a distance, we think it deserves a separate term: Bir-Abu-Munqar Horizon (p. 155).

Some 60 ms of grayish clay overlie the marker beds. In some parts the clay is rather silty. Higher up it becomes slaty with another silty intercalation that ends with a glauconitic sandy band. From there on upward we encounter gray, red, and variegated clays. Immediately below Tarawan Fm. there appears an additional band of glauconitic sand with phosphorite nodules. We found that the terminal part of D.S.M. is very variable from place to place. Thickness of the Gebel-Gifata section is 260 ms.

From the Qûr-el-Malik to the W and NW, the Ammonite Hill Mb. substitutes most of the middle part of the D.S.M. and the upper part is replaced by the Peak Hill Mb.

In northern Farafra depression Tarawan Fm. entirely replaces the D.S.M. Toward the S the D.S.M. thickens and NE the eastern descent of the pass to Bir-Abu-Munqar the top of the member partly consists of greenish silty marls with Schizaster and their burrows. Otherwise the top is formed by red and green clays the slope of which are studded with limonitic specimens of a stunted fauna. *Globorotalia angulata* (White) dates the D.S.M. top bed at this locality to Montian. The overlying Tarawan Fm. (with *Globorotalia pseudomenardii* Bolli) follows on a lacuna comprising the upper *Globorotalia pusilla* Bolli-Zone (cf. p. 162).

Bir-Abu-Munqar Horizon of Dakhla Formation

Figs. 7, 8, 16, 17

At the base of the scarps immediately N of Abu-Munqar, especially in the neighbourhood of the big outlier and the western scarp-spur along the old route to Ain-Dalla, a bed studded with fossil remains in phosphoritic preservation is exposed. The peculiar faunal aspect is widely distributed and may be used as a marker horizon.

Omara et al. (1970) presented a small stratigraphic table at the foot of their fig. 2 map. In this an "Abu Monquar Fm." includes upper and lower shales and coralline limestone. While the coralline limestone represents a separate lithologic unit, the shales are the Dakhla Shale Member of Said (1962). Beside this, "Abu Munqar Fm." would not be valid because there is no reference section cited.

Bir-Abu-Munqar Horizon (B.A.M.H.)

Name: Bir-Abu-Munqar, at the bend of the Farafra – Dakhla road; junction of various old caravan routes.

Reference area: W of spur, W of the old Ain-Dalla route.

Definition: The bed is 1,5 ms thick at the reference section. It consists of a grayish to yellowish marl with angular quartz grains, glauconite and rare ferric ooids. In the lower part (0,5 ms) phosphatized fossils with gray to slightly red metallic luster on the surfaces abound. The characteristic faunal elements are large and medium gastropods.

The horizon may be followed toward the SW into the Sand Sea. It also crops out in the foothills of the scarp N of the Bir-Abu-Munqar – Dakhla route. Further SE it is removed by pre-Oligocene erosion as one approaches Qûr-el-Malik. The horizon

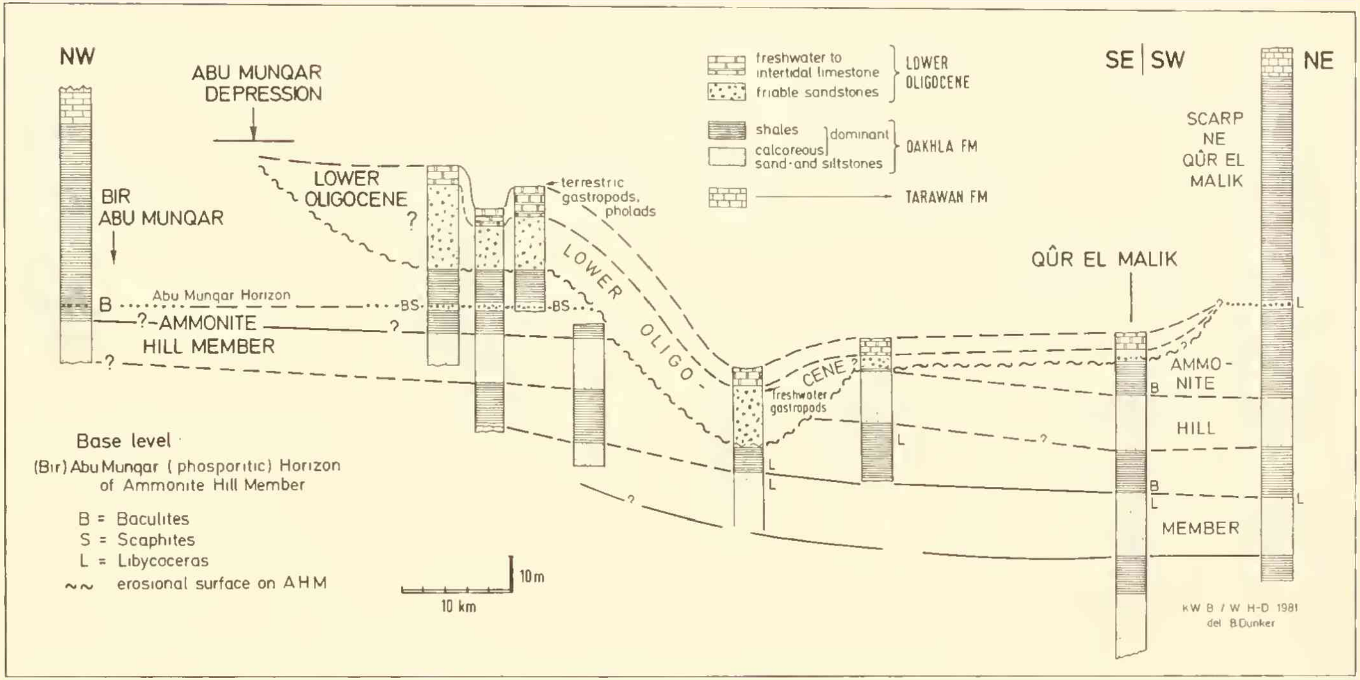

Fig. 8: Series of sections between Bir-Abu-Munqar and Qûr-el-Malik. Striking feature is the Lower Oligocene (?) sandstone and limestone sequence. Presentation shows the Oligocene beds as originally laid down in a former depression. Apparent deformation of the depression is due to straightening the originally updomed Bir-Abu-Munqar Horizon as baseline. Other specifications as in explanation to fig. 6.

reappears again in the cliff of D.S.M., NE of the Qûr and holds out to Gebel-Gifata section, where it is represented by a rather thin band of "phosphorite" associated with a sandstone bed, separated by 7 ms of clay from a similar horizon below. According to ABBASS & HABIB (1969) the horizon is very strikingly developed in the Gebel-Edmonstone ("Mawhoub") region, where these authors consider that "conglomerate" as the top bed of their "Mawhoub Fm.".

In the Sand Sea the phosphorite content vanishes locally and ferric ooids become the paramount constituent.

The more important faunal elements of the Abu-Munqar Horizon include: *Libycoceras* sp., *Baculites* sp., *Scaphites* sp., *Eutrephoceras desertorum* (QUAAS), *Pseudocenoceras applanatum* (WANNER), *Hercoglossa danica* (v. SCHLOTHEIM), *Aturioidea* aff. *schweinfurthi* (QUAAS), *Exogyra overwegi* (v. BUCH) numerous gastropods and pelecypods, "*Terebratula*" *libyca* WANNER, fruits of *Nipa* and others. While the ammonites suggest a Maastrichtian age, some gastropods and nautiloids have Paleocene aspects. The foraminiferal fauna of the late *Globigerina (Eoglobigerina) pseudobulloides* PLUMMER-zone *Planorotalites compressus* (PLUMMER), *Globigerina (Eoglobigerina) pseudobulloides, Globigerina (Eoglobigerina) triloculinoides* PLUMMER) clearly points to early Mid-Danian deposition. From the Abu-Munqar Horizon at the scarp NE of Qûr-el-Malik we recovered *Plummerita hantkeninoides* (BRONNIMANN) and *Rugoglobigerina scotti* (BRONNIMANN) of the Uppermost Maastrichtian.

Thus Abu-Munqar Horizon may be used as a mapable expression of the Cretaceous/Tertiary boundary, involving smaller hiatus of various extent.

Ammonite Hill Member of Dakhla Formation

Figs. 6, 8, 9, 11, 16, 17

This unit was first created for a scarp-forming feature with special surface reflexion properties useful in compiling a modern map based on remote sensity (edit. LIST & KLITZSCH). Hence the term Ammonite Hill Member rests only on reflexion properties as no defined reference area was ever given.

During two seasons in the field it became clear that the member is facially not interrelated and not identical with ZITTEL's "gray foliate clays with *Exogyra overwegi*" („Graue Blättertone mit *E. o.*", ZITTEL 1880, 1883 as described by QUAAS [1902, 328]): The „Blättertone" form part of the lower Dakhla Shale Mb.

Ammonite Hill Member (A.H.M.)

Name: After the scarp named „Ammoniten-Berge" by ZITTEL (1880), now "Ammonite Hills" on the 1941 map of Egypt (1:500000, sheet 7 [Dakhla]).

Reference area: Ammonite Hill scarp at interdunal channel between 26°N and 26°10′N and along 27°05′E. Since the former Conoco seismic line 20 was laid out along this channel, the term Conoco 20 channel is also used in this paper.

Definition: A series of carbonate-bound siltstones and sandstones, sometimes several ms thick, intercalated with gray to greenish foliated clays. Some of the thinner sandstones are heavily bioturbated, and others are immensely rich in fossils. A few rare beds contain phosphorite nodules and phosphoritized fossils.

In the reference channel the member consists of two scarps, the southern Ammonite Hill scarp proper, and another one about 15 kms north of it. The base of the member is represented by highly carbonatized scarp-forming beds, usually weathering into bizarre structures and "cannon balls". The top is exposed in the northern scarp and above the last occurrence of *Exogyra overwegi* is characterized by predominance of clays with carbonatic siltstone beds enclosing myriads of *Turritella.* In Conoco 20 channel the A.H.M. is approximately 95 ms thick (compound section!).

Toward the W, sand content and sandstones increase while in eastern direction clays become more and more dominant. This quantitative increase of sand and sandstones toward the W, also observed in the other members of Dakhla Fm., is very

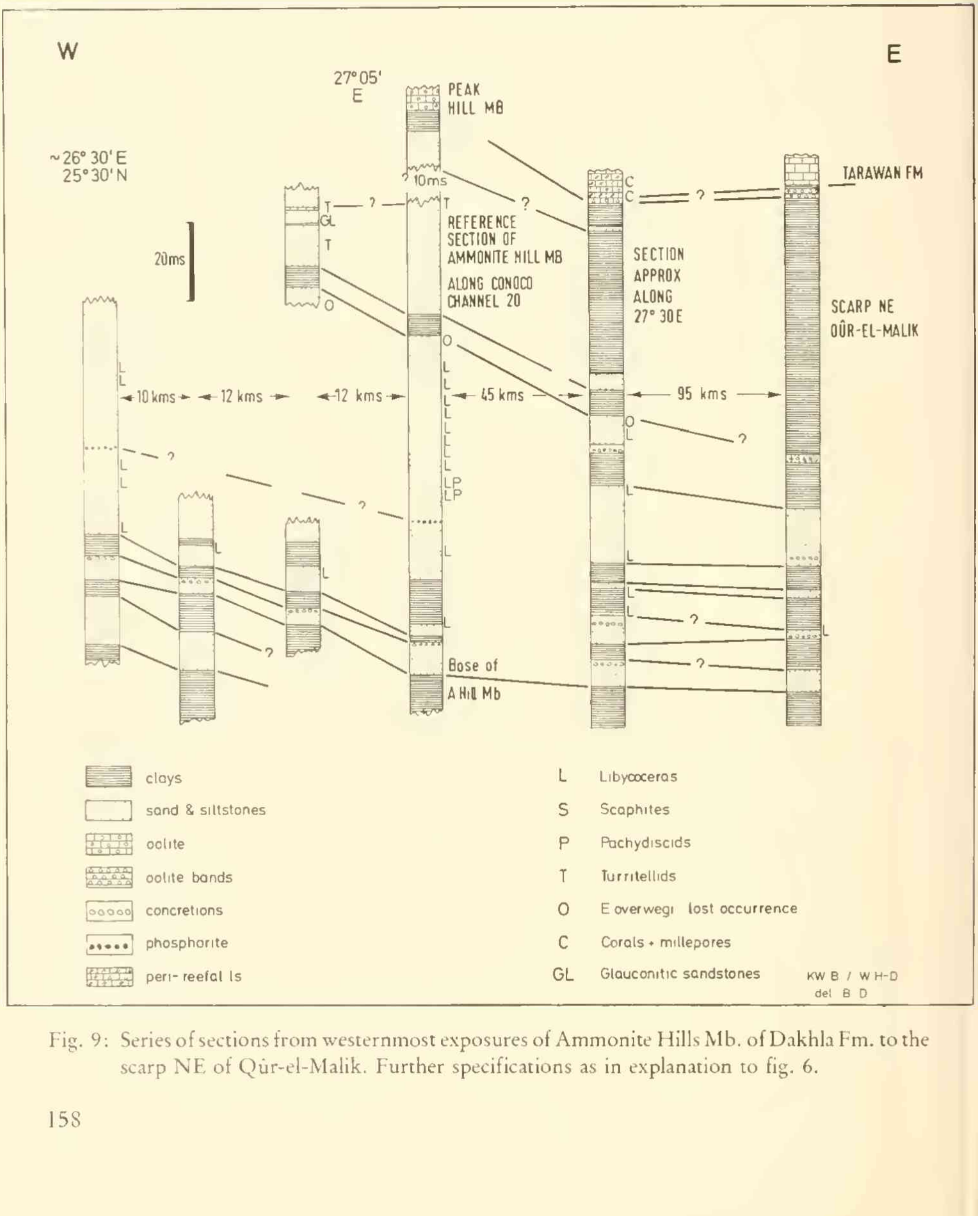

Fig. 9: Series of sections from westernmost exposures of Ammonite Hills Mb. of Dakhla Fm. to the scarp NE of Qûr-el-Malik. Further specifications as in explanation to fig. 6.

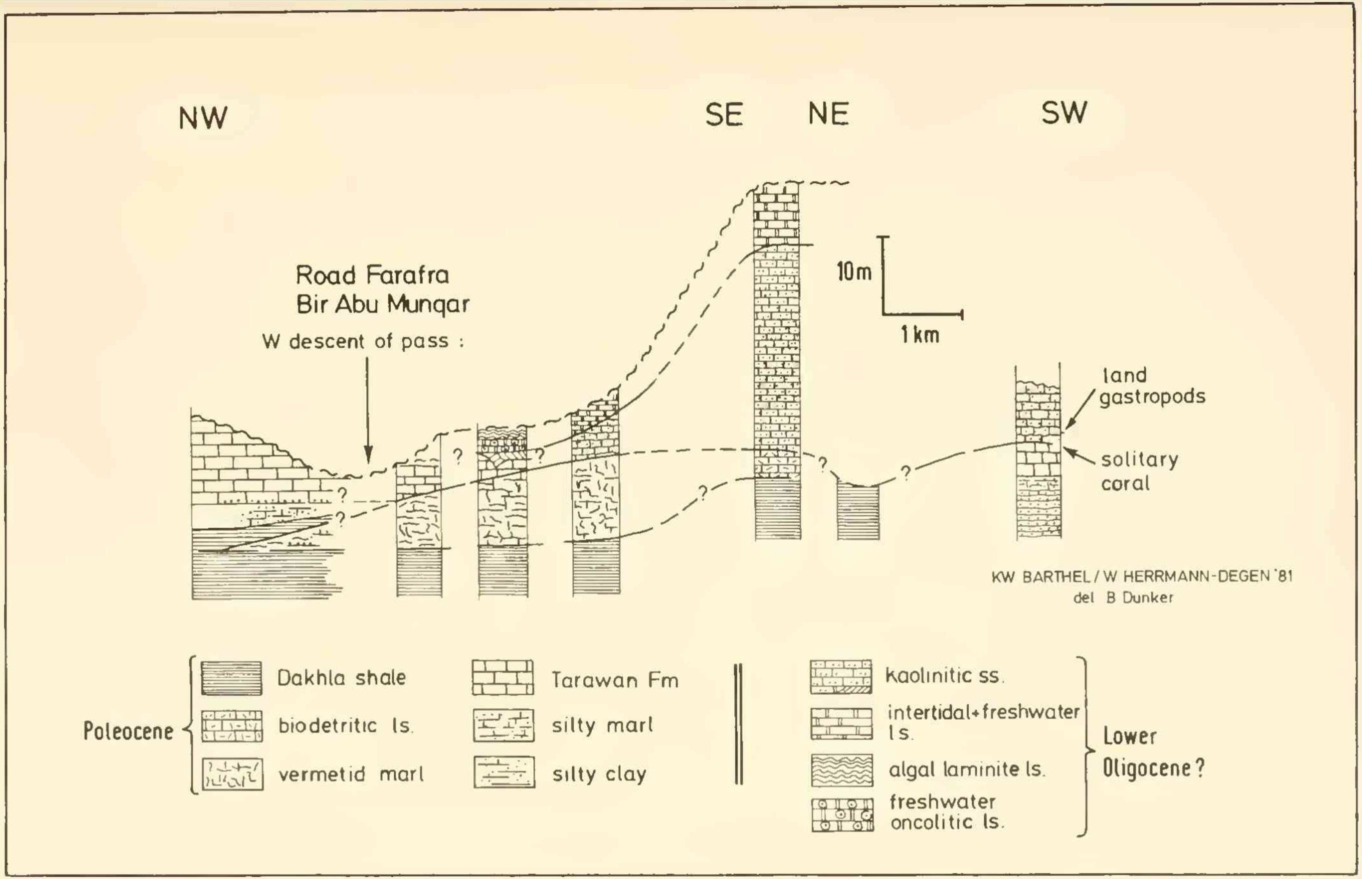

Fig. 10: Sections in vermetid marl facies at the western descent of pass between Farafra and Bir-Abu-Munqar depressions. Note that in SE the Lower Oligocene (?) sandstone-limestone sequence is underlain by intertidal carbonate. The vermetid facies builds a fan from the former area of uplift toward the NW.

much consistent with the structural outlines given by BEALL & SQUYRES (1980; cf. Fig. 1). In the reference region of Dakhla Fm., at Gebel-Gifata (p. 150) the A.H.M. is reduced so that only a few indicative banks exist.

A.H.M. is assumed to be a fan originating from the southwestern flank of the Gilf-el-Kebir spur.

In the Ammonite I section a tongue of Tarawan Fm. replaces part of the A.H.M.

Morphologically the A.H.M. remains scarp-forming as far as there is a sequence of at least several closely spaced sandstone beds. The scarp can be followed from approximately 26°30′ E to the scarps SSE of Bir-Abu-Munqar. In most cases the immense number of *E. overwegi*, weathering out from thin sandstone-ledges and often remaining as a residual cover on clay surfaces, signals the presence of the A.H.M.

Considerably more restricted in frequency and vertical distribution in the A.H.M. is *Libycoceras ismaelis* (ZITTEL).

In the western exposures of the A.H.M. vertebrate remains become increasingly more numerous, turtles and fishes being the most frequent. Among the rarer finds are bones of mosasaurs, plesiosaurs and dinosaurs.

Peak Hill Member of Dakhla Formation

Figs. 9, 11, 16, 17

In the Sand Sea, above the Ammonite Hill Member, clays, carbonate-bound sandstones, and siltstones continue upsection. There, however, is an intercalation of true carbonates. These beds, with high probability, represent a lagoonal facies of Tarawan Fm. in the E.

Peak Hill Member (P.H.M.)

Name: After interdunal channel marked by a peak (about 60 kms SW El-Qûss-Abu-Said, southern end).

Reference area: Scarp 5 kms N of the peak. 27°02′30″ E and 26°26′ N.

Definition: The striking sediments of this unit are whitish to yellowish oolites.

The oolites are intercalated in the normal clay-carbonatic siltstone-sequence. In higher levels the usual greenish to grayish clay may turn vermilion in color. Red marls with oolites in the same color are locally important. A chain of small patch reefs (*Platygyra, Favia, Actinastrea, Caulastrea, Siderastrea* [Siderofungia]) apparently limits the oolite facies to the E (27°21′30″ E and 26°26′ N). Due to erosion, in this region, interrelations with the Tarawan are still tentative. These coral reef structures are an equivalent in time to the oil bearing reefs at the NE (Libyan) side of the Gilf-el-Kebir spur (TERRY & WILLIAMS 1969).

In the reference area the member starts with several carbonate-bound siltstone beds which are topped by a bed of biodetritic oolite. Vermilion marls, containing silts and ooids, follow, grading upwards into pure crossbedded oolites. The section closes with grayish to purplish marls rich in organic detritus. Above these marls a nodular to dense limestone with large gastropods (*Campanile* [?]) may be an equivalent of Farafra Fm.

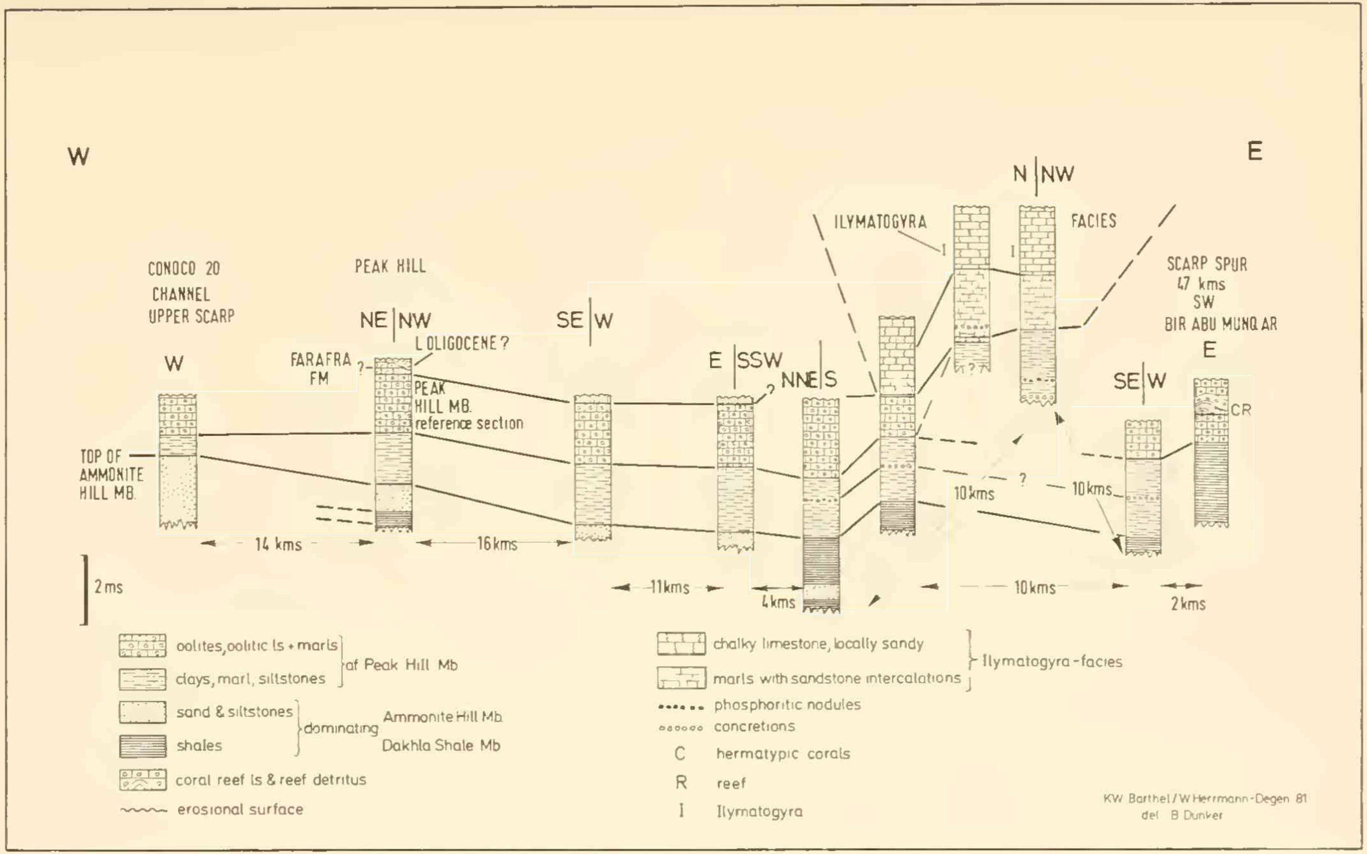

Fig. 11: Series of sections in the Peak Hill Mb. of Dakhla Fm., from Conoco 20 channel to approximately 50 kms W of Bir-Abu-Munqar Note the coral reef development at E margin of oolite deposition. In the N the oolites are overlain by mudbank carbonate with *Ilymatogyra osiris* (ZITTEL).

The oolites of the P.H.M. can be followed south in erosional relics to latitude 26° 17′ N.

In Conoco 20 channel, N of Ammonite Hill scarp, and above the A.H.M., oolites occur in reduced thickness. Siltstones become increasingly more important.

Foraminifera from the Ammonite 1 well suggest a range from Late Danian(?) to Ilerdian for the Peak Hill Mb.

Oolites were observed as far as 10 kms north of the reference section but may still range further N.

The oolites proper are poor in fossils, except for occasional *Echinolampas* and *Gitolampas*.

Tarawan Formation ("Tarawan Chalk")

Figs. 6–10, 12, 14–17

Awad & Ghobrial (1966) used this term for the white limestones and chalks covering Dakhla Fm. in Kharga Oasis. Tarawan Fm. also forms the top of the scarps in Dakhla Oasis, and in part of the Farafra depression. S of the Qûss-Abu-Said plateau, higher levels of the formation exhibit intensive burrowing by callianassids.

In the basal layers sometimes pebbles of phosphorite, of sandstone, of glauconite, and even of quartz, as well as shark teeth, form some sort of a diluted transgressional conglomerate. Interruptions of sedimentation may occur at various levels.

It is noteworthy that Tarawan Fm. in many places holds a rich fauna, including among others *Echinocorys fakhryi* Fourtau, large voluthid gastropods, *Lobostoma ramosum* Wanner (stylasterina), *Palaeopsammia multiformis* Wanner, *Caryosmilia granosa* Wanner, and a characteristic sponge assemblage with *Schizorhabdus libycus* Zittel, *Rhizopoterion poculum* (Wanner), and the genera *Eutactostomium, Diphyllospira, Leptophragma, Plecteurete, Aphrocallistes* of which Herrmann-Degen described 7 new species (1980).

The Tarawan Fm. in the scope considered so far, lies with a gap on Dakhla Fm. The time lapse of the gap has to be determined from place to place. As one proceeds toward the W the base of Tarawan Fm. becomes younger. This statement is valid for the Dakhla – Bir-Abu-Munqar stretch and SW Farafra. The general thickness is reported to vary from a few ms to several tens of ms.

In some instances the base of Tarawan Fm. was dated by planctonic foraminifera:

1. in SW Farafra, W of the road to Bir-Abu-Munqar, a fauna of the *Globorotalia pseudomenardii* Bolli-zone proves a Thanetian age.
2. at Gebel-Gifata, near Mut, *Globorotalia uncinata* Bolli and *Globigerina (Eoglobigerina) trinidadensis* (Bolli) give an Early Montian *(uncinata*-zone) level.

On El-Kharafish in the Dakhla area, the top of Tarawan Fm. has been narrowed down by overlying Late Thanetian limestones with *Glomalveolina dachelensis* (Schwager) (Hottinger 1960, 54).

At the eastern narrows of the passage from Qasr-el-Farafra to Ain-Dalla the top of the Tarawan yielded a Latest Thanetian or Earliest Ilerdian microfauna *(Globorotalia pseudomenardii* Bolli, *Globorotalia velascoensis* (Cushman).

Summarizing our knowledge in the field, we have to expand the concept of Tarawan Fm. Thus we include the virtually identical "Farafra Chalk" of YOUSSEF & ABDEL-AZIZ (1971) that, after these authors, spans Campanian to Danian. "Farafra Chalk" is invalid because "Farafra Limestone" (p. 172) has priority. This "chalk" largely forms the bottom of Farafra depression and after BARAKAT & ABDEL HAMID (1974), reaches 160 ms of subsurface thickness, resting, with a few ms of dolomite in between, on "Nubian sandstones". Adding 60 ms of Tarawan Fm. exposed on the surface, it reaches a total thickness of 220 ms.

Both "chalks", Tarawan Fm. s. str. and the chalk of Farafra depression, become united near the road climbing the pass to Bahariya. There the exposed sequence covers the time from at least Late Maastrichtian (*Globotruncana gansseri* BOLLI, *Globotruncana conica* WHITE, *Globotruncana aegyptiaca* NAKKADY) to Thanetian (*Globorotalia pusilla* BOLLI, *Globorotalia angulata* [WHITE]).

Tarawan Fm. in the revised sense is interfingering with Dakhla Fm. in the S (cf. BARAKAT & ABDEL HAMID 1974) and SW. A Late Maastrichtian "tongue" was encountered even in Ammonite I well. Wells between Farafra and Dakhla should eventually prove that

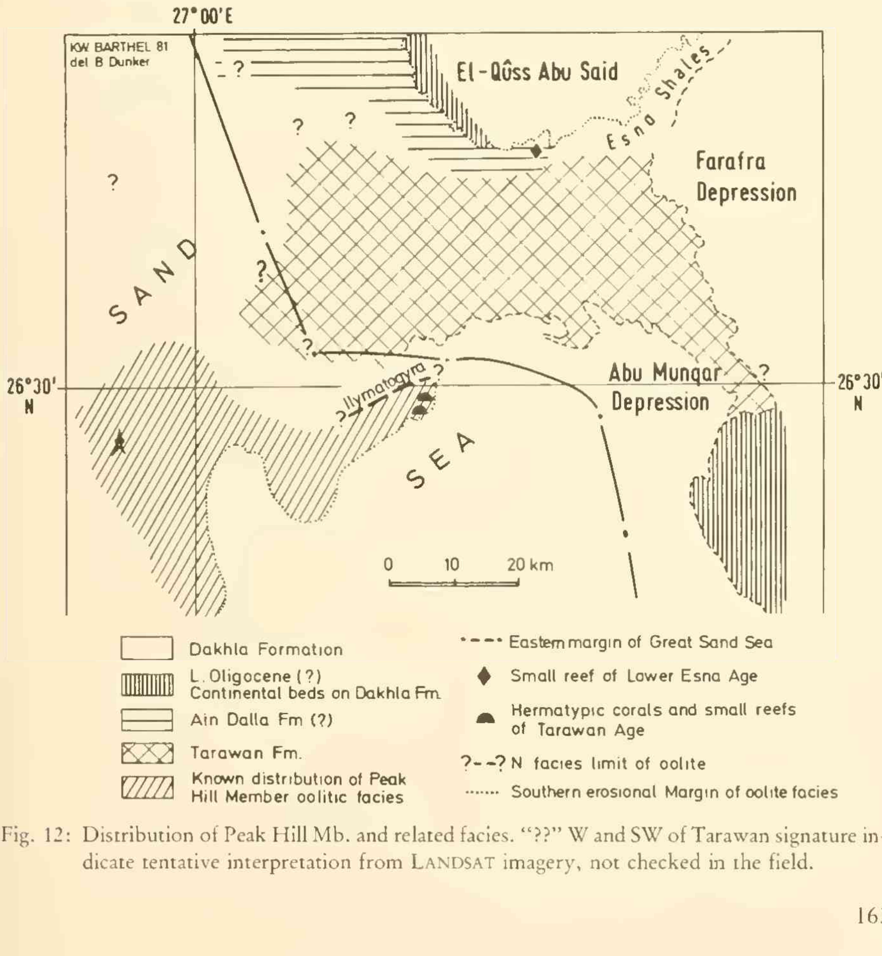

Fig. 12: Distribution of Peak Hill Mb. and related facies. "??" W and SW of Tarawan signature indicate tentative interpretation from LANDSAT imagery, not checked in the field.

the Qûr-el-Malik Mb. is but another such "tongue". The replacement of Dakhla Fm. by Tarawan Fm. which may even turn somewhat sandy toward the N, and the center of carbonate deposition in Farafra depression suggest for Tarawan Fm. a fairly shallow marine origin on a swell, in our case on the Bahariya Arch.

In Ain-Maqfi and eastern Qûss-Abu-Said regions the top of Tarawan Fm. may intercalate with Esna Fm. Interfingering is frequently associated with hiatus.

In the SE Sand Sea Tarawan Fm. is substituted by the Peak Hill Mb. of Dakhla Fm. Coral reefs are found in the transitional region.

Vermetid debris facies

Fig. 10

The small scarp rimming the eastern side of Abu-Munqar depression exposes a peculiar type of sediment. A mass of fossil debris among which vermetid fragments are the most striking elements, is bound by sandy marls. The thickness of this deposit decreases from 14 ms in the SE to pinchout in the NW, over a stretch of about 5 kms. Pinchout occurs approximately 1 km NW of the Farafra – Abu-Munqar road where it descends from the scarp.

While the substrate of the vermetid debris facies is uniformly red or green Dakhla Shale. It may, however, be covered by Tarawan Fm. (NW) or by Lower Oligocene (p. 172) sandstones and limestones.

Unfortunately erosion has truncated the SE connection with the large plateau SSE Abu-Munqar, which is covered by a thick Lower Oligocene sequence. In the area where eastern and southern scarps meet, these Oligocene beds rest on a yellowish crumbly limestone, fragments of which show birdseye structures. The limestone contains shell debris, badly preserved ostracods and foraminifera, peloids, fragments of stromatolithic crusts, remains of dasyclads, characeans (?). The various components are bound by coarse sparry calcite. Here we probably face the coastal (intertidal) facies, contemporaneous to the vermetid sandy marl and marginal to an uplifting area (p. 177). The masses of vermetus remains are indeed in accord with an uplift as the paper by Tzur & Safriel (1978) shows: "... they [the vermetids] can exist only where the coastal rocks are sufficiently soft and erodable and where the coast is rising at an appropriate rate relative to the rate of marine erosion."

A sample from immediately below the base of the vermetid marls is dated to Montian by *Globorotalia uncinata* Bolli and *Globorotalia angulata* (White).

Esna Formation (Esna Shale)

Figs. 15–17

Most of the eastern and western cliffs framing Farafra depression are made up by greenish clays and marls of Esna Fm. Since this unit received due consideration by LeRoy (1953), R. Said & Kerdani (1961) and Youssef & Abdel-Aziz (1971) we refer to their papers. A shallow water limestone intercalation (1–2 ms) in the lower part of the Ain-Maqfi area apparently is a useful marker bed and therefore was named Ain-Maqfi Member of Esna Formation by R. Said & Kerdani.

At the base and in transition to Tarawan Fm., Esna Fm. sometimes contains beds of hard limestones. Relics of these on the El-Kharafish Plateau (Dakhla region) have been dated Late Thanetian by *Glomalveolina dachelensis* (Schwager) (Hottinger 1960). Esna Fm. in Farafra ranges from Upper Thanetian through the Middle Ilerdian. The approximate thickness is 150 ms in the E, decreasing steadily toward the W.

In southwestern direction (S corner of El-Qûss-Abu-Said) the base of Esna Fm. becomes strongly carbonatic and small coral reefs *(Actinacis* [?]) are developed. Intercalations of biodetritic material become numerous. The lowermost of these is crowded with *Nummulites deserti* de la Harpe and *Nummulites fraasi* de la Harpe. Toward the NW, i. e. in the Ain-Dalla area and the passage from Farafra to Ain-Dalla, Esna Fm. is laterally grading into the yellowish chalky limestones of Ain-Dalla Fm. (p. 165).

Ilymatogyra-Facies
Figs. 11, 12

About 30 kms WSW of Bir-Abu-Munqar the Peak Hill Mb. in northern direction is replaced by marly to chalky limestones.

Above Dakhla Fm. the sequence starts with 7 ms of carbonate bound sandstones and marls. The sandstones are heavily burrowed by callianassids.

This complex is followed by 6–10 ms of alternating beds of chalky limestones and thin marls. The bases of some limestone beds are riddled with callianassid burrows. At the top 6–8 ms of massive limestone and chalk are preserved. The limestones show whitish to yellowish tints.

15 kms further W the sequence seems to grade into chalky marls and, still further W, it again is replaced by latest Peak Hill Mb. sediments. A chalky transitional facies is also observed toward the SW.

We had no opportunity to trace the *Ilymatogyra*-facies toward the N and NE but we assume that it is a lateral substitute of Ain-Dalla Fm.

In some of the beds the rudist-imitating mud-screw oyster *Ilymatogyra osiris* (Zittel) is very abundant. Among other faunal elements, we mention *Deltoidonautilus* cf. *tamulicus* (Kossmat).

Unfortunately our micropaleontological samples from this facies turned out to be barren. According to the geological constellation the *Ilymatogyra*-beds should be the equivalents of Ain-Dalla Fm.

Under the term Abu-Tartur Fm., Hermina (1967) described an apparently similar facies. It is exposed along the Darb-el-Tawil, across the northern Abu-Tartur plateau. The first who mentions *Ilymatogyra* from this region was Zittel (1883, LXIX). Hermatypic corals also have been reported from this region. The carbonate sequence there is considerably thicker than ours (tectonic repetition?).

Ain-Dalla Formation
Figs. 13, 15–17

Proceeding westward in the northern passage from Qasr-el-Farafra to Ain-Dalla, it becomes obvious that Esna Fm. is laterally replaced by limestones and that the underlying Tarawan Fm. disappears. The limestones of the scarps around Ain-Dalla were generally mapped as "chalk", but differ from Tarawan Fm. by their yellowish appearance and their fauna.

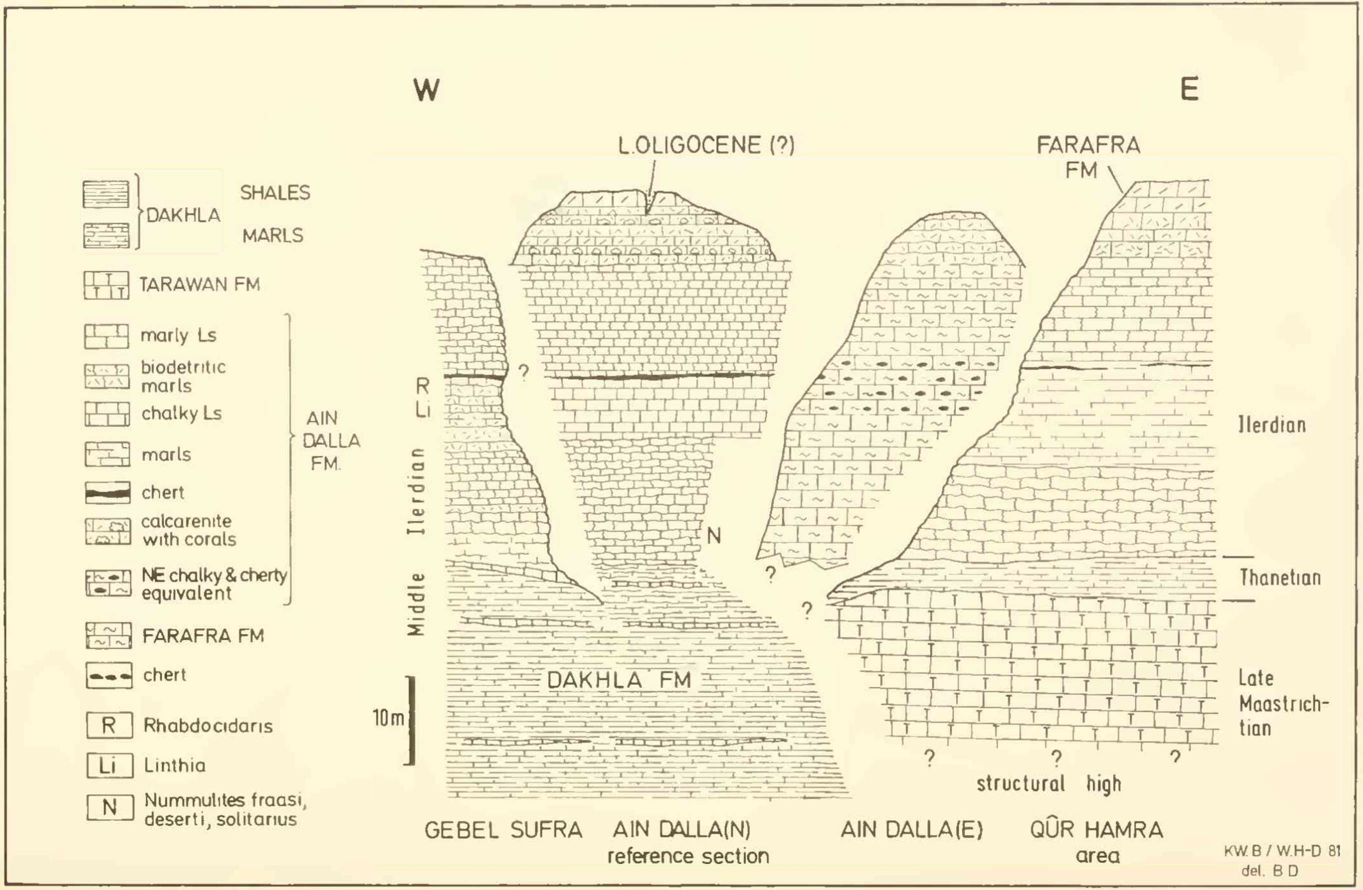

Fig. 13: Combined and simplified sections of Ain-Dalla Fm. Scale only approximate, lateral extent about 35 kms. Note that in N and NE directions Ain-Dalla Fm. grades into Tarawan Fm.

Ain-Dalla Formation

Name: After Ain-Dalla, a well approximately 70 kms WNW of Qasr-el-Farafra.

Reference area: Scarp-spur 10 kms N of Ain-Dalla; 27°18'47''E and 27°24'19''N.

Definition: Whitish to yellowish well bedded limestones. The average thickness of a single bed is 15 cms. Bank-surfaces are undulating green to gray marls of various thickness separate thin limestone beds. In the lower part of the section of the reference area marls are still fairly well represented and echinoids, ostreids as well as other molluscs *Nummulites deserti* DE LA HARPE, *Nummulites fraasi* DE LA HARPE, *Nummulites solitarius* DE LA HARPE abound. The lower part ends with a bed that is heavily bioturbated, contains many *Operculina* and red sediments. This may mean interruption of sedimentation. Up-section follow bedded chalks that terminate with a laminated chert band. Above the chert lies another series of alternating marl and limestone beds. The section terminates with calcarenitic limestones that contain hermatypic corals in two levels *(Latiphyllia*-type). The reference section measures 47 ms. The section yielded *Globorotalia (Morozovella) subbotinae* MOROZOVA, *Globorotalia (Morozovella) marginodentata* (SUBBOTINA), *Acarinina wilcoxensis* (CUSHMAN & PONTON), and *Pseudohastigerina wilcoxensis* (CUSHMAN & PONTON) of the Middle Ilerdian.

At Gebel-Sufra (27°19'E; 27°17'42''N), 12 kms W of Ain-Dalla the section is rather similar, except for the middle part which here turns rather crumbly and organo-detritic. Stingers of *Rhabdocidaris* are frequent. *Linthia (Lutetiaster)* is less abundant. Turritellids and pelecypods are well represented. *Nummulites deserti* (A), *Nummulites solitarius* (A & B), *Nummulites fraasi* (A), *Nummulites praecursor* DE LA HARPE are numerous. Planctonic faunae belong to the *Globorotalia subbotinae*-zone of the Mid-Ilerdian.

Gebel-Sufra section rests on marly greenish gray Dakhla Fm.; also of *subbotinae*-zone age.

E of Ain-Dalla the sediment turns into chalk, with chert nodules in mid section, and calcarenitic limestone on the top. So far our samples from that locality were barren.

Qûr-Hamra (27°33'38''E; 27°17'36''N), an outlier of the northern scarp in the Farafra – Ain-Dalla passage, again shows a section that corresponds well with the reference area. The limestones (once more *subbotinae*-zone), however, rest on about 5 ms of marls, which are very rich in planctonics of the *Globorotalia menardii/velascoensis*-zones. These, in turn, are underlain by Tarawan Fm. (Late Maastrichtian with *Racemiguembelina fructicosa* (EGGER), *Globotruncana conica* WHITE, *Globotruncana gansseri* BOLLI, *Globotruncana aegyptiaca* NAKKADY).

The distribution of Ain-Dalla Fm. in the W and N is still unknown. From our experience with other formations we assume that sandstone and clay wedges may intercalate in the W.

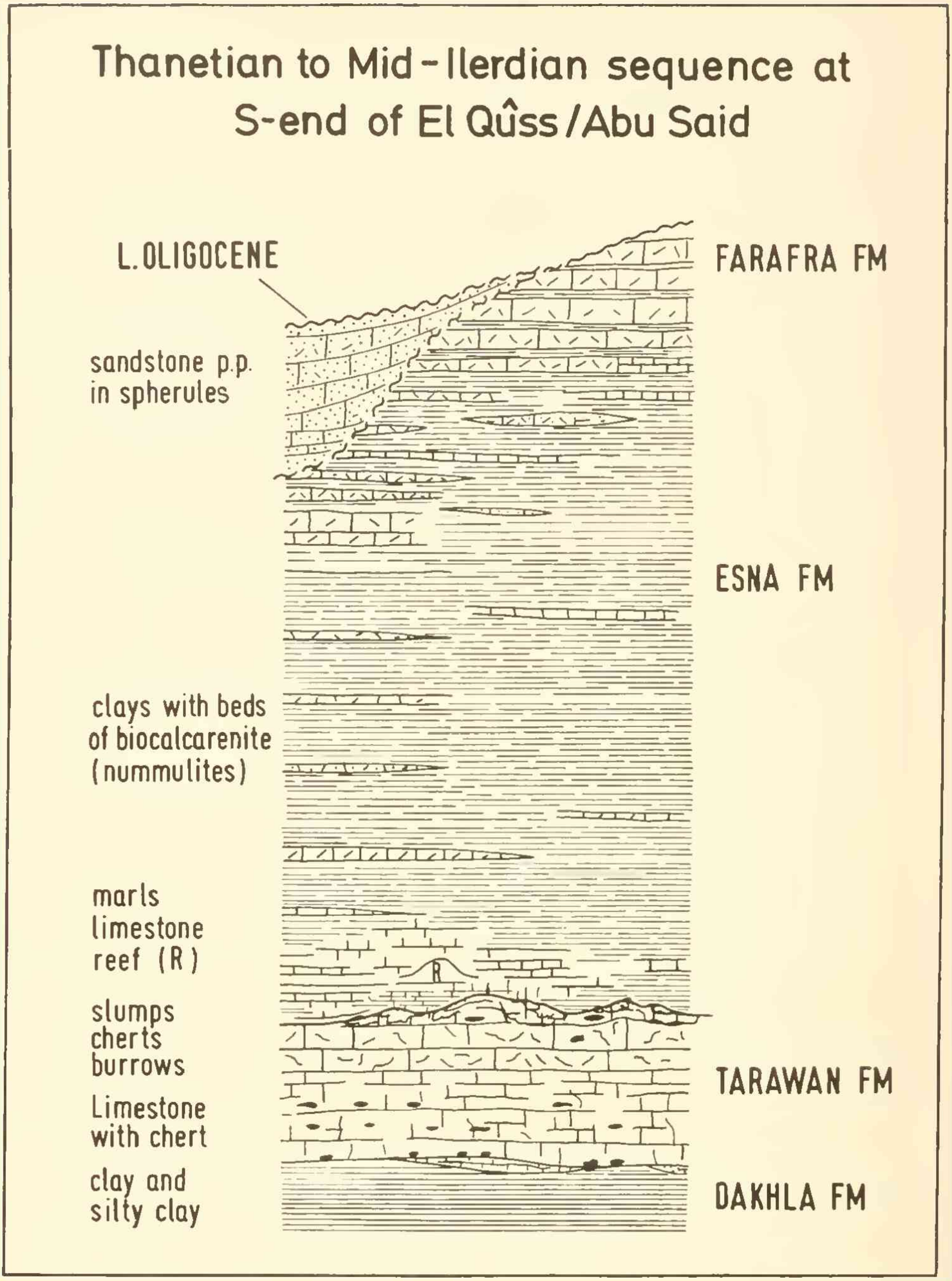

Fig. 14: General situation at S side of El-Qûss-Abu-Said. Not to scale. Lateral extent approximately 20 kms. No detailed sections were taken in upper Esna Fm. Note transition from Tarawan to Esna Fms. with slumps and small coral reefs.

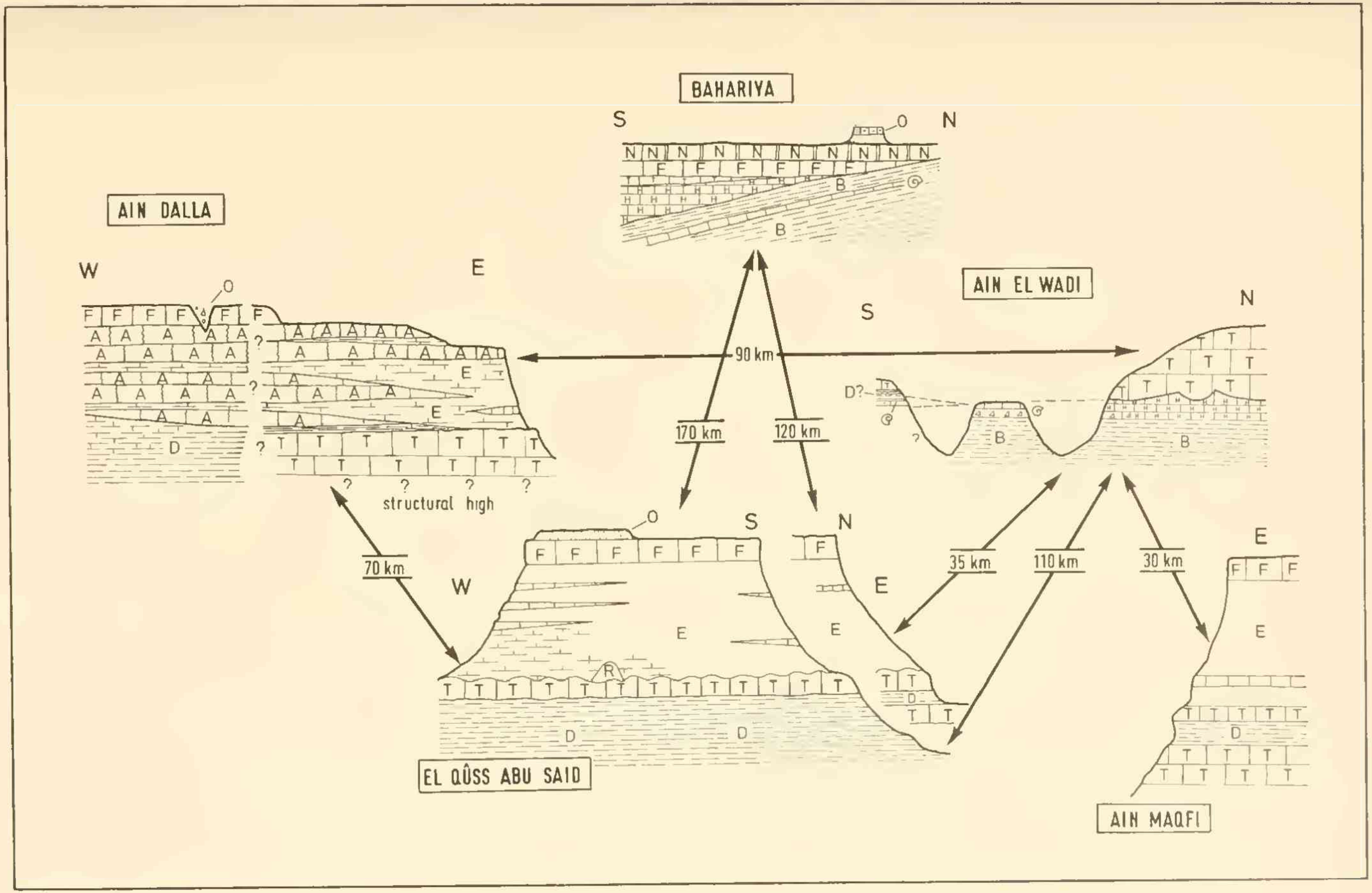

Fig. 15: Generalized sections, not to scale, to show interrelations of lithostratigraphic units in Fara fra depression and Ain-Dalla region.

A = Ain-Dalla Fm.
B = Bahariya Fm.
D = Dakhla Fm.
E = Esna Fm.
F = Farafra Fm.
H = Hefhuf Fm.
O = Lower Oligocene (?)
N = Naqb. Fm.
R = coral reef
T = Tarawan Fm.

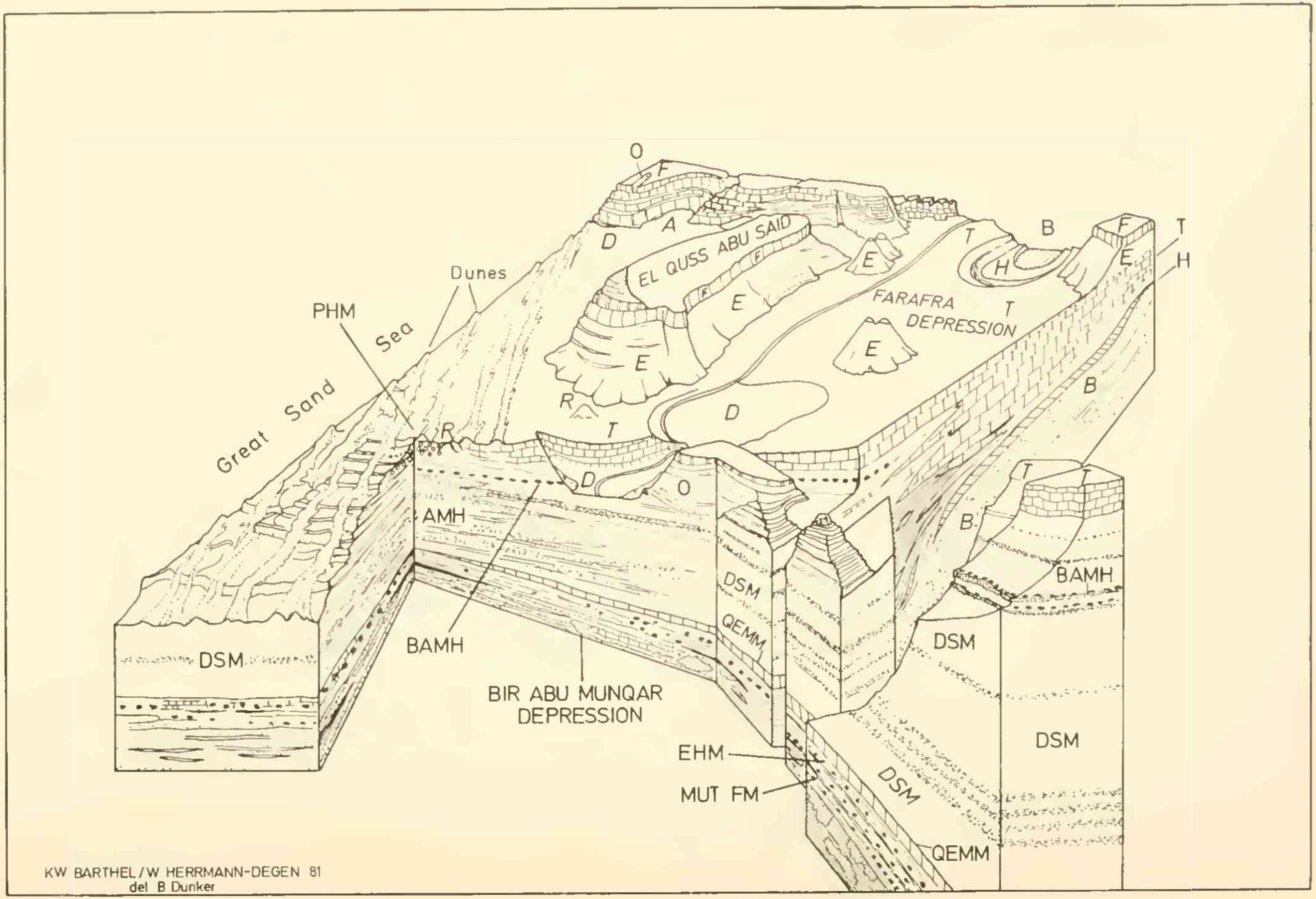

Fig. 16: Block presentation of lithostratigraphic interrelations for entire area of investigation. Not to scale and in parts tentative. Abbreviations as given in the text (pp. 149 ff.) and in explanation to fig. 15.

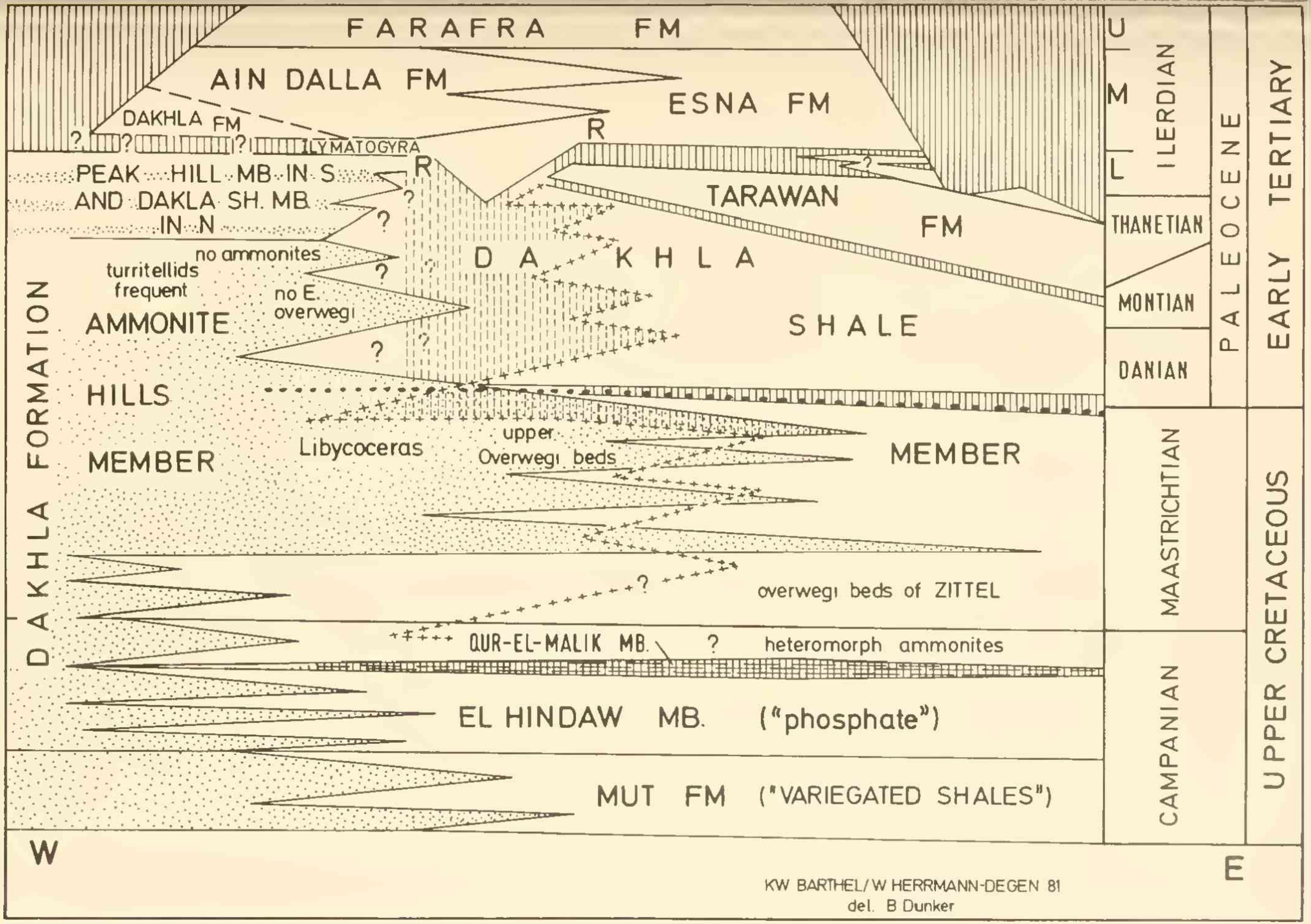

Fig. 17: Stratigraphic correlation chart. It is important to know that the Ain-Dalla – Farafra units at the top of the chart are projected into one plane with the Sand Sea to Dakhla units of the lower part of the chart. The westward interdentations of Tarawan Fm., which in Farafra depression replaces Dakhla Fm., are indicated by a line of crosses. Hiatus are presented by widely spaced vertical lines that become interrupted when hiatus exist only in the N.

Farafra Formation (Farafra Limestone)
Figs. 11–17

Farafra limestone was introduced by R. SAID in 1960 (Micropaleontology, 6: 227–286) as an equivalent of Thebes Fm. in the E. The thick beds of massive and partly calcarenitic limestone cap the Qûss-Abu-Said and Ain-Maqfi sections. Marls are intercalated in the lower part of the formation, in transition to Esna Fm. Further references on Farafra Fm. may be loked for in LEROY (1953), R. SAID & KERDANI (1961) and in YOUSSEF & ABDEL-AZIZ (1971). The age of Farafra Fm. is fixed to Middle Ilerdian by *Alveolina decipiens* SCHWAGER (HOTTINGER, 1960, 123). Frequent alveolinids and *Nummulites* of the *deserti* DE LA HARPE – group indicate shallow water environment.

Residual Blocks

Between 27°30°E/27°°E and 26³°N/27°90′N approximately, blocks of silicified limestone often litter the surface of plateaus. Badly preserved alveolines small *Nummulites* and *Operculinas* suggest that the blocks are the residue of a former cover of Farafra Fm. limestones.

Lower Oligocene ? (Qatrani Formation?)
Figs. 8, 9, 10

From the plateau NW of Bahariya Oasis LEBLING (1919) described some hills consisting of sandstones covered by sandy limestones. This sequence rests on limestones of Mokattam Fm. LEBLING associates them with Qatrani Fm. and, consequently, regards them to be of Lower Oligocene age.

We were surprised to find a similar sequence of sandstones and limestones forming the scarp SSE Bir-Abu-Munqar and continuing S along the road Farafra – Dakhla. These sediments, however, rest on detritic carbonate, on reddish Upper Dakhla Shales, and, further S, on clays with siltstones of the Ammonite Hill Mb. This means, on Lower Ilerdian to Late Maastrichtian substrates.

The most complete sections are located SSE of the western descent of the small pass between Farafra and Abu-Munqar depressions. 30–40 ms of fairly coarse sandstones, crossbedded with partially kaolinitic matrix, build the cliff. In parts spherules and root (?) tubes weather out. Near the top the friable sandstones occasionally are replaced by carbonates. Above the sandstones whitish to gray limestones of intertidal and freshwater origin extend over the plateau.

From kaolinitic sandstones near the base, as well as from the carbonates above, we recovered terrestric gastropods. The carbonates on top, on the other hand, also bear pholad borings. Freshwater gastropods were discovered a few ms below the rim limestones in carbonate freshwater deposits.

Following the scarp along the road to Dakhla in southern direction, we recognize a decrease of sandstone-thickness, and in some localities, moderate increase of the limestone.

The last traces of this deposits are preserved on the N summit of Qûr-el-Malik. There the 10–12 ms sequence starts with a conglomerate of residual chert nodules and other silicified sediments with *Operculina canalifera*. Above these fine breccias are followed by but a few ms of kaolinitic sandstone and another few ms of the scarp-limestones.

Fig. 8 shows a reconstruction of the situation. According to it, uplift and erosion occured, possibly during Late Paleocene. Thereafter downwarping caused a depression, that received the sandstones and the plateau-limestones.

The gastropods, mentioned above, were examined by G. FALKNER (Munich): He gave us the following short account:

"The small mollusc material is, in spite of its imperfect preservation, of high interest. It comprises four apparently undescribed species of pulmonates, two freshwater snails and two land snails. Only in one case the material is sufficient to allow naming and description. With regard to the considerable age of the samples – they are dated as Lower Oligocene, perhaps even the older, but not younger – the general aspect of this faunula is quite 'modern'. It is therefore, impossible to derive, from the fossils themselves which are closely related to living forms, a more precise dating.

The samples containing molluscs have been collected at the following localities:

131180/2/Layer 4: 25 km ESE Bir Abu Munqar; foot of the escarpment S of the route Bir Abu Munqar/Farafra.

161180/1: 30 km SE Bir Abu Munqar; edge of the plateau at the escarpment NE of the route Bir Abu Munqar/Dakhla.

161180/3: 50 km SE Bir Abu Munqar; near the edge of the plateau of the escarpment N of the route Bir Abu Munqar/Dakhla.

The material has been deposited with the Bayerische Staatssammlung für Paläontologie und historische Geologie, Munich (BSP).

A. **Basommatophora**

1. *Radix* sp.

3 internal moulds from locality 161180/3 (BSP 1981 I 93).

The moulds are nearly complete and give a good idea of the features of the former shell. Although they represent presumably a new species, it is impossible to name and describe them, because they do not show such important characters as columellar twisting or original shape of the aperture. The spire is produced, slender and pointed, and the whorls are rather convex. The largest individual shows, at the basis of the aperture, the rest of a broadly expanded lip, a feature known in forms of seasonally filled shallow pools.

Measurements of the largest individual: Whorls 5.3, diameter (9,5) mm, height 17.5 mm, diameter of aperture (7.5) mm, height of aperture 13.0 mm (measurements in brackets are estimated).

This species fits hardly into the early tertiarian *Radix*-group, but shows much affinities to the more evolved younger *socialis*-strain. It is directly comparable with certain conchological varieties of the recent western palearctic *peregra* as well as some forms of the African *natalensis* with slender spire.

2. *Indoplanorbis bartheli* n. sp. (Fig. 18).

5 internal moulds (1 with rests of the test) from locality 161180/3 (BSP 1981 I 94–96).

Diagnosis: A fossil species of *Indoplanorbis* with slightly sunken spire, concave umbilicus with central deep pit, body whorl of mature shell on the upper side with bevelled and flattened edge, a sculpture of regular fine axial riblets, and, from the juvenile to the adult stage, with repeated formation of strong internal riblike barriers around the peristome (perceptable in the mould as sharp constrictions).

Description: At the juvenile age the whorls of the relatively thick shell show a rather high and slender, nearly oval cross-section, which with the growth of the shell becomes more and more flattened, reaching an upside obliquely sloping and angular shape. The moulds of juveniles have, already at a diameter of 4–5 mm, deep constrictions showing that the shell itself had a prominent labial callus around the peristome; concluding from the present material these barriers are formed up to five times at irregular intervalls.

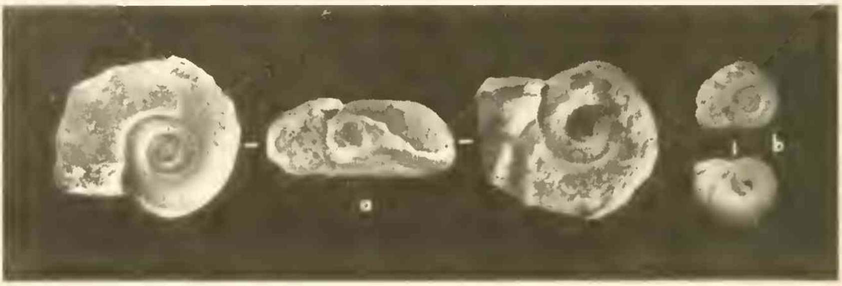

Fig. 18: *Indoplanorbis bartheli* n. sp., 2/1.
a. Holotype (BSP 1981 I 94). b. Juvenile paratype (BSP 1981 I 95). – Phot.: F. HÖCK.

The upper side (left side, functional lower side) is only very slightly sunken and shows a narrow suture spiral, the body whorl being on this side three times as broad as the preceeding and bluntly angled near the suture. The lower side (right side, functional upper side) is broadly concave with deeply pitted umbilical centre. The embryonic whorls in the centre of the umbilicus are hidden so that the first visible whorl appears rather thick; from this one can conclude that the very early embryonic and postembryonic growth stages show a somewhat *Bulinus*-like appearence and have no umbilicus. Only three whorls can be counted on the lower side, of which the last is well rounded and two times as broad as the preceeding. The aperture is rather steep and forms an angle of about 20° with the axis. The fragments of the test which are preserved on the holotype and the corresponding impressions in the sediment show on the lower side of the body whorl a regular sculpture of distinct fine riblets (about 12 per mm). There are no traces of spiral sculpture.

Measurements of the holotype (BSP 1981 I 94): Whorls 4.9, major diameter 12.6 mm, minor diameter 9.7 mm, height 5.4 mm, width of umbilicus 5.6 mm, height of aperture 5.4 mm, diameter of aperture 4.8 mm.

Locus typicus: Egypt, Libyan Desert; 30 km SE Bir Abu Munqar; edge of the plateau at the escarpment NE of the route Bir Abu Munqar/Dakhla.

Stratum typicum: Lower Oligocene (?) – Quatrani Formation (?); marly limestones connected with caolinitic sandstone.

Derivatio nominis: Dedicated to the memory of Prof. Dr. K. W. BARTHEL.

Remarks: The new species is closely related to the recent generotype *Indoplanorbis exustus* (DESHAYES) and differs mainly by its sligthly smaller size, the slightly flatter shell and the somewhat finer riblets. *I. bartheli* agrees with the recent species amongst other features by the characteristic shape of the whorls with the blunt angle parallel to the suture, the formation of the lower side and umbilicus, the very steep aperture, and particularly by its sculpture of fine riblets. This confirms the generic positions in the aberrantly discoid genus *Indoplanorbis* among the generally *Physa*-like subfamily Bulininae of the Planorbidae, and excludes with some certainty a relation to conchologically similar groups of the Biomphalariinae or the Helisomatinae[2]). Other fossil forms of this genus are unknown, and an examination of the fossil planorbids in the BSP did not yield any wrongly classified species of other conchologically similar genera[3]).

The up to now monotypic genus *Indoplanorbis* has a recent distribution from Indo-China to SE Arabia, it occurs isolated on the island of Socotra, and has been introduced by man in several Indopacific localities.

Indoplanorbis belongs to the Bulininae, one of the old well established phyletic branches of the planorbids, the *Physa*-like forms of which presumably already occurred during the Jurassic (ZILCH 1959: 103). It is considered to be a younger, more evolved descendant of this *Physa*-like main group, having developed the discoidal shell independently from the other planorbids (HUBENDICK 1955: 522). With respect to this the fossil species allows the following conclusions: (1) As in its present form *Indoplanorbis* existed already during the Lower Oligocene, the splitting point must lie before the evolution of the modern Afro-Australian *Bulinus*-group at pre-Oligocene times, and (2) the genus *Indoplanorbis* must be considered as a highly conservative one without any tendency to speciate, which agrees with the existence of only one but widespread recent species without geographical variation.

The place, where the fossils have been found is situated – in a general zoogeographical sense – on the western border of the present area of *Indoplanorbis*.

B. Stylommatophora

3. Enidae sp. 1 (cf. *Chondrula*)

1 complete internal mould embedded in the freshwater limestone from locality 161180/1 (BSP 1981 I 97).

The dextral shell has about 8.5 flat-sided whorls separated by a shallow suture, a diameter of 4.1 mm and a height of 12.0 mm; height and diameter of the aperture each measure about 3.3 mm. It seems that the peristome has been heavily calloused and the aperture was perhaps obstructed by two or three teethlike swellings of the lip. The thickened parietal wall is nearly parallel to the suture and forms a sinulus at the upper angle. The general appearance of the snail corresponds fairly well with some slender species of *Chondrula* (subfamily Chondrulinae).

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[2]) I am indebted to C. MEIER-BROOK (Tübingen) and H. SCHÜTT (Düsseldorf) who very friendly sent me valuable specimens of tropical Planorbidae for comparison.

[3]) As a casual result of this examination for example it turned out that *Planorbis subovatus* DESHAYS is without any doubt a genuine *Planorbarius* (subfamily Helisomatinae). – *Planorbis similis* FÉRUSSAC belongs to the African group of *Biomphalaria* and is comparable to small forms of *B. pfeifferi*. – *Planorbis lincki* SCHÜTZE belongs also to *Biomphalaria* and shows affinities to *B. sudanica*.

4. Enidae sp. 2 (cf. *Paramastus* or *Chondrus*)

1 internal mould fragment of the upper whorls from locality 131180/2/Layer 4 (BSP 1981 I 98).

The dextral spire fragment has 6.7 whorls, a greatest diameter of 4.5 mm, and a height of 7.8 mm. From the mould fragment one can infer a moderately slender shell with a rather thin test and perhaps the double height of the fragment. It agrees with certain forms of the genera *Paramastus* or *Chondrus* (Subfamily Eninae).

These two enids seem to belong to two different species and show convincing conformity with recent genera of the subfamilies Chondrulinae and Eninae. The genus *Napeus* (subfamily Eninae), widespread with many fossil records in the Tertiary and actually restricted to the Macaronese Islands, and the indigenous tropical African subfamily Cerastuinae, which is known from the Lower Miocene of East Africa, can be excluded with some certainty. The genera with which the two fossils must be compared have a recent distribution centre in the northern Near East and no fossil records are hitherto known from pre-Pliocene deposits.

In spite of the uncertainties resulting from the small number and imperfect preservation of the mollusc remains, one can draw some inferences as to the former environment: the ectotype of the two freshwater species indicates seasonal fluctuations of the water body and occasional drying up of their habitats, so that they had to survive on moist mud. For example I found *Radix peregra* with broadly expanded peristome in pools that had dried up in the inundation area of the Elbe marshes at Schnackenburg. The development of the apertural ribs in the Planorbidae is certainly induced by ecological factors but the ability to form these barriers must be genetically fixed. Their evolution is presumably connected with drier climatic conditions as suggested by Watson (1954: 213) when discussing this phenomenon in *Biomphalaria*. The enids indicate corresponding terrestrial conditions. Especially the *Chondrula*-like specimen shows that this species regularly had to survive dry periods. All this leads to the assumption of a moderate warm to subtropical and semi-humid to semi-arid climate with an open landscape."

Identical sandstones as those described above overlie Farafra Fm. at the SW corner of Qûss-Abu-Said.

Sandy to carbonatic fissure fillings associated to fissure breccias are encountered fairly often in plateau-forming limestones of Paleocene and Eocene age. The fissure fillings are thought to be connected with the events that led to the accumulation of the Lower Oligocene sandstone – limestone series.

Relations between structural pattern and stratigraphy

Figs. 16, 17

We are well aware that over the area initially indicated and with time limited by logistic problems, we can present a rather coarse stratigraphic grid only. It is, however, the first attempt to go beyond the scope of R. Said (1962). Though numerous details on the geology of the oases have been added since (cf. pp. 147 ff.), none of the publications reaches the impact of R. Said's work.

Our major contribution to the Late Cretaceous/Early Tertiary stratigraphy consists of an outline of facies variations beyond the oases, along the Gilf-el-Kebir spur, i. e., the western margins of Dakhla Basin (Fig. 5).

Dakhla Basin primarily was filled by Paleozoic sandstones and by "Nubian" sediments deposited in a sandy deltaic plain, occasionally flooded by the sea (BARTHEL & BÖTTCHER 1978).

Thus, at the end of the "Nubian" sedimentation, Dakhla Basin had only weak relief. From the Campanian and especially from Mid-Maastrichtian onwards two major features seem to determine sedimentation:

1. Gilf-el-Kebir N spur and
2. Bahariya-Arch.

The Gilf-el-Kebir spur continues to act as source of clastic material throughout the Late Maastrichtian and the Paleocene. The peak of sand deposition was reached during the Ammonite Hills Mb. sedimentation. This was possibly a time of general uplift, effective at least until the close of the Thanetian which also may have caused the elevation of the area between Bir-Abu-Munqar and Qûr-el-Malik.

The origin of reefs and back-reef oolites at that time, along the Gilf-el-Kebir spur (cf. TERRY & WILLIAMS 1969) fit in this picture. According to our findings, the Nile Valley structures presented by YOUSSEF (1968, fig. 1) show parallel features further west. The structural trends exhibited by the course of the Nile Valley are a *compound* of the Dead Sea and Gulf of Suez trends. In the W these trends are repeated exactly by the uplift-axes of the oases: Bahariya/Farafra and Kharga axes follow the Dead Sea alignment, while the stretch between Bir-Abu-Munqar and NW Dakhla repeats the Gulf of Suez direction. The structure mentioned last is marked by thick Lower Oligocene (?) sediments (cf. Fig. 8). Still another Gulf of Suez lineament runs between Bahariya Oasis and El-Minya. The age for the Nile Valley structures was assumed to be Paleocene which would match the time of the movements in the oasis structures.

The entire structural development is thought to have happened in the course of the pre-rift uplift phase during the origin of the Red Sea. Following these considerations further we come to conclude that these tectonic events must have been also responsible for the origin of the oases. The sequence of events suggested is: 1. pre-rift updoming caused local uplift on top of basement faults; 2. erosion and downwarping, subsequent to gravity sliding along the basement faults as the rift opened; 3. downwarping caused depressions partly filled with thick Lower Oligocene (?) sediments.

In the course of those structural events a maximum differentiation of facies resulted in Mid-Ilerdian times. Some of those facies diversities continued into the Mid-Ilerdian along the Gilf-el-Kebir spur, with Ain-Dalla Fm. and the Ilymatogyra-facies which both are western equivalents of Esna Fm.

The second major structural element, the Bahariya-Arch, remains rather stable during the Campanian and Maastrichtian. Fairly thin sediments are found as one approaches the Bahariya center of uplift (= Bahariya Oasis). At the SW end of the arch (Farafra Oasis), Tarawan Fm. ("Chalk") is very thick, interfingering in the S with Dakhla Fm. In the N the Campanian share of sedimentation of Tarawan Fm. is represented by Hefhuf Fm. Hiatus mark the transition from Tarawan to the subsequent Esna Fm. (Thanetian [?] to Mid-Ilerdian). In the N, Tarawan Fm. replaces both, the western Ain-Dalla Fm. and the eastern Esna Fm.

When complete, the sections are topped by Farafra Fm. (late Mid-Ilerdian) all over the northern part of the area of investigation.

Perhaps it should be added that at the SE margin of Dakhla Basin, S of Baris, sedimentation shows the strong influence of the Nubian platform (cursory personal observation). This region, however, is not considered here, as it demands an extensive separate study.

Acknowledgements

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As in the 1977 and 1979 campaigns J. Schmid joined our team. Once more he deserves high praise for taking care of the vehicles and mastering the camps.

Last not least we gratefully mention Mrss. S. Boog, B. Dunker, E. Kubig, Messrs. B. Kleeberg, K. Nikoleit and B. Wischnewski, whose technical and manual skills were essential in preparing the mansucript.

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