Chapter I
Introduction

I. Introduction

1.1 General outlook

The Western Desert is the most characteristic physiographic features of Egypt. It was generally known as the Libyan Desert in old literatures. The Farafra Oasis represents one of the most important oases present in the Western Desert of Egypt. Its ancient name was "Ta-iht" which means "land of the cow". The origin of the name Farafra is not known. This name is mentioned in the Temple of Luxor in the list of localities which produced minerals and dates from the region of Ramsses II (Fakhry, 1974).

Farafra was the first oasis described in the geographical work of the Rohlfs Expedition. He crossed the plateau to the Farafra escarpment, whence the road descends the cliff to Bir Murr and passed Bir Karawin (Keraui of Rohlfs) to reach Qasr El-Farafra in December, 1873. After a short stay at this village, Rohlfs, accompanied with Zittel and Jordan, traversed the road past Bir Dikker through the sand dune area to Qasr El-Dakhl. In January 1874, Rohlfs and Zittel, leaving Sittra, steered by compass to Farafra descending the cliff to the northwest of Ain El-Wadi and reached Qasr El-Farafra early in March (Beadnell, 1901).


Rohlfs Gerhard (1831-1896)

The Farafra Oasis comprises a very thick and well-exposed Upper Cretaceous–Lower Tertiary succession. This succession is marked by obvious lateral and vertical lithologic facies variation. It is very rich in micro- and macrofaunal contents. Despite the fact that the Farafra Oasis has received much attention by so many stratigraphers and paleontologists for many years, only a few of them focused on the eastern and northwestern reaches of the Farafra Oasis.

I.2 Location of the study area

The Farafra Oasis is located in the central part of the Western Desert and covers an area of about 12,000 square kilometers. The area under investigation is present between Latitudes 26° 40` and 27° 40` N and Longitudes 27° 00` and 29° 00` E. It covers an area of approximately 19,000 square kilometers. This oasis lies about 300km west of Assiut, 560km southwest of Cairo, 200km southwest of Bahariya Oasis and 300km northwest of Dakhla Oasis (Fig. 1.1).

The eastern plateau of the Farafra Oasis extends eastward to join the Assiut Plateau, west of the Nile River, while the northern plateau extends northeastward to join the plateaus surrounding the Bahariya Oasis to form one continuous rugged surface.

I.3 Accessibility of the study area

The Farafra Oasis can be reached easily from Cairo by the asphaltic road which passes through the Bahariya Oasis. It is also reached from Assiut through the Kharga and Dakhla oases.

The eastern scarp of the Farafra Oasis can be reached from Qasr El-Farafra by a new paved road to Bir Karawin, while its western scarp is reached by the old cross-road to Ain Dalla. Also, there are some desert tracks pass from Ain Dalla to Bahariya and Siwa oases. In addition, many local unpaved roads run from Qasr El-Farafra to the scattered villages in the Farafra Oasis. Traveling toward east and west of the Farafra Oasis is very difficult because of: 1) The very thick sand dunes which cover more than 45% of its surface and hidden all land marks, 2) The presence of many fine loose playa sediments and 3) The hard tough residual rocks.

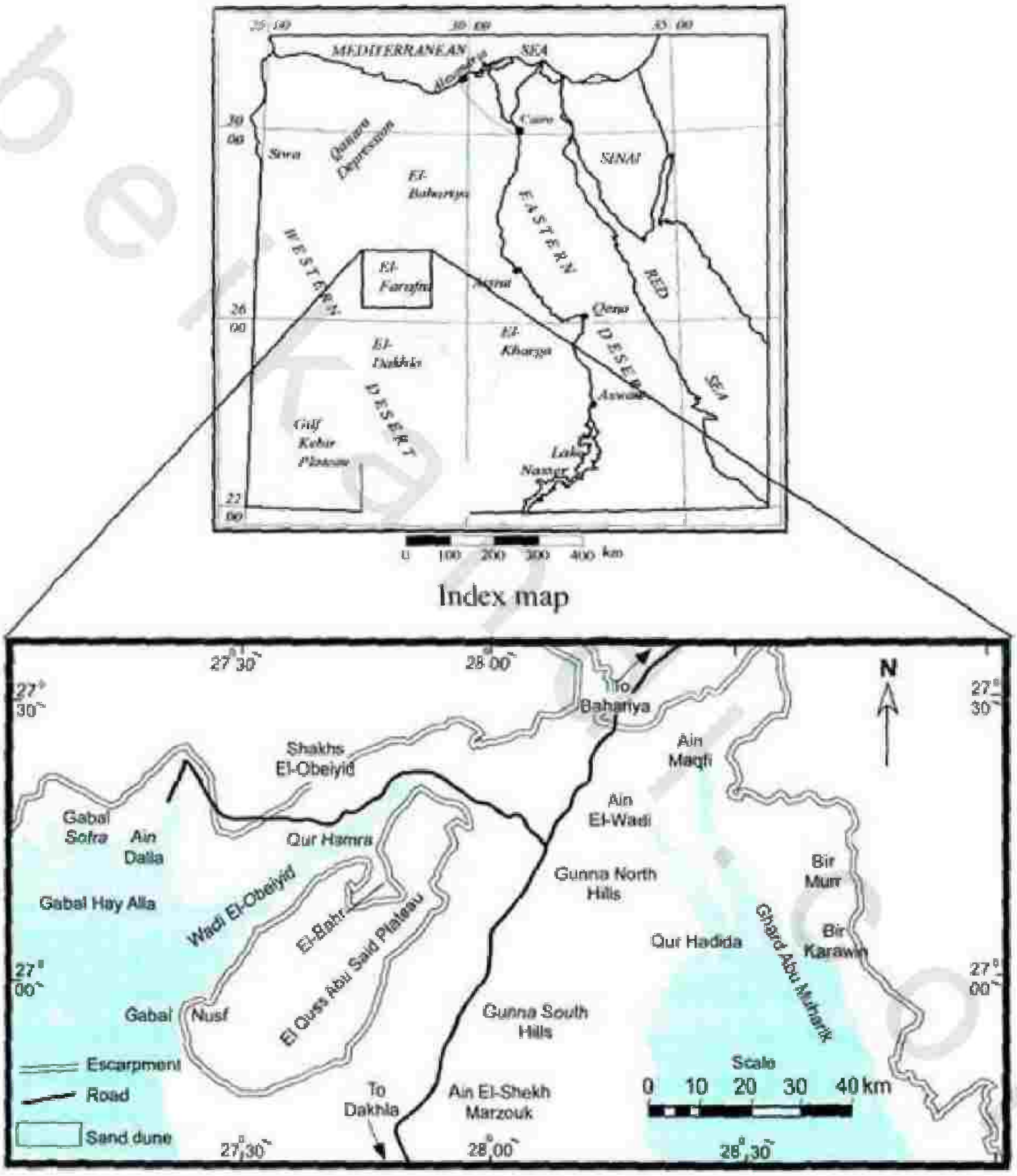

Fig. 1.1 Location map of the Farafra Oasis, Western Desert, Egypt.

1.4 Aim of the present study

The present study aims to clarify the stratigraphic set up and sedimentological characteristics of the Upper Cretaceous-Lower Eocene succession exposed in the Farafra Oasis. To achieve this target the following are carried out:

- Review the previous studies to elucidate the controversial stratigraphic settings and nomenclatures of the Upper Cretaceous-Lower Eocene sediments in the Farafra Oasis.
- Draw a photogeological map of the study area at a scale of 1:1000 000.
- Measure fourteen surface stratigraphic sections to recognize the different exposed rock units and their marked lateral changes in facies and thickness.
- Describe the sedimentary facies characteristics of the studied formations and interpret their palaeoenvironments.
- Study the micro- and macrofaunal contents of the Upper Cretaceous–Lower Eocene sediments; their types, frequency, diversity and planktic/benthic ratio.
- Establish the biostratigraphic zonations of the concerned succession.
- Draw a correlation chart for the studied surface stratigraphic sections to clarify the lateral variations in facies and thickness.
- Correlate the results of the present study with those of the previous works given by various authors.
- Detect the depositional sequences present in the studied succession as well as their associated sequence boundaries, systems tracts and vertical stacking patterns.
- Reconstruct the basin palaeogeography of the studied

sequences and their facies evolution.

- Create depositional models for the Upper Cretaceous-Lower Eocene sediments in the Farafra Oasis.

I.5 Materials used in the present study

All the available materials including the topographical, photogeological, litho- and biostratigraphical, sedimentological and structural data are dealt with in the present work to offer a near complete picture concerning the study area. The materials on which this study is carried out include field and laboratory works. The field work includes the recognition of the field relations of the different lithostratigraphic rock units which drawn on a photogeological map at a scale of 1:1000 000.

More than 700 rock samples are collected for the different rock types to describe their megascopic and microscopic characteristics. Most of these samples were prepared for the foraminiferal study to identify their benthic and planktic contents and to assign their ages. More than 500 megafossil specimens, mostly molluscans, were collected from the studied sections. The most important specimens are cleaned, identified and photographed.

About 50 thin sections are selected and investigated for their microfacies associations, which are used to reveal the different palaeoenvironments, prevailed during their accumulation. In addition, a series of different graphic illustrations, depositional models, tables, photographs are also prepared to illustrate the stratigraphic succession, sedimentological characteristics, palaeoenvironments and other geologic features of the Farafra Oasis.

The materials studied are deposited at the Geology Department, Faculty of Science, Al-Azhar University.

1.6 Geomorphology

The Farafra Oasis has an irregularly triangular shape with an apex lies to the north and a breadth increases southward (Fig. 1.2). The length of the oasis is about 200km while its width is about 90km, measured from El Quss Abu Said Plateau at the west to the eastern scarp at Bir Karawin.

The Farafra Oasis is surrounded from two sides by well-defined escarpments. The northern plateau, some 100m higher than the floor of the depression, extends for about 25km northward to the Bahariya Oasis. This plateau encircles Ain Dalla depression. The eastern plateau extends for about 300km eastward to Assuit and 200km southeastward to join the northeastern escarpment of the Dakhla Oasis. While, the western escarpment, some 200m higher than the depression, runs in a NE-SW direction for a distance of about 75km along El Quss Abu Said Plateau. To the south, the Farafra Oasis is open and its floor gradually rises to merge into the plateau on the southern and southeastern sides. El Quss Abu Said Plateau, which forms the northwestern and western limits of the depression, is delineated in its northwestern side by another depression; the Ain Dalla depression. The surface of El Quss Abu Said Plateau is nearly flat, locally rocky covered with flints, but becomes very rugged where karst topography occurs. The plateau surface consists of the Farafra Limestone of the Early Eocene age, whereas the slopes are represented by a succession of shale, argillaceous limestone and mudstone of the Esna Shale. There are two successive plateau surfaces developed above each other especially in the northern part of the Farafra Oasis, reflecting the presence of two successive limestone units. The lower plateau is a few kilometers wide, stands about 150 m above the ground at Ain El-Wadi and is gradually dipping toward east. It rises about 40m above the ground at Ain Maqfi and is dissected

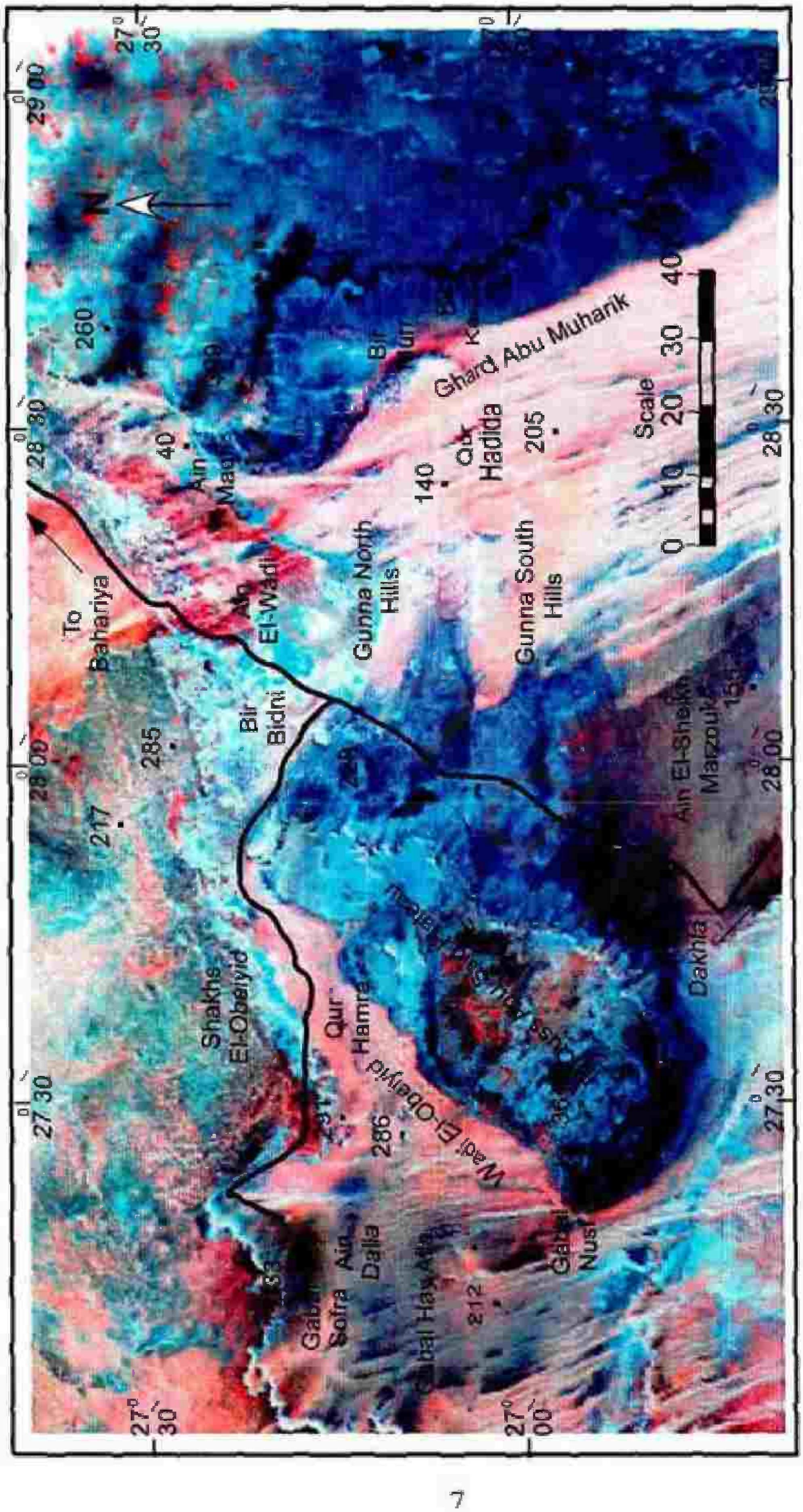

Fig. 1.2 Landsat image of the Farafra Oasis showing its geomorphological units.

into endless buttes near Bir Murr. The lower plateau is finally leveled with the ground near Bir Karawin. East Bir Karawin, the upper plateau surface is 275-300m above sea level. It decreases to 250-275m a.s.l. in the north and to 200-230m a.s.l. in the vicinity of Qaret El-Sheikh Abd Alla. The floor of the Farafra depression is covered by chalk or dolostone, which is hidden by wadi deposits, wind blown sands, scattered playa deposits and wild desert plants.

In fact, a major part of the Farafra depression is covered by sands especially in its western and eastern parts. The most common type of sand accumulations is in the form of longitudinal (seif) dunes which are of considerable length.

The Playa deposits are recorded from several places within the Farafra Oasis such as in Ain Dalla, Bir El-Obeiyid, Bir Bidni, Bir Karawin, Bir Murr, Ain El-Wadi and Abu Minqar (Fig. 1.3).

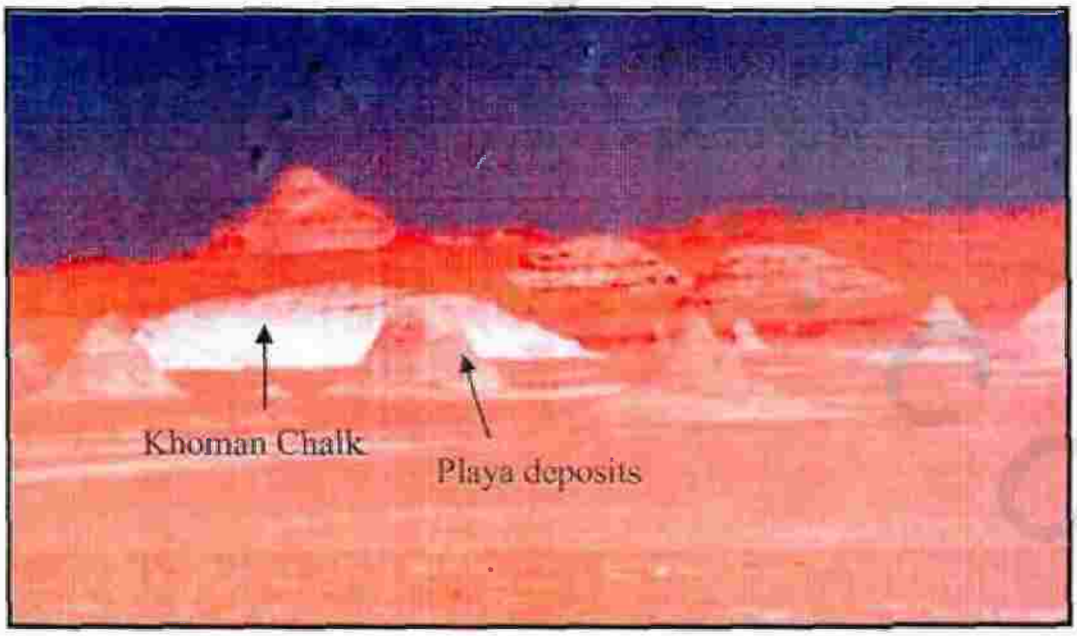

Fig. 1.3 The Playa deposits at Bir El-Obeiyid surrounding the Khoman Chalk. Photo is looking north.

The playa deposits consist of olive gray to grayish yellow silts and silty sands which are hard to moderately compact and highly affected by mud cracks. They may reach a thickness up to 4m. There are about 70 playas recorded in the Farafra depression (Embabi, 1999). The largest ones are about 10km long and 3-6km wide (e.g. Qasr El-Farafra and Abu Nuss). Because a large part of the Farafra is made up of carbonate rocks, carbonate constitutes 50-90% of samples taken from many playas in the Farafra area (Embabi, *op. cit.*). The playa deposits are attributed to the Holocene, substantiated by radiocarbon age measurements on charcoal in situ samples, to the pre-Holocene age, possibly even early palaeolithic during episodes of greater rainfall Holocene time (Hassan *et al.*, 2000). The Holocene playas are called hidden valley in the Farafra Oasis by Hamdan *et al.* (2004).

The Farafra depression is also characterized by the presence of several springs, wells and Hatiyets (i.e. the small semi-circular areas within the Farafra depression covered by sand with bushes). Some springs are now dry and chocked by sands and vegetation forming phytogenic mounds such as at Hatiyet El-Sant (Fig. 1.4).

Fig. 1.4 The phytogenic mounds present in Wadi Hennis area. Photo is looking east.

While other springs are still flowing such as Ain El-Sheikh Marzouk and Ain El-Balad. The drainage system (wadi) is not well developed in the Farafra Oasis. The major wadis present are Wadi Hennis and Wadi El-Obeiyid.

I.6.1 Major landforms

The major recorded landforms in the Farafra Oasis could be subdivided into depression, main scarp, interfluves, inselbergs and hills.

- Depression

The floor of the Farafra depression is nearly flat and monotonous. It has a general level of 30-105m above sea level and mostly consists of Maastrichtian chalk. Toward north, the floor decreases to 26m above sea level at Ain El-Wadi. Over there the floor cuts in two big hollows; Wadi Hennis and Ain Maqfi area, 18-20m above sea level. Owing to the fact that this locality is structurally high, older Santonian clastic rocks crop out. Similar clastic rocks are also found east of Bir El-Obeiyid. Another local depression, which comparatively smaller in size than the Farafra depression is present; the Ain Dalla depression. This depression lies about 120km to the northwest of the Farafra depression. The height of the depression is 98m above sea level near Ain Dalla spring. Ain Dalla depression covers an area of about 680km^2. The contour 100m (a. s. l.) nearly encircles the depression floor before it rises gradually to the south and abruptly to the north, most probably because the Ain Dalla depression is structurally controlled.

The Farafra depression is bounded from the northwest and northeast by scarps of about 100m high above the level of the depression. It is open in its southern end and covers by sand dunes of the eastern fringes of the Great Sand Sea.

- Main scarp

The main scarp of the Farafra Oasis is formed of the Esna and Farafra formation (Fig. 1.5). The slope profile of the Farafra scarp is divided into scarp crest, free face and pediment, as three slope elements.

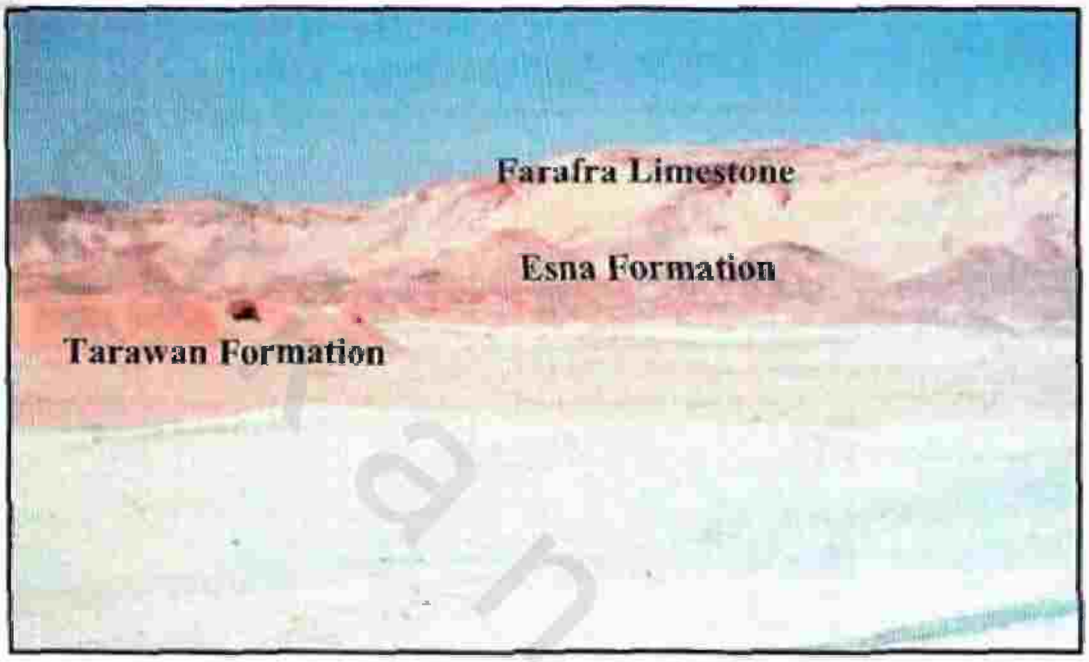

Fig. 1.5 The main escarpment of the Farafra Oasis at El Quss Abu Said. Photo is looking west.

The scarp crest is the summit areas of the scarp with slope angle up to 50° the depression. The free face is the steep sloped bed rock along the scarp and has a rock thickness up to 80m. The slope of the upper 50m of the free face scarp is very steep, about 75°. The free face is directly connected with the scarp pediment, which behaves like the debris slope. The scarp pediment is a broad gentle sloped area of 0.5-4km wide, with slope angle up to 5°. Fluvial meanders commonly passage freely along the pediment leaving the interfluvial areas in-between.

The lower part of the main scarp is often covered by descending wind blown sands coming from the north or by slope sediments. The slope sediments are represented by fallen blocks, boulders and cobbles from the upper scarp part.

- Interfluves

The interfluvial areas are the remaining islands within the fluvial system derived from the scarp pediment into the depression. These interfluves include mature and degraded towerkarsts.

The mature towerkarst consists of steep slope hills forming the connected or disconnected interfluves of the northern and eastern segments of Farafra main scarp. It is closely spaced, steep walled, flat–topped and symmetrical landforms. The height of these landforms is up to 55m with a basal diameter of about 90m. The towerkarst pediment is mostly covered by thick accumulations of talus and scree derived from the upper free face. The degraded towerkarst landforms, on the other hand, are commonly distributed along the scarp pediment and the depression. Winds played an assisting role in this process as a transporting agent of the weathering products, followed by excavating a new surface of the rock to weathering. The eolian erosion and the rapid retreat of the escarpment were probably aided by the presence of a tectonic uplift in the central part of the Farafra Oasis. The rock is, however, attacked along joints and near the ground where wind erosion is at its acme. Chimney rocks are remarkably common in some places, especially near Gunna North, Ain El-Wadi and Bir Bidni (Figs. 1.6 & 1.7). Based on the shape and size of these landforms, they are classified to three main types; pinnacles, karst cones and stacks.

- Inselbergs and hills

Three hills lying about 15km north of Qasr El-Farafra are traced within the Farafra depression. Beadnell (1901) called them El-Gunna North hills. The highest of these hills is 220m above sea

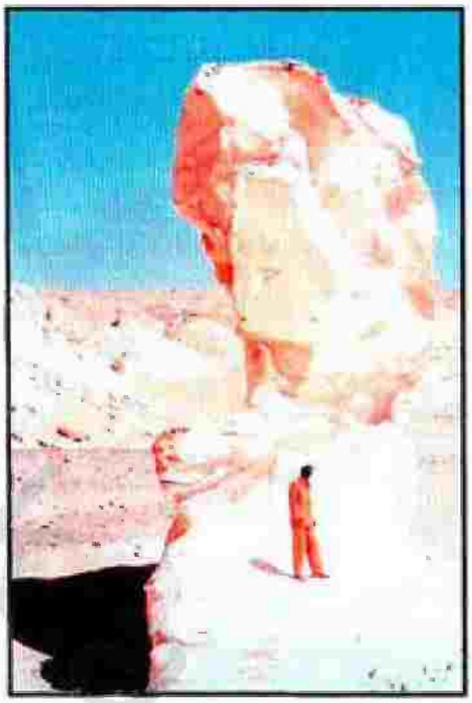

Fig. 1.6 The chalk stack at the foot of northwest Ain El-Wadi. Photo is looking northwest.

Fig. 1.7 The chalk stack in the Khoman Formation at White Desert, northwest Ain Maqfi. Photo is looking east.

level. Thirty kilometer due to south of El-Gunna North hills there are another two peaks called El-Gunna South hills by Beadnell (op. cit.). They are remarkable steep-sided residual hills or inselbergs. The highest of them is 229m above sea level. The slope elements of these hills include free face, constant slope and pediment. Also, there are some hills and hillocks present within the depression and consist of chalk and limestone (e.g. Bir Murr). The average height of these hillocks is 20m. The number of hillocks increase towards the escarpment and at its foot. At Qur Hadida area, 35km NE of Qasr El-Farafra, two prominent hillocks consisting of chalk at the base and dolostone at the top are recorded. Gabal Sofra lying at the extreme northwestern part of the study area is considered as a table land hill which is 214m above sea level.

The area of Wadi El-Obeiyid is also characterized by the occurrence of a few conspicuous inselbergs such as Qur Hamra, Shakhs El-Obeiyid and Gabal Hay Alla to the south of Ain Dalla.

I.6.2 Karst landforms

Karsting is the process of leaching out of soluble fractured rocks by moving underground waters resulting in the formation of peculiar closed depressions on the earth surface and caves and channels in the subsurface. The deposition of mineral matter occurs when some carbon dioxide escapes from the solution making it supersaturated with calcite. As a result, calcite and alabaster layers or pockets are deposited within the host rock. Underground waters are always charged with dissolved salts and gases. Therefore, what acts on rocks is a complex solution with a continually changing concentration of salts and gases. Water saturated with carbon dioxide dissolves limestone and dolomite many times faster than chemically pure water. Typical karst areas generally possess fairly thick and well jointed limestone strata.

The following karst landforms are recognized.

- Subsurface karst bridges and tunnels

Large subsurface tunnels are recorded along the foot walls of some mature and degraded karst landforms, especially the karst cones. Collapsed chalk fragments of pebble to boulder size are commonly present around the mogot including this karst feature. Also, karren, scour remnant ridges, solution ripples and solution cavities are widely distributed along the inner walls of these bridges as minor solution features. The karren is recorded as horizontal and vertical widened joints and as solution ripples. The scour remnant ridges are small-scale solution forms present associated with the solution ripples within the internal surface of the karst bridges and tunnels. While, the solution cavities are intraformational dissolution features commonly present within the Khoman Formation.

- Karst sediments

The surface and subsurface karst solution features distributed within the carbonate rocks of the Farafra depression are covered and filled with two diagentic calcareous sediments including the surficial calcareous duricrusts and the intrakarstic deposits. El-Sayed (1995) mentioned that karstification possibly took place during pluvial time when calcite was developed with partial dissolution and calcitization of the dolomite of El-Hefhuf Formation. After the pluvial time, humid phase prevailed and residual clays were formed. The Farafra Oasis and the surrounding areas display an extensive development of duricrusts and karst products. The first recorded calcareous duricrust is caliche covering the summit of Gunna North and Gunna South inselbergs. This caliche is composed of highly brecciated carbonate rocks and denudated, while some remnants of its sediments are recorded as talus fragments along the mount slope profile. The second recorded calcareous duricrust is dolocrete (dolomitc calcareous crust) covering the floor of the Farafra depression. In north Ain El-Wadi (Lat. 27° 27` 36`` N and Long. 28 ° 15` 2`` E), secondary deposition of intrakarstic deposits are recorded forming hidden valley within the Khoman Formation. These deposits consist of dolostone with sandy clay interbeds. The dolostone is brown, compact and porous forms sharp vertical contact with the Khoman Formation (Fig. 1.8). At this area, the underground water of the hidden valley dissolved the carbonate beds of the Khoman Formation, forming collapsed and brecciated limestone fragments.

Fig. 1.8 Dolostone beds of the intrakarstic deposits stand against the chalk of the Khoman Formation, north Ain El-Wadi. Photo is looking north.

The thickness of the deposits filling the hidden valley varies between 2m and 48m. These deposits are also found to overlie the Khoman Formation further north and east of the above mentioned locality (Lat. 27° 23` 57`` N and Long. 28 ° 24` 30`` E) (Fig. 1.9). They have a wide areal distribution in the northeastern part of the Farafra Oasis.

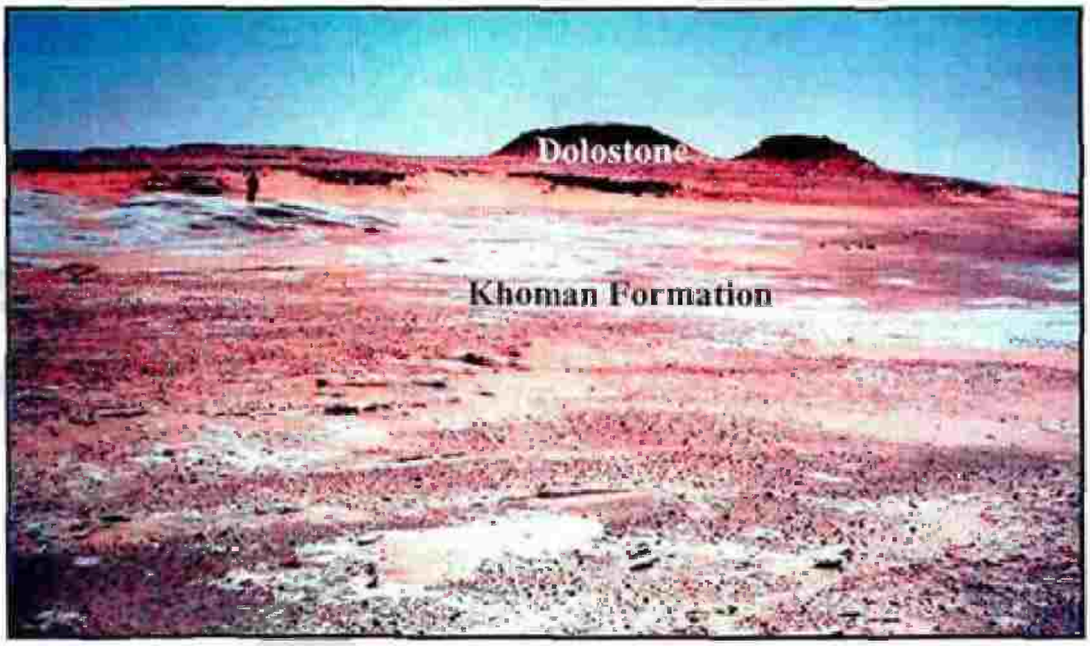

Fig. 1.9 Dolostone beds of the hidden valley overlie the chalk of the Khoman Formation, north of Ain El-Wadi. Photo is looking northeast.

El-Sayed (1995) summarized the sequential development of the duricrust and void-fills as follows:

- Partial dissolution that responsible for the development of caves in the Khoman Chalk.
- Calcitization and dissolution of the dolomite of El-Hefhuf Formation.
- Coarse calcite then precipitated filling the caves and pores under phreatic environment. With progressive dissolution considerable part of the chalk was deteriorated.

According to Sokkar (1991), the Farafra Oasis could be related to multi erosion cycles involving Karstification, pedogenesis and pedimentation processes, most probably during the tropical climate of the Oligocene time and the subsequent humid climates (Miocene-Quaternary?). He considered the Farafra as one of the largest Uvala recorded allover the world.

I.6.3 Yardings

The word yarding or yardang was derived from the Turkish word which means "steep bank". Yardings are parallel aligned erosional shapes and makings sculptured on desert hills due to the action of wind. Most of the playas in the Farafra depression are eroded into several yardings and streamlines with wind and water streams which eroded and shaped them. In the past, these yardings were described as playas with higher top surfaces than in the present, whereas they stand a few meters above the ground level.

Yardings are commonly carved in the Farafra outliers, where the action of wind is apparent in the aligned dissection of bed rock surface. They display highly burnish heads with splayed fluting as well as flutes and pits along their flanks and lee sides. Yardings rang in length from less than a meter to a kilometer or more and typically are distributed in parallel arrays aligned with the prevailing wind direction. Extensive wind-eroded bed rock fields called "Marble yardings" are formed in the depression, tens to hundreds of meters long and a few meters to ten of meters high.

I.6.4 Sand dunes

The largest sand dune, named Ghard Abu Moharik, is found on the eastern side of the Farafra Oasis extending from east Ain Maqfi to the south of the Farafra depression. It extends in a northwest-southeast direction for about 150km. This dune is oriented parallel to the direction of the prevailing wind which has a SSE direction. Another group of sand dunes are present along the western part of the Farafra Oasis covering the area of Bir El-Obeiyid and Ain Dalla depression and extends to the south forming the Great Sand Sea. The height of some sand dunes may reach up to 205m above sea level at Bir Karawin and 225m above sea level at Gabal Hay Alla. There are two simple linear forms of dunes: seif dunes and linear ridges which take a NNW-SSE direction. Tsoar (1978), Fryberger (1979) and Livingstone (1986) revealed that linear dunes occur in bi-directional wind regimes, included the wide unimodal regimes.

I.7 Tectonic setting

The Farafra Oasis lies in the northern margin of the tectonically stable shelf of Egypt. The presence of large-scale, gently dipping folds in the Farafra Oasis refers to a transitional setting between the typical stable and unstable shelf conditions (Hermina, 1990). The sedimentary record of the Farafra Oasis indicates that a number of tectonic movements affected the area at different times. The dip of the strata in the Farafra Oasis is nearly horizontal and ranges from 2° to 3° increasing to 7° near the fault and close to the flanks of the anticline.

Four folded structures are recorded in the Farafra Oasis by El-Ramly (1964), Omara *et al.* (1970) and Hermina (1990). These folds are:

1- Farafra main (central) anticline

2- El Quss Abu Said faulted syncline

3- Ain Dalla anticline

4- El-Ghard syncline

The Farafra main (central) anticline is a doubly plunging anticline, trending northeast-southwest with the steeper plunge in the northeast. The crest of this anticline lies between Ain El-Wadi and Ain El-Maqfi; where the clastics of the oldest rocks in the area are exposed. The northwestern flank of the Farafra anticline is defined by a parallel-trending and double plunging syncline of El Quss Abu Said, which in turn is defined by Ain Dalla monocline in its northwestern flank. The latter, however, is an ill-defined structure due to the vast cover of sand in the area. A huge syncline is present to the southeast of the Farafra main anticline, the axis of which trends in a northeast-southwest direction, in the dune area between Bir Karawin and Qur Zuqzg (El-Ghard syncline). This syncline is proved in the present study by the occurrence of the Esna Formation of Early Eocene age at its central part in southeast Qur Hadida.

Hermina (1990), howeve, described synclines and anticlines in the subsurface of the Farafra Oasis and considered them as being inversion to the topography exist today. Barakat and Abdel Hamid (1974) pointed out that faults, joints and folds present in the Farafra Oasis indicate movements in the basement, but they are faintly distinguished on the surface due to a relatively thick sedimentary cover in the Farafra Oasis.

Faults are rather difficult to detect in the Farafra Oasis due to sand cover. Although individual faults have been traced for a considerable distance on the scarp faces of the Farafra Oasis, no one fault is found to extend completely across the whole scarp (Hermina, 1990). Moustafa *et al.* (2003) mentioned that faults are not common on surface of the Farafra Oasis. The recorded faults are found in the northern part of the area as a response to rejuvenated tectonic movements. These faults affected the Farafra Limestone in the northern scarp and the Khoman Formation in the south of Wadi Hennis. They are dominantly NE and ENE trending normal faults with low throw, 10-20m, and have lengths ranging from 6 to 25km for each fault segment. The surface faults of the Bahariya and Farafra oases have a NE-SW direction parallel to the subsurface faults of the Pelusium line, in an apparent continuity with a zone of linear uplifts (Saleh, 2005). Another of faults and joints are recorded around Gunna North Inselberg and Qasr El-Farafra which affect the Khoman Formation. The joints in the latter area are filled with calcite, which stands above the ground surface for a few centimeters as low ridges.

In Ain Dalla area, the Esna Formation is faulted down against the Ain Dalla Formation, while in Gabal Qur Hamra, the Tarawan Formation forms syn-form structure below the Esna Formation. In addition to, the occurrences of natural springs such as Ain Dalla and Bir El-Obeiyied together with the geomorphologic considerations indicate that the Ain Dalla area is a positive structure. The movement corresponds to this structure uplifted this area during deposition of Ain Dalla Formation. Nakhla and Podbelova (1973) and Hassaneen (1988) mentioned that Ain Dalla, Wadi El-Obeiyid and most of El Quss Abu Said Plateau represent uplifts in the basement, bounded by northeast-trending faults. Features which appear in the sedimentary cover possibly developed preferentially over these lines of weakness in the basement.

The joints, on the other hand, are well marked in the chalk forming the floor of the Farafra depression. These joints are usually mineralized and filled with calcite, iron oxides and pyrite. The dip of the joint plane is nearly vertical, with thickness of about 10cm. There are three sets of joints which are oriented in N 20° E, N 30° E and N 50° E directions. El-Ramly (1964) pointed out that these joints partly contemporaneous with the folding affecting the Farafra Oasis.

I.8 Previous work

Many obvious lateral and vertical facies changes mark the stratigraphic succession of the Farafra Oasis. This led the previous authors to use different names for the different rock units (Table 1.1). However, a few works have been done on the eastern and western parts of the Farafra Oasis. The most important studies

Table. 1.1 Correlation chart of the most important Upper Cretaceous - Lower Eocene formational names proposed by the different authors in the Farafra Oasis.

Age		Said and Kerdany (1961) Ain Maqfi	Youssef and Abdel Aziz (1971) Farafra Oasis	Barthel and H. Degen (1982) Farrafra and Dakhla oases	Khalifa & Zaghloul (1989) Abu Mingar-Farafra stretch	Hermina (1990) Kharga, Dakhla and Farfra oases	Abdel-Kireem and Samir (1995) Gunna North	Present study
Pleistocene			Ain El Wadi					
Eocene	Middle					Naqb Fm.		
Eocene	Ypresian	Farafra Limestone	Farafra Limestone; Esna Shale	Farafra Limestone; Ain Dalla Fm. ~ Esna Fm.		Naqb Fm. ~ Farafra Fm.; Ain Dalla Fm. (Garra Fm.) ~ Esna Fm. ~ Garra Fm.	Farafra Fm.; Esna Fm.	Farafra Fm.; Ain Dalla Fm. ~ Esna Fm. ~ Maqfi Mb.
Paleocene	Thanetian	Esna Shale	Tarawan Chalk	Tarawan Chalk ~ Peak Hill Mb.	Esna Fm.	Tarawan Fm.	Tarawan Fm.	Tarawan Fm.
Paleocene	Selandian	Maqfi Limestone	Dakhla Shale	Tarawan Chalk ~ Ammonite Hill Mb.		Khoman Fm. ~ Dakhla Fm.	Dakhla Fm.	Dakhla Fm.
Paleocene	Danian	Esna Shale						
Maastrichtian	Late	Chalk	Farafra Chalk	Tarawan Chalk ~ Bir-Abu-Minqar Horizon (Dakhla Formation)	Abdala Limestone - Tarawan Chalk		Khoman Fm.	Khoman Fm.
Maastrichtian	Early			Tarawan Chalk ~ Dakhla Shale (Dakhla Formation)	Dakhla Fm. - Khoman Chalk	Khoman Fm. ~ Dakhla Fm.		
Santonian - Campanian				El-Hefhuf Fm. ~ Qur-el-Malik Mb.; Baharya Fm. ~ El-Hindaw Mb.; Mut Fm. (Dakhla Formation)	Ain Giffara Fm.; Nubia Fm.	El-Hefhuf Fm. ~ Duwi Fm.; Wadi Hennis Fm. ~ Quseir Fm.		El-Hefhuf Fm.

carried out on the Upper Cretaceous-Lower Eocene successions in the Western Desert generally and the Farafra Oasis specifically are given hereunder:

Zittel (1883) wrote the first comprehensive account on the stratigraphy of the Farafra Oasis. He concluded that the Farafra succession is of Late Cretaceous-Early Eocene age with no hiatus within it. He considered the Farafra Oasis as a complete record marking continuous sedimentation from the Late Cretaceous to the Early Eocene. Zittel (op. cit.) measured three surface sections and classified the sediments of the measured sections stratigraphically as follows:

Early Eocene	- Hard, well bedded Alveolina and Operculina limestone. - Marls, clays and shales, partly fossiliferous.
Late Cretaceous	- White chalk forming the plain of the depression.

At El Quss Abu Said, Zittel (1883) measured the succession from top to base as follows:

4. Snow white, well-bedded marly limestone with *Alveolina pasticillata*, *Orbitolites pharanum*, *Velates schmiedelii* and *Turritella aegyptiaca.*

3. Greenish yellow marly limestone with *Nummulites deserti, Nummulites guettardi* var. *antique, Nummulites biarritzensis* var. *praecursor* and *Operculina libyca.*

2. Soft green clayey marl and hard limestone with abundant veins of fibrous gypsum. Individual harder beds are rich with *Hemiaster schweinfurthi, Ostrea aviola, Vulsella aegyptiaca, Vulsella zitteli* and *Vulsella eymari.*

1. Soft green shale and gypsum containing leaf marls with *Operculina libyca, Nummulites deserti* and *Nummulites fraasi.*

He also erected a new stage for the Lower Eocene of Egypt; the "Libysche Stufe or Libyan Stage", and placed the succession of El Quss Abu Said in its lower part (lower Libyan).

Zittle (1883) found that the cliff section at Nekeb Farudgeh, near Bir Murr in the eastern side of the depression, to be similar to El Quss Abu Said section in the western side, except for a slight variation. Fossils which are very common in the western cliff are rare or absent in the eastern cliff.

Beadnell (1901) was the first to record the oldest exposed rocks at north Ain El-Wadi, in the northeastern part of the Farafra depression. These rocks lie below the Cretaceous chalk with no visible unconformity. The following is the measured section to the north of Ain El-Wadi spring.

Top:

4. Hard bed of grey crystalline limestone.
3. Yellowish sandstone and sandy clays.
2. Black shaly carbonaceous clay with numerous plant remains.
1. Interbedded shaly clays and buff colored sandstones.

Base:

Beadnell assigned these beds to the Danian. He pointed out to the presence of an unconformity surface between the Cretaceous and the Paleogene in the Farafra Oasis, based on the difference in the dips of the strata of the two systems. Beadnell (1901) summarized the succession at El Quss Abu Said from the detailed section worked out by Zittel (1883) as follows:

Plateau

Early Eocene (240m)

4. Alveolina limestone: Yellow, often marly, very rich in echinoids and Lamellibranchs, etc...85m.

3. Green shaly clays (Esna Shale)...................................150m.

Late Cretaceous (Danian age).

2. Green shaly clays with numerous fossil casts rich in ironstone..3.5m.

1. White chalk forming the plain.

Beadnell correlated bed No. 3 or its upper part with the Esna Shale in the Nile Valley. He also mentioned that the basal part of this shale has fossils similar to those occurring along the surface of the Farafra – Dakhla road via Bir Dikker. This led him to assign a Cretaceous age to the basal member of the Esna Shale.

LeRoy (1945) prepared a preliminary micropaleontological report for the South Mediterranean Oil Company which was the nucleus for his later work in 1953 (quoted from Abdel Aziz, 1968). He gave the following stratigraphical and faunal summary:

Early Eocene (Ypresian)

Maqfi beds: Sharply transitional to the underlying Farafra shale; thus indicating continuous deposition despite the lithological and faunal dissimilarities.

Farafra Shale: The contact with the underlying limestone beds is well defined and exceptionally sharp. Additional work may prove a hiatus at this contact.

Abdalla Limestone: It rests disconformably on sediments of Upper Cretaceous age. This contact is erosional, smooth to irregular and locally a limestone breccia may be observed.

Upper Cretaceous Unit 1: The lower boundary appears to be sharply transitional with the underlying Unit 2. Possible unconformable relationship is due to the lithological and faunal variations and also to the presence of glauconite.

Upper Cretaceous Unit 2: Possible a minor hiatus at the top and obscure bottom relationship owing to the incomplete exposure.

LeRoy (1953) studied the stratigraphy and paleontology of the Cretaceous-Lower Eocene sediments cropping out in Ain Maqfi area, about 69km northeast of Qasr El-Farafra, Farafra Oasis. He identified 132 foraminiferal species and classified the section into five rock units, each is considered as a microfaunal interval except unit II (Esna Shale) which is subdivided into several benthonic foraminiferal intervals. Unit A, which includes the lower chalk with abundant *Globotruncana canaliculata* and *Gumbelina* spp., is considered of Maastrichtian age. It is underlain by variegated clay and sandstone of probable Late Cretaceous age, while the overlying Early Tertiary is classified into four units (IV, III, II and I) which are considered to be of Early Eocene age. Disconformities and erosional surfaces are supposed to separate the different units.

Said and Kerdany (1961) described 180 foraminiferal species from the Upper Cretaceous-Lower Tertiary succession in Ain Maqfi section. They reported that the Maastrichtian chalk is unconformably overlain by the Esna Shale of Late Paleocene (Landenian) age. Also, they divided the Esna Shale into two biozones: a lower *Globorotalia velascoensis/Globorotalia simulatilis* Zone and an upper *Globorotalia colligera/Globorotalia esnaensiss/Globorotalia pentacamerata* Zone. The latter zone is associated with *Nummulites* and *Operculina*. They mentioned that cutting through the lower part of the Esna Shale is a Maqfi

Limestone Member. which is recorded for the first time.

Hassan (1969) described and identified three new regular echinoid species from the Maastrichtian-Paleocene rocks of the Kharga and Farafra oases. These are: 1) *Porocidaris farafrensis* from the Maqfi Limestone Member (Landanian), 2) *Salenia alta* from the Tarawan Chalk (Landanian) and 3) *Salenia intermedia* from the Dakhla Shale (Late Maastrichtian)

Omara *et al.* (1970) studied the structure of the Farafra Oasis and noticed four structural units: Farafra main (central) anticline, El Quss Abu Said faulted synclinal basin, Ain Dalla minor anticline and Abu Minqar up thrown faulted block. They introduced a new formational name called Ain El-Wadi Limestone to describe a sequence of grey, crystalline and cavernous limestone that underlies the chalk and overlies the Nubia Group. The crystalline limestone is thought to be equivalent to the later established El-Hefhuf Formation in the Bahariya Oasis.

Youssef and Abdel Aziz (1971) noticed that the lateral lithologic and, in some cases, faunal variations are remarkable in the Farafra area. Their micropaleontological study revealed the presence of a number of unconformities, some of which seem to be of regional extent (e.g. Maastrichtian/upper Danian disconformity). Other unconformities are local and not synchronous in the different sections, resulting most probably from the syndepositional tectonic activity. This syndepositional tectonism, resulted in considerable reworking, revealed by ubiquitous derived fossils throughout the greater part of the succession. Youssef and Abdel Aziz (op. cit.) introduced two new formational names: Farafra Chalk to describe the chalk that forms the floor of the depression and ranges in age from Early Maastrichtian to Late Danian and Ain El-Wadi Formation to designate a Pleistocene lake deposit formed as a result of the dissolution of the Farafra Chalk. They used a new composite name, the Thebes-Farafra limestone, for the carbonate rocks that terminate the shale at Gunna North. They claimed that these carbonate rocks differ from the typical Farafra Limestone, as they are devoid of Alveolinids and contain a few Operculines and Nummulites as well as their white or bluish gray color recall the Thebes Formation of the Nile Valley. These rocks might represent a deeper water variant of the Farafra Limestone.

Issawi (1972) differentiated the Upper Cretaceous/Lower Tertiary rocks in south and central Egypt into the following facies:

1. Nile Valley facies: It extends from the Red Sea coast in the east to the Kharga Oasis in the west.
2. Garra El-Arbain facies: It occurs in west and south of Aswan as well as south of Kharga Oasis along Darb El-Arbain.
3. Farafra facies: It is present in the Farafra and Bahariya areas. The Maastrichtian deposit is calcareous rather than clastic as in the south and the Duwi Phosphate is missing or represented by thin lenses. The Paleocene sediment is not recorded in the Bahariya Oasis and contains more calcareous rocks in the Farafra Oasis than in the south. The Lower Eocene facies is reefal. Thus, the succession of the Farafra facies is classified into the Campanian El-Hefhuf Formation; the Maastrichtian Farafra Chalk; The Paleocene Tarawan Chalk and Esna Shale, and the Ypresian Farafra Limestone.

These three facies are present in three different basins within the marginal trough on the northern flank of the African shield (Fig. 1.10).

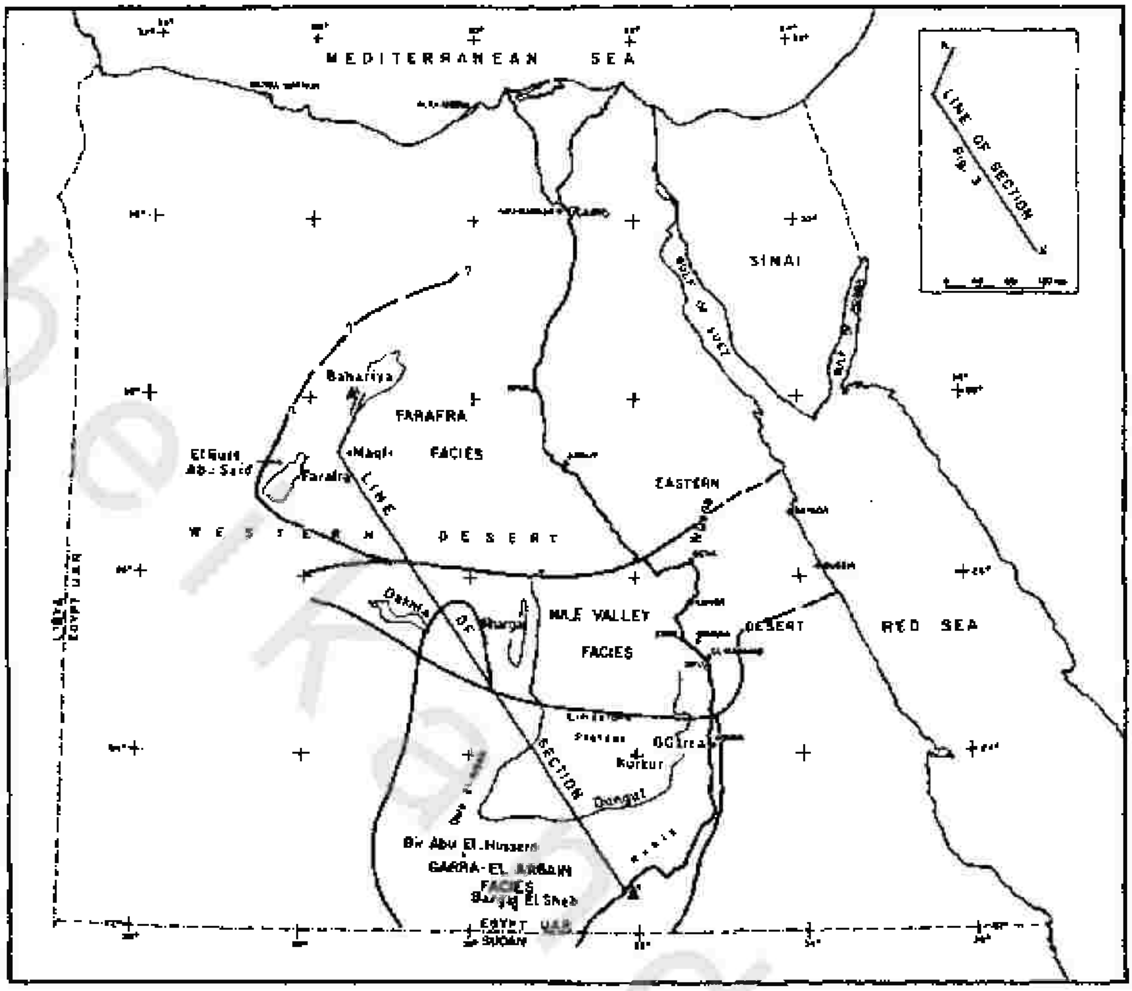

Fig. 1.10 Areal distribution of the different facies types of the Upper Cretaceous-Lower Tertiary sediments as given by Issawi (1972).

Barakat and Abdel Hamid (1974) divided the surface succession in the Farafra Oasis from top to base as follows:

Farafra Limestone	Early Eocene	50m
Esna Shale	Early Eocene	190m
Tarawan Chalk	Late Paleocene	5.5m
Chalk (Dakhla Shale	Maastrichtian-Paleocene	12m

In addition, they subdivided the subsurface succession from top downwards as follows

3. Chalk

2. Compact dolomitized limestone.

1. Nubia Group.

The compact dolomitized limestone is a key bed met in all the studied wells and cropping out in the northern part of the Farafra Oasis.

Barthel and Herrmann-Degen (1981) divided the Dakhla Shale in its reference section at Dakhla Oasis into El Hindaw Member at the base, Qur El-Malik Member and Dakhla Shale Member at the top. Bir Abu Minqar Horizon, which is encountered in the top most part of the section, is defined as a mappable expression of the K/T boundary. Westward in the Great Sand Sea, they introduced the Ammonite Hill Member and the Peak Hill Member as lateral equivalents of the middle and upper parts of the Dakhla Shale Member respectively. They are also introduced Ain Dalla Formation as a new name to the yellowish white, well-bedded limestone that laterally replaces the Esna Shale in Ain Dalla area.

Dominik (1985) introduced a new formational name, the Wadi Hennis Formation, to the lower clastic unit exposed in Ain El-Wadi area and correlated it with the Quseir Formation (Late Campanian) widely exposed in south Egypt.

Khalifa and Zaghloul (1989) studied the stratigraphy and depositional history of the Upper Cretaceous-Paleocene sediments in Abu Minqar-Farafra stretch. These sediments are described as follows from top to base:

5. Esna Shale (Late Paleocene)
4. Abdalla Limestone/Tarawan Chalk (Late Maastrichtian)
3. Dakhla Formation/Khoman Chalk (Early-Middle Maastrichtian)
2. Ain Giffara Formation (Campanian-Maastrichtian). It is attributed to the phosphatic beds that overlie the Nubia Formation in the core of the Maqfi anticline.
1. Nubia Formation (Santonian-Campanian). It crops out in Ain Maqfi anticline, Wadi Hennis and east of Bir El-Obeiyid. This formation corresponds to Wadi Hennis Formation of Dominik (1985).

They noticed the lateral facies and thickness changes within the Esna Formation of the Farafra–Ain Dalla area. These changes mark thick shale with thin limestone in the pre-existing lows (El-Quss Abu Said, Gabal Sofra, Bir Karawin areas) and thin carbonates in the pre-existing highs (Qur Hamra, Ain Dalla and Ain Maqfi areas).

Hermina (1990) mentioned that the 35m thick clastic deposits exposed at Wadi Hennis–Ain Maqfi area are representing the Upper Campanian Wadi Hennis Formation of Dominik (1985). This formation lies unconformably below a carbonate unit of El-Hefhuf Formation with a phosphatic, fossiliferous and ferruginous bed in its lower part. He considered the Khoman Chalk in the Farafra Oasis to range in age from latest Campanian to Early Maastrichtian. He also mentioned that the overlying shale (17m thick), below the Tarawan Formation, is a tongue of the Dakhla Formation (uppermost part of its Kharga Shale Member). The latter is of Early-Middle Paleocene age, whereas the overlying Tarawan Formation is of Late Paleocene age. He assigned a late Paleocene age to the lower two thirds of the Esna

Formation and an Early Eocene age to its upper third.

Zaghloul *et al.* (1993) classified the Cretaceous-Lower Eocene sediments of west Bahariya area into the following rock units from top to base:

6. The Farafra Formation..Ypresian

5. The Esna Formation...........................Landenian-Ypresian

4. The Abdalla Limestone

3. The Khoman Clhak.......................................Maastrichtian

2. The Hefhuf Formation......................................Campanian

1. The Heiz Formation...................................... Cenomanian

Samir (1994) examined the Khoman Formation in the area between the Bahariya and Farafra oases by means of planktonic foraminifera. The R-mode factor analysis of the planktonic foraminifera led to the recognition of three different faunal assemblages. He attributed the Khoman Formation to the Early-Middle Maastrichtian *Globotruncana aegyptica* and *Gansserina gansseri* zones. The microfaunal content indicates a gradual shallowing in the depositional environment from the Early to Middle Masstrichtian.

Abdel-Kireem and Samir (1995) studied the exposed Maastrichtian–Lower Eocene sediments in the Gunna North section and divided their planktic forminiferal content to eleven zones. These zones are: *Globotruncana aegyptiaca* Zone, *Gansserina gansseri* Zone (Khoman Fm.), *Morozovella trinidadensis* Zone, *Morozovella uncinata* Zone, *Morozovella angulata* Zone (Dakhla Fm.), *Igorina pusilla pusilla* Zone, *Planorotalites pseudomenardii* Zone (Tarawan Fm.), *Morozovella velascoensis* Zone, *Morozovella subbotinae* Zone, *Morozovella aragonensis* Zone (Esna Fm.) and *Acarinina pentacamerata* Zone

(Farafra Fm.).

Boukhary *et al.* (1995) described two new species, *Nummulites luterbacheri* and *Assilina farafraensis*, from the basal Ilerdian of the southern escarpment of El Quss Abu Said. They also recorded the presence of *Nummulite sroselli* Schaub, 1981 for the first time in Egypt. They considered the shale forming this portion of El Quss Abu Said Plateau and the overlying Farafra Limestone as belonging to a new formation named the Nusf Formation.

Samir (1995) studied the palaeoenvironmental significance of the Upper Cretaceous-Lower Tertiary foraminifera in the North Gunna section. He believed that the basal and top parts of the Khoman Chalk as well as the base of the Esna Shale to be deposited in a lower neritic (100-200m) depth environment; the middle part of the Khoman Chalk, the upper part of the Dakhla Shale and the overlying Tarawan Chalk to be deposited in an upper to middle bathyal (200-1000m) depth environment. A middle bathyal depth (600-1000m) is indicated to the middle part of the Esna Shale, which is followed by shallowing conditions during deposition of the upper part of the Esna Shale and the overlying Farafra Formation.

Strougo (1996) discussed the Libyan Stage of Zittel (1883) as a chronostratigraphic unit and proposed a fourfold division of the Libyan Stage. In El Quss Abu Said Plateau, the type locality of this stage, he subdivided the succession by means of macro-invertebrates, mainly bivalves and echinoids, into four stratigraphic levels designated as 1b1 through 1b4, in ascending order. The Esna Shale comprises the levels 1b1, 1b2 and 1b3 while the Farafra Limestone belongs to 1b4.

Strougo and Hewaidy (1999) studied the Paleocene/Eocene succession of LeRoy Ain Maqfi section. They mentioned that the

Dakhla Shale. Tarawan Chalk and the basal Esna Shale which correspond to LeRoy Unit IV should be assigned to the Paleocene, while Unit II is younger and belongs to the Early Eocene. Unit III is somewhat older than the Nummulite-bearing limestone at the southern scarp of El Quss Abu Said, (Fig. 1.11).

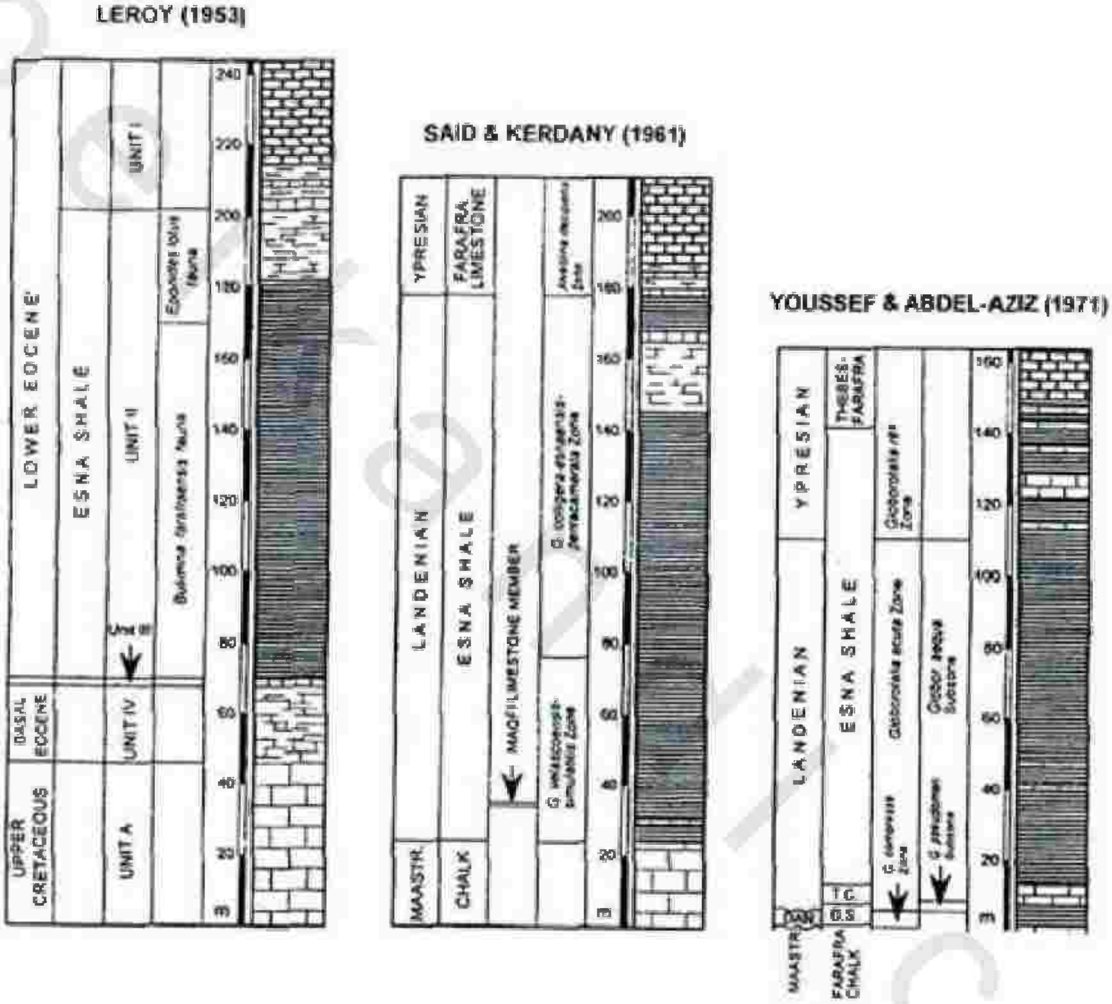

Fig. 1.11 Columnar sections showing the variations in lithologic and micropaleontologic subdivisions of the Ain Maqfi section as given by different authors (after Strougo and Hewaidy, 1999).

El-Azabi and El-Araby (2000) studied the sedimentary facies characteristics and cyclicity of the Dakhla Formation in west Dakhla-Farafra stretch. They identified ten depositional cycles, delineated from each other by a bounding surface and four depositional sequences, separated by five type 2 sequence boundaries. The first and second sequences correspond to the Upper Maastrichtian Mawhoob Shale and lower-middle part of the Beris Mudstone members, respectively. The third sequence comprises the Beris Mudstone Member (upper part) and the uppermost Maastrichtian partition of the Kharga shale Member. The well-documented Cretaceous-Tertiary boundary marks the sequence boundary at the top of the third sequence. The last depositional sequence coincides with the late Early-Middle Paleocene partition of the Kharga Shale Member. These sequences comprise nine systems tracts mainly of transgressive and highstand systems tract deposits.

Issawi and Osman (2000) traced a marked lateral change in lithology in the Upper Cretaceous–Lower Tertiary succession across a line passing south of the Farafra area (south of Latitude 27° N). They mentioned that the Dakhla, Tarawan and Esna formations in the south are replaced by the Khoman, Abdalla and Ain Dalla formations in the north. They also noticed a lateral facies variation in the upper part of the Esna Formation which may extend to the overlying Farafra Formation in Ain Dalla area.

Hewaidy and Strougo (2001) studied the smaller benthic foraminifera of the Gunna North (Maastrichtian-Early Eocene), El-Sheikh Marzouk (Early Eocene) and the Twin Spikes (Late Paleocene-Early Eocene). They recorded the disappearance of the *Anomalinoides grandis* and others at the end of the Maastrichtian and the *Anomalinoides pseudoacutus*, *Gyroidinoides girardanus* and *Angulogavelinella avnimelechi* at the end of the Paleocene. The Early Eocene, on the other hand, was marked by a sudden appearance of the *Gaudryina Africana* and *Heterolepa libyca*. They also pointed out that relatively deeper conditions (outer shelf-upper bathyal depth) prevailed during the Maastrichtian, the upper part of the Paleocene, and the basal part of the Early Eocene at Gunna North. A radical change in the depositional environment resulting in an intra-Lower Eocene disconformity is traced at the Twin Spikes, which may also identified at El-Sheikh Marzouk.

Khalifa *et al.* (2002a) studied the facies and depositional environments of Ain Giffara Formation (Campanian-Maastrichtian) in the Bahariya Oasis. They mentioned that Ain Giffara Formation is separated from the underlying El-Hefhuf Formation by an unconformable contact. In addition, they applied this term in the Farafra Oasis at Wadi Hennis.

Khalifa *et al.* (2002b) in their study on the lithostratigraphy and sequence stratigraphy of the Turonian-Santonian rocks in the Bahariya Oasis mentioned that the term Wadi Hennis Formation of Dominik (1985) is not suitable to describe the clastic sequence either in the Bahariya or in the Farafra oases. They added that the formation does not follow the rules of the stratigraphic codes and consequently introduced the term Naqb El Sillim Formation to describe the clastic facies occurring below Ain Giffara Formation in the Farafra and Bahariya oases, which was erroneously named El-Hefhuf Formation by Hermina (1990).

Abdel Mohsen (2002) studied the palynological content of the subsurface succession underling the Khoman Formation in the Farafra Oasis and classified it into El-Heiz Formation of Early Cenomanian age and El-Hefhuf Formation of Turonain-Santonian age with an unconformity surface at the contact between them.

Khalil and El-Younsy (2003) examined the Maastrichtian-Lower Eocene succession in three measured sections at Gunna North and El Quss Abu Said. They subdivided the succession into five rock units (Khoman, Dakhla, Tarawan, Esna and Farafra formations) with three major third-order depositional sequences separated by two sequence boundaries.

Moustafa *et al.* **(2003)** pointed out that the tectonic evolution of the Bahariya Oasis shows a great similarity to the deformation of the tectonically unstable area of the north Western Desert. They concluded that the Bahariya region has been affected by positive structural inversion in the Late Cretaceous to Early Tertiary causing the development of a large anticlinal structure with a broad crestal area, known as the Bahariya Swell, in addition to many other second order folds. The inversion started before deposition of the Maastrichtian chalk which on lapped the margins of the Bahariya Swell with the overlying Paleocene and Lower Eocene rocks. They added that four distinct ENE-oriented structural belts are developed over deep-seated faults; three of them define the shape of the Bahariya depression, whereas the fourth lies in the plateau between the Bahariya and Farafra. The latter is a 20km long monocline with a steep flank dipping up 16° NW and affects the thick Upper Cretaceous-Lower Eocene sediments. This structural belt may extend southwestward for at least 100km to the northern reach of El Quss Abu Said in the Farafra area.