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For my Mother,
My second mother, Tahani Abdalla,

and

Professor Ahmed Abu Khadrah, Professor Ronald Steel, Professor Nicholas Christie-Blick,

and

The Moghra Team

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Introduction

1.1 Introduction

The northern cliffs of the Qattara Depression exhibit excellent outcrops of the Lower Miocene Moghra Formation, which is known for its fossil vertebrates. Despite this successful focus on the vertebrate of Moghra area, there is still a noticeable gap in our knowledge about Lower Miocene sedimentology and sequence stratigraphy of this area. The literature about the sedimentology and sequence stratigraphy of the Moghra Formation has been sparse, despite some excellent work over the years by academic and petroleum workers. Moreover, the studied area is within what was a front-line of World War II, where mine fields and war relics are scattered and cover wide reaches. This has resulted in limited geologic mapping in the past. Thus, great attention is paid in this study to establish a robust sedimentology and high-resolution sequence stratigraphic framework for the Lower Miocene Moghra Formation. Included are works based on outcrops and, most importantly, new sedimentological and chronostratigraphic information not previously available. Moreover, the palaeogeographic reconstruction and facies distribution of the Lower Miocene in this area (onshore Mediterranean) will directly impact the offshore petroleum exploration strategies in terms of reservoir prediction and proximal–distal facies variation.

1.2 Location

The area under study, covering about 40 km^2, is limited by Latitudes 30° 10′ and 30° 30′ N and Longitudes 28° 30′ and 29° E (Fig. 1.1).

The area is accessible from El Hammam and Alamein (about 60 km to the south) on the Mediterranean coastal zone, by unpaved tracks, traversing the studied area. Moreover, it can be reached from Wadi El Natrun, to the east, by a

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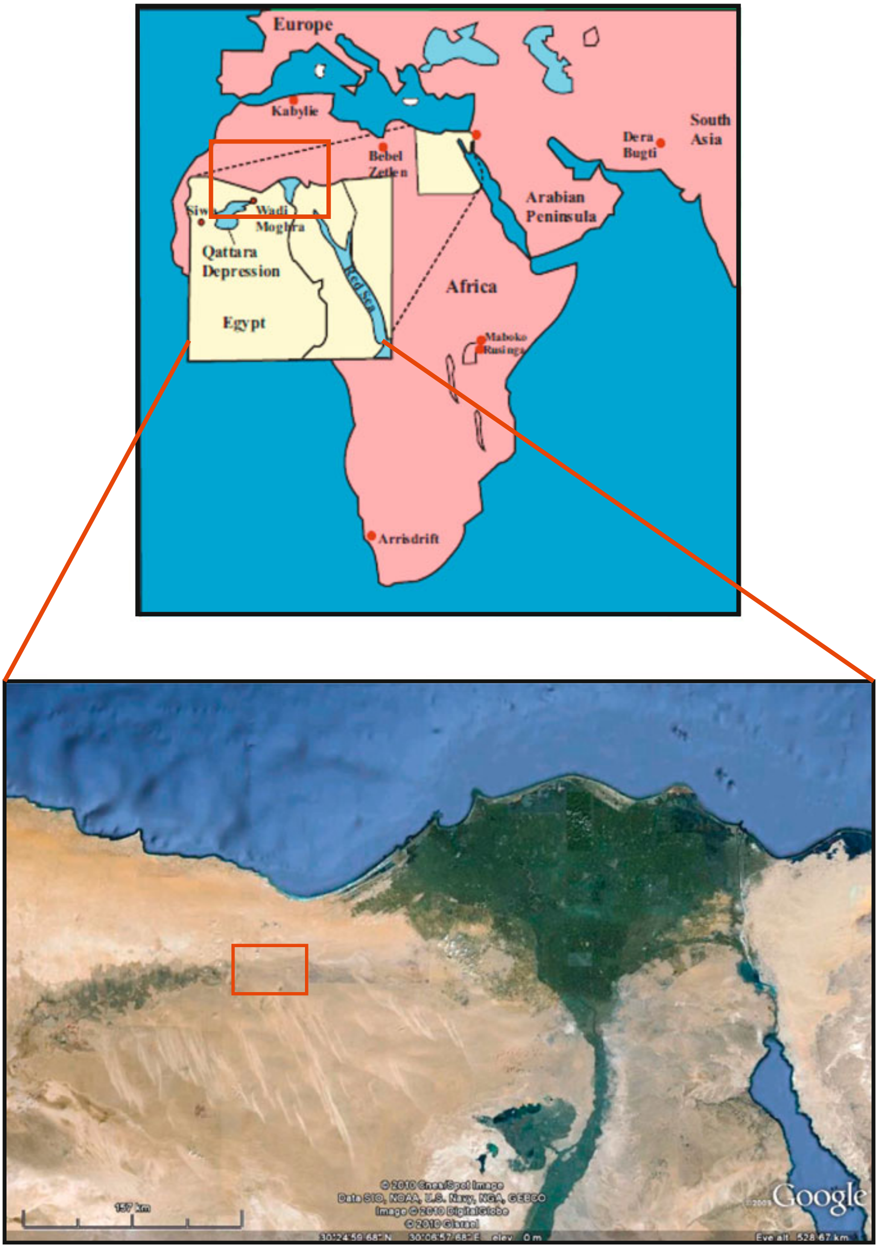

Fig. 1.1 Location map of the study area (*Red square*, modified after Sanders and Miller 2002)

poor and undefined track. Now, the area is easily accessible after some urban development has moved towards the area, and the low-lying land of the area has been cultivated for different type of crops.

1.3 Aim and Scope of Study

Despite the progress made on understanding the paleontology and general stratigraphy of Moghra, a number of research questions remain to be addressed regarding the depositional facies and their time/space distribution. No sequence stratigraphic studies have previously been undertaken in the Moghra area.

The aim of the study is to establish a robust high-resolution sequence stratigraphic framework for the Lower Miocene Moghra Formation and to reconstruct the palaeogeography for that time. Moreover, the palaeogeographic reconstruction and facies distribution of the Lower Miocene in that area (onshore Mediterranean) will directly impact the offshore petroleum exploration in terms of reservoir prediction and proximal distal facies variation.

The present work provides a large amount of new data on all aspects of the Moghra Formation, ranging from stratigraphy to chemostratigraphy to sequence stratigraphy. Perhaps one of the important contributions is the isotope stratigraphy. There is a lack of suitable material for absolute dating of the Moghra Formation. Nevertheless, indirect dating using strontium isotope stratigraphy has been possible. It has been known, particularly for the mid-Cenozoic, that the strontium isotope sea-water curve changes rapidly with time, and so is particularly appropriate for geochronology. In this time interval, resolution of stage boundaries is better than 0.5 m.y. (Howarth and Mcarthur 1997; Oslick et al. 1994), making the method a powerful tool for improving correlation between chronostratigraphic time-scales and biostratigraphy. So combined biostratigraphic and strontium isotope analysis has resulted in a much firmer age setting for the Moghra Formation.

1.4 Methodology

Different approaches will be followed in reaching the targets of the present study through field work, work flow of sequence stratigraphy and laboratory analyses.

1.4.1 Work Flow

Sequence stratigraphic principles can be readily applied to outcrops by using the following workflow steps.

1. Facies analysis. In order to correctly identify the depositional environments, a facies model needs to be constructed, so that proximal, distal and lateral facies relationships can be assigned. A facies model is constructed by careful study of all elements of the sedimentary succession, identifying the signals of physical processes that were taking place during the deposition, and interpreting environmental systems. In a vertical succession, using the facies model, a shallowing- and or deepening upwards succession can be defined.

2. Stacking patterns, parasequences and parasequences sets can be recognized and recorded.
3. Following the documentation of parasequences and the processes that produced them, systems tracts can be identified based on the overall stacking patterns of the parasequence sets, and how the stacking pattern changes through the succession.
4. Surfaces of maximum regression (sometimes equivalent to the sequence boundaries, but not where there are lowstand deposits) and surfaces of maximum transgressions (maximum flooding surfaces) can be defined and supported by field observations. The succession then can be divided into sequences.
5. Accurate delineation of the age and timing of subaerial exposure, unconformities and truncation surfaces is a powerful tool for detecting sea-level change and sediment supply change.
6. Different time scales are defined as orders and used in the linkage between various scales of cyclo-stratigraphy. Special emphasis is given to the relationship between third-order (1–10 m.y. period) depositional cycles and their component fourth-order (0.1–1 m.y.) cycles through detailed stratigraphic analyses of Moghra Formation.
7. Building the concept of an early Miocene integrated depositional and sequence stratigraphic model in the study area.
8. Finally, The sequence stratigraphic framework is developed, and then the results are compared with the global sea level curves of Haq et al. (1987, 1988) and Pekar and Christie-Blick (2008).

1.4.2 Field Work

Field work was carried out through the following steps in order to complete the study of the Lower Miocene of Moghra Formation.

1.4.2.1 Reconnaissance within the Study Area

This has been carried out using a map produced by the satellite image of Lower Miocene Moghra Formation in The Qattara Depression, North Western Desert to select suitable section localities, as well as to check the previous work. In addition, we used the topographic map El Moghra, sheet NH35: L1. Scale 1:100,000.

1.4.2.2 Measurement and Sampling of the Selected Sections Through the Following Steps

a. Stratigraphic sections have been measured, and described across all the studied area from the East to the West.

b. More than 500 rock samples have been collected for different litho facies. They show that there is remarkable facies change within every section.
c. Palaeocurrent measurements are also used for the palaeogeographic interpretations.
d. The best sections in the studied area were selected and a detailed sedimentological and palaeontological study was conducted in order to provide a serious base for environmental reconstruction.
e. The depositional environment has been modeled in relation to the sequence stratigraphic framework.

1.4.3 Laboratory Work

These were carried out for some special samples of certain interest to fine-tune the characterization of the units. The results are used for supporting and enhancing stratigraphic and sedimentologic interpretations. Among laboratory analyses used are:

1. The collected hand specimens and polished slabs have been examined by eye to detect the variations in their lithology, colours, sedimentary structures and textures (at mesoscopic scale).
2. Petrographic microscopy of thin section. Most samples were subjected to microscopic examination in thin sections. The results obtained are used to determine the petrography of the rocks and to shed more light on the framework of sedimentation and history of diagensis.
3. Chemostratigraphy dating of some samples of good preservation.
4. We have determined the $^{87}Sr/^{86}Sr$ ratios and derived absolute ages for more than 15 macrofossil samples collected from several biostratigraphically dated Lower Miocene sections in the Moghra area. Measurement on a mass spectrometer of the strontium (Sr) isotope ratio $^{87}Sr/^{86}Sr$ in marine fossil shells has provided absolute ages for those shells.
5. Paleontology investigation of selected samples for more accurate age determination.

1.4.4 Previous Works

The Miocene sequence in the Western Desert has been studied by many previous workers: Fourtau (1920), Shata (1955), Said (1960, 1961a, b, 1962a, b, 1971 and 1990), Abdallah (1996), Marzouk (1970), Philip et al. (1973), Philip and Darwishe (1973), Omara and Sanad (1975), El-Khashab (1977), Misak (1979), Al-Wakeel (1989), Abu-Zeid and Al-Wakeel (1992), Abdallah (1996), Sharaf (1995), Miller and Simons (1996), El-khoriby (2004), Abd-Alla (2001).

Fourtau (1918), published the first treatise on the Moghra vertebrate fauna (see also Blanckenhorn, 1901), and in 1920 he re-published his previous account with additional appendices.

Shata (1955) discriminated the Miocene rocks of the Western Desert into two horizons: 1. An upper horizon of Middle Miocene shallow marine limestone of maximum development of 300 m thick, becoming partially fluviatile east of longitude 29° E.

2. A lower horizon of Lower Miocene mainly composed of shallow marine fossiliferous limestone and marl changing to sand and silt south and east of the Qattara Depression. It attains a thickness of approximately 300 m.

Said (1962a, b) divided the Miocene sediments of the Western Desert of Egypt into two distinct rock units from base to top: the Moghra Formation and Marmarica Limestone Formation (Table 1.1). Moghra Formation covers all the facies exhibited by the Lower Miocene sediments of the North Western Desert. He distinguished an "estuarine", marine, reefal and open bay facies. In addition, a genuine fluviatile facies, given the name Gebel Khashab Redbeds, is also recognized. Furthermore, he concluded that the lowermost Lower Miocene (Aquitanian) is not found. The Moghra Formation is of Burdigalian age. The Marmarica limestone unit which caps the underlying Moghra clastics shows little lithological change throughout its entire thickness and width which covers almost 6° of longitude. It changes from solid limestone unit in the west to a sandy limestone unit in the east. The lower clastic Moghra Formation shows areal variations with regard to its lithology and its faunas. This variation is intimately connected with the geological history of the region during lower Miocene time. Two facies can be recognized: a proper marine facies in the west and a fluvio-marine facies in the east.

Abdallah (1966) stated that the Lower Miocene Moghra Formation is deposited under fluviomarine, semicontinental and estuarine conditions. This is proved by the presence of vertebrate remains, marine macro and micro-fossils, wood remain, thin gypsum seams or lentils and thin carbonaceous and brown coal very thin seams and specks. The Moghra Formation is Burdigalian Age and also the lowermost Lower Miocene (Aquatanian) is not found. From the tectonic viewpoints, no major true structural displacements (faulting or folding) are recognized. Nevertheless, few exceptions are observed, represented by fracturing and jointing caused by epeirogenic movement and/or mild post-Miocene extensional forces (Pliestocene?). Jointing (fractures in general sense), landslides and minor pseudofolding (i.e. upwards gentle doming "Aufwolbung") are the main surface structural features recorded.

Norton (1967) delineated the following three rock units (from base to top):

1.The Moghra group (Oligocene to Early Miocene) is represented by interbedded sandstone, marls, shale and gypsum, with occasional limestone beds and several fossil wood and vertebrate remains. Oligocene basalt is interbedded in the Moghra group west of Giza where it conformably overlies Upper Eocene deposits.

2. The Qaret Shushan Formation (Oligocene to Early Miocene) conformably overlies the marine Oligocene shale and is represented by interbedded shale,