Chapter V

Sequence Stratigraphy

V. Sequence Stratigraphy

V.1 Review

Sequence stratigraphy is the most recent and revolutionary paradigm in the field of sedimentary geology. It completely revamps the geological thinking and the methods of stratigraphic analysis (Catuneanu, 2002). Sequence stratigraphy is used to provide a chronostratigraphic framework for the correlation and mapping of the sedimentary facies and for the stratigraphic prediction.

A stratigraphic unit composed of a relatively conformable succession of genetically related strata bounded at its top and base by unconformities or their correlative conformities is defined as sequence (Mitchum, 1977). The term unconformity in this definition was an initial cause of confusion, because the precise usage of the term can vary. Mitchum (op. cit.) initially included marine hiatuses and condensed intervals in the term "unconformity", but as models of cyclic deposition driven by sea level variation developed, it became clear that basin-margin subaerial unconformities need to be distinguished from basin-centre marine hiatuses.

Sequence stratigraphy is often regarded as a relatively new science, evolving in the 1970s from seismic stratigraphy. It was first applied in a comprehensive way to the Lower Paleozoic of Montana. The term sequence was originally introduced by Sloss *et al*. (1949) to designate a stratigraphic unit bounded by subaerial unconformities. Sloss (1963) also emphasized the importance of tectonism in the generation of sequences and bounding unconformities, an idea which is widely accepted today, but was largely overlooked in the early days of seismic stratigraphy.

The sequence stratigraphic model depends on the quality and variety of the input data. Therefore, integrated disciplines of sedimentology, stratigraphy, geophysics, geomorphology, isotope geochemistry and basin analysis and mutual calibration of many data sets as possible are recommended. The most common data sources for a sequence stratigraphic analysis include outcrops, modern analogues, drilled cores, well logs and seismic data (Catuneanu *et al.*, 2005).

The main controls which effected on the sequence stratigraphic interpretation are sea level change, subsidence, uplift, climate, sediment supply, basin physiography and environmental energy. The interpretations of the sequence stratigraphy in the present-study are based on integration of lithostratigraphy, biostratigraphy, facies characteristics and depositional environments.

The chronostratigraphic resolution obtainable from fossil markers depends on the geological period, the number of fossil groups used and the type of depositional environments. The resolution of a fossil group .is calculated by dividing the geological period by the number of biozones in a particular global scheme. All fossils have potential application to the sequence stratigraphy, although to date sequence boundaries and maximum flooding surfaces accurately a high frequency of chronostratigraphically significant fossil events is required. This is best obtained through the integration of marker taxa from several different fossil groups. The most useful group in the present study includes foraminifers which exhibited distinct and rapid morphological change so as to be unequivocally identifiable. It is also important that they are distributed widely and therefore correlatable within and between basins, and occur in sufficient abundance that their presence is a statistically viable event. If significant erosion has occurred at the sequence boundary, a biostratigraphic hiatus may be resolved by the juxtaposition of younger fossil assemblages on older ones and the negative evidence of absent fossil markers. The age and palaeoenvironmental contrast indicated by the fossil assemblages from above and below the boundary, are both a function of the magnitude of relative sea-level fall (McNeil *et al.*, 1990). Lithostratigraphy is very important to maintain the traditional descriptive stratigraphic units, particularly the lithostratigraphic units during the sequence stratigraphic studies. The vertical boundaries of the lithostratigraphic units are likely to correspond to sequence boundaries.

The lateral changes into coeval rock units express equivalent systems tracts. Allostratigraphic factors assisted in defining the sedimentary cycles and sequence boundaries. The good match between the lithostratigraphic units and the sedimentary cycles suggests genetic variations. Correlating the suggested sequence stratigraphic sedimentary cycles with geomagnetic chrones strongly points out to a probable universal control which is mostly global tectonics.

V.2 Terminology of sequence stratigraphy

The following is a brief description of the widely used terms in sequence stratigraphy based on the works of Mitchum (1977), Jervey (1988) and Van Wagoner *et al* (1988).

– **Sequence boundary:** A sequence boundary is a chronostratigraphically significant surface produced as a consequence of a fall in relative sea-level.

– **Systems tract:** The systems tract is associated stratigraphic units that were deposited during specific phases of the relative sea level cycle. It is defined on the basis of boundary surface, position within a sequence, and parasequence stacking patterns. It is easy to become lost in the complexities of systems tract terminology, and it is always worth remembering the purpose of stratigraphic division into systems tract. The systems tract represents the fundamental mapping unit for stratigraphic prediction, because it contains a set of depositional systems with consistent palaeogeography and depositional polarity, and for which a single palaeogeographic map can be drawn.

– **Lowstand systems tract:** The basal (stratigraphically oldest) systems tract in a type 1 depositional sequence is called the lowstand systems tract.

– **Transgressive systems tract:** The transgressive systems tract is the middle systems tract of both type 1 and 2 sequences and deposited during that part a relative sea-level rise cycle when topset accommodation volume is increasing faster than the rate of sediment supply

– **Highstand systems tract:** The highstand systems tract is the youngest systems tract in either a type 1 or type 2 sequences and represents the progradational topset-clinoform system deposited after maximum transgression and before a sequence boundary, when the rate of creation of accommodation is less than the rate of sediment supply.

– **Transgressive surfaces:** The transgressive surface is the first significant marine-flooding surface across the shelf within a sequence.

– **Maximum flooding surface:** The maximum flooding surface separates the transgressive systems tract from the highstand systems tract and represents the maximum landward extent of the marine conditions.

– **Parasequences:** parasequences is represented by a transition from shallower to significantly deeper water facies. Often the upward-deepening component and only by a hardground or omission surface marking and can be recognized in logs, cores and outcrops as shallowing-upwards depositional units separated by surfaces of abrupt deepening (i.e. marine flooding surfaces). Parasequence boundaries form the lowest-order partical chronostrigraphic framework for correlation and mapping.

– **Accommodation space:** The concept of accommodation describes the amount of space that is available for sediments to fill. It is being measured by the distance between base level and the depositional surface. Accommodation is controlled by base level because in order for sediments to accumulate, there must be space available below base level. The base level datum varies according to depositional setting. The contrast between the rates of change in accommodation and the sedimentation rates in localities placed in the vicinity of the shoreline may shift either landward or seaward during time of base level rise (Catuneanu *et al*., 2005).

The identification of large scale vertical and correlation of sequence boundaries and other characteristic surfaces enables a better understanding and interpretation of a large scale vertical and lateral facies relationships in a depositional system.

Although all sequences originating from relative sea level changes show principally the same succession of systems tracts, but their lithologic and stratigraphic expressions very enormously from the near shore to deep water settings. In coastal setting, the sequence boundaries are represented by erosional unconformities and the sequence is composed of fluvial and shallow marine sands. While, in deeper water domain the same transgressive-regressive cycle may be bounded at the base by a submarine fan and its top by an inconspicuous conformable surface with a hemi-pelagic unit representing an increasing sedimentation rate.

In deep-water sequences, pelagic organisms and occasional volcanic ash layers are used to date the cycle. In shallow water sequences, relics of benthonic life commonly predominant and transgressive and regressive erosional larger deposits mostly contain mixed faunas from reworked sediments of various ages. Therefore, an exact dating of sequence boundaryes is frequently problematic (Einsele, 1991).

Such basics are of prime importance in sequence stratigraphical concepts. They help to re-evaluate the record of relative sea level changes and re-build the sedimentary history of the Upper Cretaceous–Lower Eocene succession in the Farafra Oasis. Relative sea level fluctuations have left their impact on the studied Upper Cretaceous-Lower Tertiary depositional sequences in the Farafra Oasis. It resulted in a variety of shallow and deep marine sediments with many distinct lateral and vertical variations in facies and thickness. The Farafra Oasis has been subjected to several tectonic movements (LeRoy, 1953; Said and Kerdany, 1961, Barthel and Hermann-Degen, 1981 and Hermina, 1990), which accompanied with the pronounced sea-level changes through the Late Cretaceous-Early Eocene times.

The Upper Cretaceous-Lower Eocene succession is classified into eight well-defined, third-order depositional sequences which are separated by obvious sequence boundaries as a result of drastic falls in relative sea-level. These boundaries typify evidence for sub-aerial exposure such as erossional surface with reworked fauna, intense dolomitization and evaporite formation, and submarine breaks and non-deposition marked by faunal break and extensive bored hardground. They also display a sudden upward change in facies and stacking patterns of parasequence sets.

V.3 Sequence boundaries

Seven unconformities or sequence boundaries are detected in the Upper Cretaceous-Lower Eocene succession of the Farafra Oasis (Fig. 5.1). The distinguished sequence boundaries are from old to young as follows:

Santonian/Campanian sequence boundary (SB1)

This sequence boundary is established between the Santonian lower clastic and the Campanian upper carbonate unites of El-Hefhuf Formation (SB1, Fig. 5.1); it has a sharp erossional contact in Wadi Hennis and East Shakhs El-Obeiyid area. This contact is characterized by subareial exposure and erosion associated with reworking of some Cenomanian fauna such as *Ilymatogyra* (*Afrogyra*) *africana* (Lamarck) and *Ceratostreon flabellatum* (Goldfuss) in the overlying fossil bank at Wadi Hennis area. (Figs 2.6 & 2.7). The reworked fauna, however, shows that the source area was probably subaerially exposed at the time of the deposition of the overlying fossil bank sediments.

In east Shakhs El-Obeiyid section, the sequence boundary (SB1) is traced at the top of a phosphatic sandy dolostone bed. It is delineated by the presence of intensive bioturbation of flask and bifurcated types with iron nodules. The present author agrees with Hermina (1990) who considered the clastic unit at Wadi Hennis to lie unconformably below the carbonate unit of El-Hefhuf Formation.

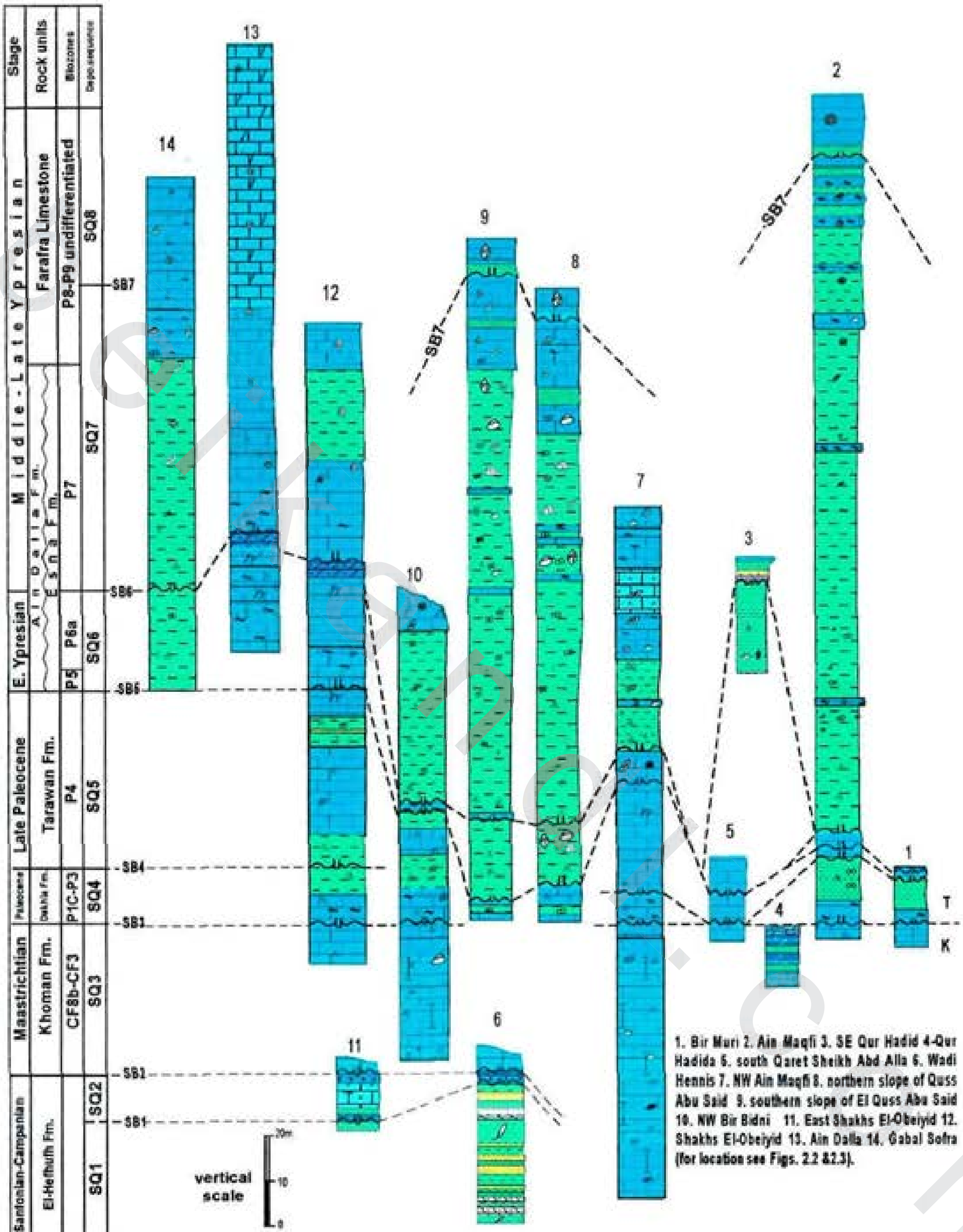


Fig. 5.1 Correlation chart of the exposed Upper Cretaceous-Lower Eocene succession in the Farafra Oasis showing its distinct lateral and vertical facies and thickness variations as well as the detected sequence boundaries and depositional sequences (horizontal distance not to scale).

Campanian /Lower Maastrichtian sequence boundary (SB2)

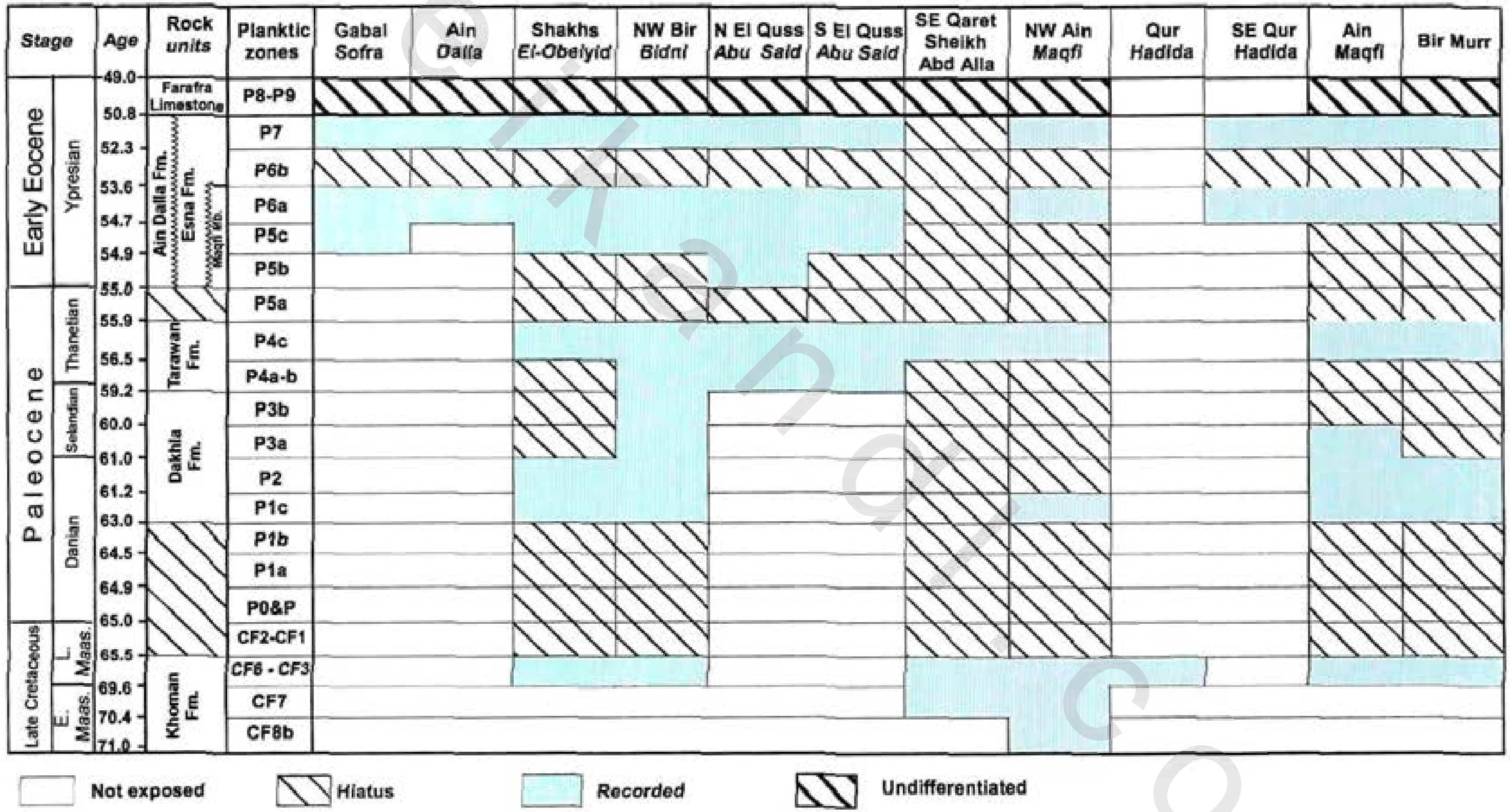
This sequence boundary is established between the Campanian dolostone bed of El-Hefhuf Formation and the overlying Maastrichtian Chalk of the Khoman Formation, it is a sharp irregular contact. This sequence boundary corresponds to the first sequence boundary SB1 of El-Azabi and El-Araby (2000), which separates between the Latest Campanian and continued until the beginning of the *Gansserina gansseri* Zone of Maastichtian age. Hermina (1990) also considered the Khoman Chalk lying unconformably over the Upper Campanian sediments of El-Hefhuf Formation.

Upper Maastrichtian/Danian sequence boundary (SB3)

This major sequence boundary, which represents the Cretaceous-Tertiary contact in the Farafra Oasis, separates the Khoman from the Dakhla formations. It coincides with the major extinction of the Cretaceous planktic species at the K/T boundary. The sequence boundary SB3 denotes the missing of the Latest Maastrichtian and lower part of the Danian record. It is characterized by a bioturbated erosional surface, partly with some reworked Late Cretaceous fauna and denotes the faunal break of the *Pseudoguembelina palpebra* (CF2), *Plummerita hantkeninoides* (CF1) in the Cretaceous period and *Parvularugoglobigerina eugubina* (P0), *P. eugubina-Subbotina triculinoides* (P1a) and *Subbotina triculinoides-Globanomalina compressa* Subzones (P1b). This faunal break represents time laps of about 2.5 Ma (Table 5.1).

In fact, an unconformity of different magnitudes occurs in the Farafra Oasis, at the Late Cretaceous-Early Tertiary boundary (Le Roy 1953; Said & Kerdany 1961 and Said & Sabry 1964).

Table 5.1 Correlation chart showing the age assignments of the depositional sequences and their bounding surfaces as detected from the planktic foraminiferal zones of the different measured stratigraphic sections in the Farafra Oasis.



The major K/T boundary is also present in the type section of the Dakhla Formation, Gabal Gifata at the base of a 1m thick, calcareous siltstone and sandy limestone that marks the base of the Abu Minqar Horizon (Tantawy *et al.* 2001). At Gabal Edmonstone, El-Azabi and El-Araby (2000) recorded the K/T boundary within the lower part of the Kharga Shale Member of the Dakhla Formation. This hiatus is represented by a submarine hardground. It is detected also by a marked thin conglomerate bed, 20-30 cm thick, with reworked Late Cretaceous fauna in west Mawhoob area (Abbass and Habib, 1971, El-Dawoody and Zidan, 1976) and in Qur El Malik (Hermina, 1990).

Danian/Thanetian sequence boundary (SB4)

This sequence boundary is detected at the contact between the Dakhla Formation and the overlying Tarawan Formation. It is characterized by a faunal break with hematite-stained along matrix due to the absences of the *Morozovella angulata-Globanomalina pseudomenardii* (P3) and the basal part of the *Globanomalina pseudomenardii* (P4a-b) Zones in Bir Murr which represent a time gap of about 4.5 m.y. This oxidized bored hardground records a break in marine sedimentation associated with sea level fall and subaerial exposure. The sequence boundary SB4 is traced also at Shakhs El-Obeiyid due to the absence of the P3 Zone accompanied with reworking of older foraminiferal fauna along the unconformity surface.

The time lapse of this hiatus varies from place to place, (Table 5.1). At Ain Maqfi, it is characterized by the absence of the *Igorina albeari/Globanomalina pseudomenardii* P3b Subzone and the basal part of *Globanomalina pseudomenardii* (P4a-b) Zone to represent a time gap ranging from 60.0 Ma to about 56.5Ma. This hiatus increases northward to represent a time gap from 61.2 Ma to about 56.5 in extreme northwest Ain Maqfi. Further north in south Qaret Sheikh Abd Alla, both SB3 and SB4 are superimposed due to the absence of the whole Dakhla Formation, recording a major hiatus of about 9.0 Ma (Table 5.1). This sequence boundary (SB4) is conformable in northwest Bir Bidni and Gunna North inselbergs as a result of continuous sedimentation. Intra-Paleocene gaps involving the absence of Zone P3 and Zone NP5 which recorded by Strougo (1986) and also mentioned that they are related to a large-scale syndepositional tectonic disturbance, including faulting, which resulted into marked changes in depositional patterns. El-Azabi and El-Araby (2000) observed the effected of this sequence boundary at Gunna North inselbergs and mentioned that the boundary is established at the top of the planktic foraminiferal *Igorina pusilla* P3b Zone between the Dakhla and Tarawan formations by the occurrence of horizontal branched burrows. This unconformable contact is traced also throughout the whole north Kharga area and at several localities in Dakhla, west Dakhla and Farafra (Hermina, 1990); where the coeval calcareous mudstone rocks recorded between the Khoman Chalk and the Tarawan Formation represent a condensed section (Loutit *et al.*, 1988).

Thanetian/Earliest Ypresian Sequence boundary (SB5)

This type 1 sequence boundary represents the contact between the Late Thanetian and Earliest Ypresian and delineates the top of the Tarawan Formation in the Farafra Oasis (Fig. 2.25). The Tarawan Formation is succeeded by the Maqfi Member of the Esna Formation with a clear unconformity surface along the eastern part of the Farafra Oasis due to the lack of the whole

Latest Paleocene P5 Zone. Along this boundary there is iron-oxide staining in the lime mud matrix. In the northern slope of El Quss Abu Said this boundary is detected due to the absence of *Globanomalina pseudomenardii/Acarinina sibaiyaensis* P5a Subzone which represents a time gap from about 55.9 Ma to about 55.0 Ma (Table 5.1). While, in other localities of the Farafra Oasis the paleontologic break extends to include the *Globanomalina pseudomenardii/ Acarinina sibaiyaensis* P5a and *Acarinina sibaiyaensis/ Pseudohastigerina wilcoxensis* P5b Subzones to represent a time gap from about 55.9 Ma to about 54.9 Ma (Table 5.1) in northwest Bir Bidni.

In northwest Bir Bidni, the sequence boundary separates between a 5m thick shale of the Tarawan Formation of *Globanomalina pseudomenardii* P4 Zone and the carbonate facies of the Maqfi Member of the Esna Formation. The remarkable variations in lithology and thickness during the Late Paleocene *Globanomalina pseudomenardii* Zone are recorded in the studied sections (Fig. 5.1). These variations suggest an uneven bottom topography resulting from tectonic disturbances during Late Paleocene. This conclusion is in accordance with Strougo (1986). In the extreme northern part of the Farafra Oasis at Qaret Sheikh Abd Alla, this sequence boundary has great time gab and defines the contact between the Tarawan Formation and the Farafra Limestone, where the Esna Formation is completely missing.

The erosional surface of the SB5 is recorded by some authors in the Farafra Oasis which represents a stratigraphic gap that includes greater parts of the Zones P5 and NP9 as well as the lower part of Zone NP10 (Tantawy, 1998). Ouda (2003) in the Paleocene/Eocene boundary of Egypt also mentioned that the uppermost part of Subzone P4c and the lower part of Zone P5 is marked by a stratigraphic gap corresponding to the lower part of Zone NP9a in the Farafra Oasis. The same stratigraphic interval is also missing at Gabal Um Ghanayem, Kharga Oasis. The short overlap of the *Morozovella velascoensis*, as noted by Berggren (1969), Toumarkine and Luterbacher (1985), and Berggren and Miller (1988), is also recognized in the Farafra Oasis, where the P5b zonal boundary lies immediately above the top of the Tarawan Formation of P4c. The P5b Zone is considerably much reduced in thickness (about 2m thick) in El Quss Abu Said Plateau. An erosional surface accompanied with a major paleontologic break has been also recognized by Issawi *et al.* (1999) at the top of the Tarawan Formation.

Early/Middle Ypresian sequence boundary (SB6)

This type 1 sequence boundary is traced near the base of the Esna Formation between the Early and Middle Ypresian age due to the absence of the *Morozovella formosa/M. lensiformis-M. aragonensis* Subzone (P6b) in the Farafra Oasis (Table 5.1).

This remarkable sequence boundary is detected in the lower part of the Esna Formation of southeast Qur Hadida area at the base of a 1m thick evaporite bed (Fig. 2.30). In addition, a reworking fauna is common underlain the evaporate bed. This reworked fauna is also recorded at the same stratigraphic position in the northern part of El Quss Abu Said which is followed upward by a highly fragmented dolostone bed of about 30cm to separate the Early and Middle Ypresian sequences. This sequence boundary is delineated at the base of a ledge-forming carbonate unit packed with nummulitids and discocyclinids (*Nummulites luterbacheri* bank) lying about 20m above the base of Esna Formation in the southern slope of El Quss Abu Said. This bank disconformably overlies grey shale with a sharp erosional base and cm-thick iron stained hardground. The sequence boundary SB6 is also traced at the top of a sandy siliceous dolostone bed in Ain Dalla Formation to separate between the P6a and P7 Zones (Fig 2.26).

Hewaidy and Strougo (2001) mentioned that the exact biostratigraphic level of the *Nummulites luterbacheri* bank is not fixed yet, which Boukhary *et al.* (1995) assigned it to the basal Ilerdian sensu Schaub (1981). Wielandt (1999) restricted the range of the *Nummulites luterbacheri* bank to the upper Zone NP9 and to middle Zone P5 sensu Berggren *et al.* (1995). She correlated the Nummulites bank with the shallow benthic Zone SBZ6 of Serra-Kiel *et al.* (1998). Calcareous nannofossils, recently obtained from the *Nummulites luterbacheri* bank in the western hillock of the Twin Spikes, suggest that this bank can not be older than the uppermost Zone NP10 relying on the presence of *Tribrachiatus orthostylus* among the identified assemblage (Strougo and Faris 2000). Furthermore, the Zone NP10 is recognized a couple of meters below the *Nummulites luterbacheri* bank are correlatable with the *Morozovella formosa* and/or *Morozovella lensiformis* (P6a) in the present study. Therefore, the present author agrees with Strougo and Hewaidy (1999) in considering the disconformity at the base of the *Nummulites luterbacheri* bank of the Twin Spikes and that at the base of the Maqfi Member in the eastern part of the Farafra Oasis are not representing the same stratigraphic hiatuses. The Maqfi Member lies directly above the Tarawan Formation forming the hiatus of the Paleocene/Eocene sequence boundary (P5/P6), while the disconformity at the base of the *Nummulites luterbacheri* bank separates between the P6b and P7 biozones.

This unconformable surface is recorded by Abdel-Kireem and Samir (1995). Ouda (2003) mentioned that a hiatus can be recognized at about 25m above the base of the Esna Formation in El Quss Abu Said due to the *Morozovella formosa, M. lensiformis* and *M. aragonensis* appear together. He pointed out to the reduction of the Subzone P6b in the Farafra Oasis as compared with other Lower Eocene sections in the Nile Valley, e.g. Dababiya which represents the stratotype for the Paleocene/Eocene boundary in the World.

Intra-Lower Eocene sequence boundary (SB7)

This sequence boundary is locally defined in the upper part of the Farafra Limestone in El Quss Abu Said Plateau and Ain Maqfi area (Fig 5.1). It is marked by 1m broached burrow system of thick *Thalassinoides* which denotes a break in marine sedimentation. This sequence boundary is not recorded in Ain Dalla where the maximum thickness of the formation is exposed due to intense dolomitiaztion which obliterated the original textural and structures of the rock.

In contrary to the present work, Khalil and El-Younsy (2003) recorded a sequence boundary (SB-II) near the base of the Farafra Limestone due to the presence intraformational conglomerate in El Quss Abu Said. Their interaformational conglomerates are in fact a nodular limestone formed due to differential weathering of alternating soft argillaceous limestone and hard limestone interbeds.

To summarize, the common occurrence of the sequence boundaries suggests that the Farafra Oasis was tectonically active area during the deposited of the Upper Cretaceous-Lower Eocene succession.

V.4 Depositional sequences

A depositional sequence represents a complete transgressive-regressive cycle bounded above and below by erosional unconformities or their correlative conformities. The study of the sedimentary facies characteristics, paleoecology, paleobathymetry and sequence boundaries leads to the recognition of eight depositional sequences which denote third-order relative sea level cyclicity. The recorded depositional sequence and their systems tracts as well as parasequence stacking patterns are will be discussed, from old to young hereunder:

- The first depositional sequence (SQ1)

This is the oldest depositional sequence in the Farafra Oasis. It comprises the clastic sediments of El-Hefhuf Formation in Wadi Hennis and east Shakhs El-Obeiyid area. The base of this sequence is not exposed while its top is marked at the base by a *Pycnodonte vesicularis*–rich bed in Wadi Hennis or at the top of a phosphatic sandy dolostone bed at Shakhs El-Obeiyid area (Fig. 5.2 & 5.3). The upper contact denotes the Santonian/Campanian sequence boundary SB1.

Highstand systems tract

The Highstand systems tract constitutes the Santonian beds which are characterized by a progradational parasequence sets of alternating upper deep subtidal shale/mudstone, subtidal lower shoreface massive-bedded sandstone and subtidal upper shoreface cross-bedded sandstone deposits. These highstand deposits are marked by the presence of rare dinocysts with fresh water algae and abundant of terrestrial planoflora (Abdel Mohsen 2002).

Prograding highstand systems tract occurs when the rate of sediment supply is more than the amount of accommodation space being created by rising relative sea-level. They are characterized

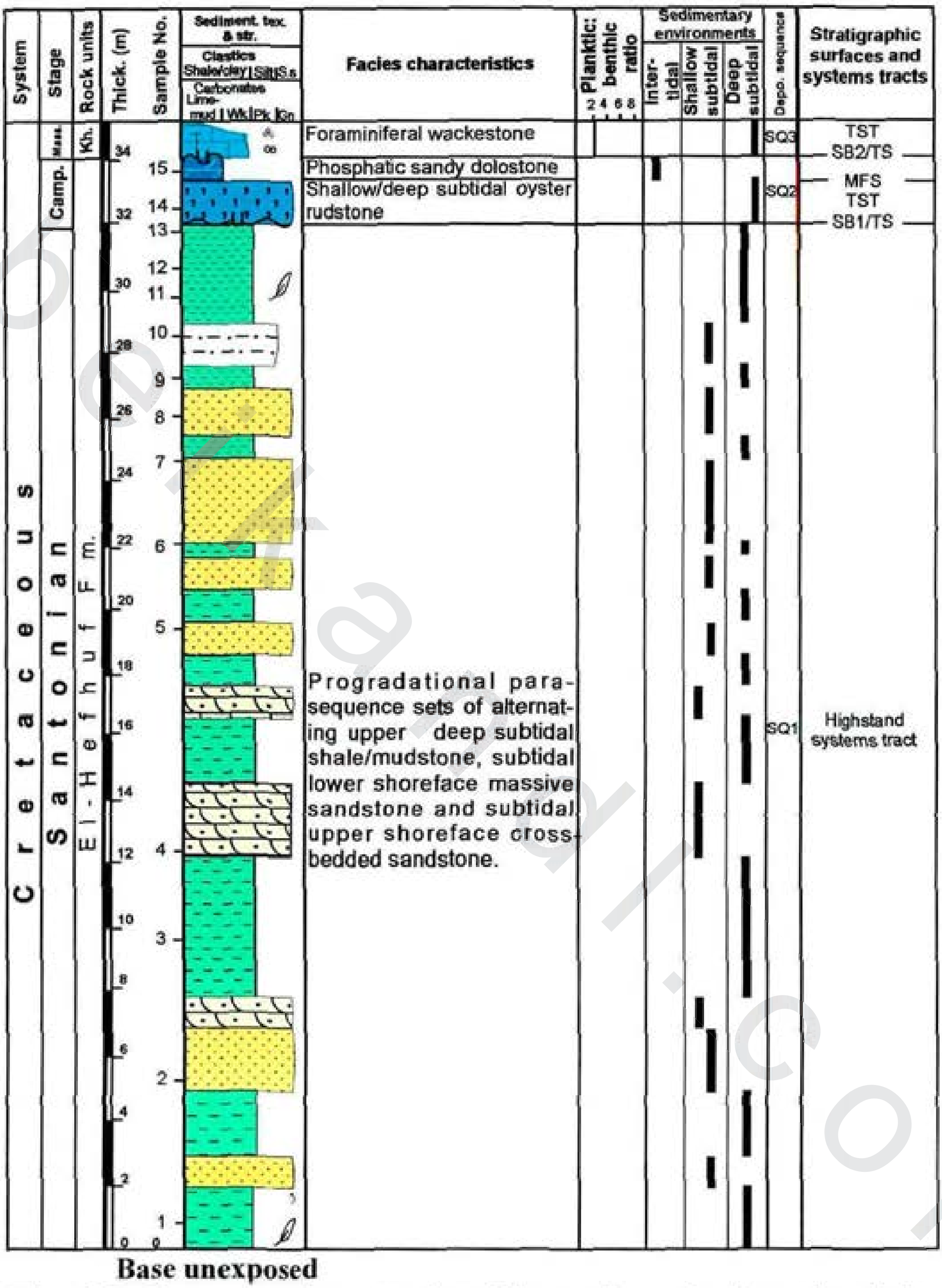


Fig. 5.2 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence *stratigraphic interpretation of the exposed* Santonian-Campanian El-Hefhufh Formation in Wadi Hennis, northeast Farafra Oasis.

by thick accumulations containing stacked inner shelf deposits with abundant terrestrial fossil assemblages with overall shallowing-up nature. The highstand deposits are interpreted to be deposited during the late part of the eustatic rise, the eustatic stillstand and during the early part of the eustatic fall (Van Wagoner *et al.*, 1988).

- The second depositional sequence (SQ2)

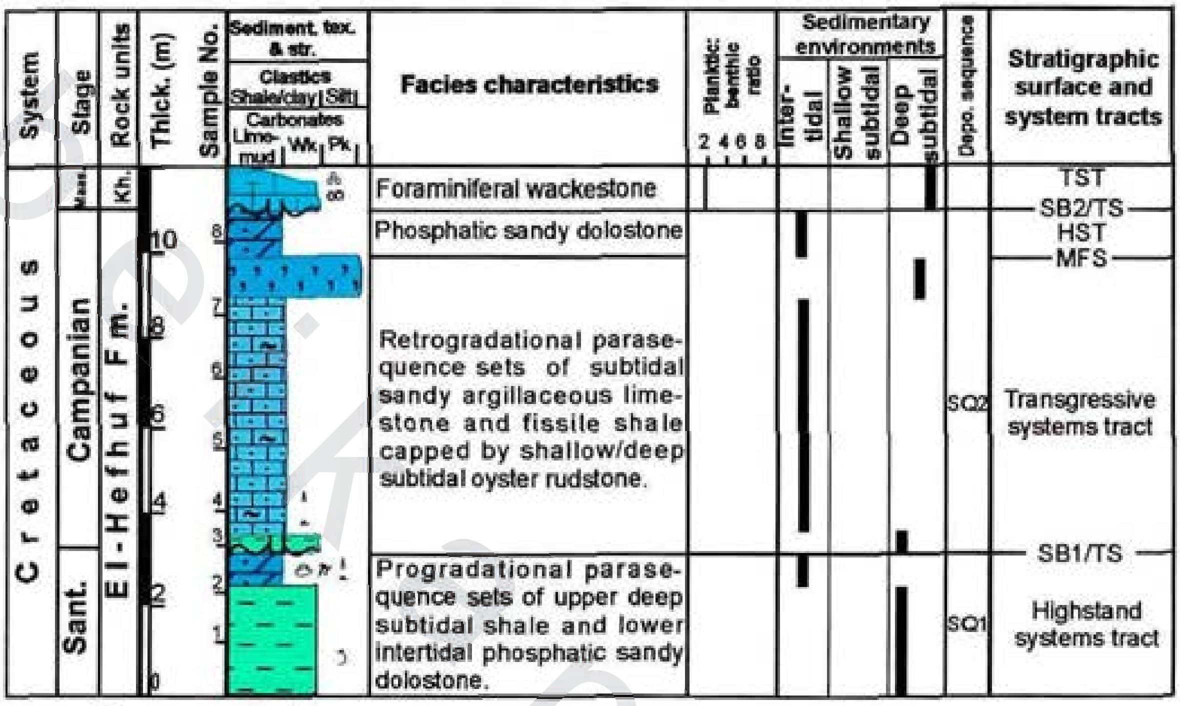
The second depositional sequence includes the top carbonate sediments of El-Hefhuf Formation which are recorded at Wadi Hennis and east Shakhs El-Obeiyid area. It is characterized by a reduced thickness including lower transgressive and upper highstand deposits. Each of these deposits is associated with a specific part of the eustatic curve. The top of this sequence is marked at the base of the Khoman Formation (Figs. 5.2 & 5.3).

- Transgressive systems tract

The base of this systems tract marks the type 1 sequence boundary SB1. This boundary is delineated by an obvious erossional surface associated with lithologic change from clastic sediments below to carbonate above. It also denotes the transgressive surface (TS) at the base of the transgressive systems tract. This system tract is made up of a retrogradational parasequence set of shallow/upper deep subtidal oyster rudstone with *Pycnodonte vesicularis* and reworking evidence in Wadi Hennis (Fig. 5.2) or sets of shallow subtidal sandy argillaceous limestone and upper deep subtidal fissile shale capped by shallow/deep subtidal oyster rudstone shale at east Shakhs El-Obeiyid (Fig. 5.3).

Indeed, the reworked fossils are often the commonest palaeontologic component present in rapidly deposited sediments.

Their presence, together with the abrupt influx into deep marine basins of terrestrial fossils such as pollen, spores and plant debris, may be used to identify the sequence boundary.



Base unexposed

Fig. 5.3 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Santonian-Campanian El-Hefhuf Formation in Shakhs El-Obeiyid, west Farafra Oasis.

Highstand systems tract

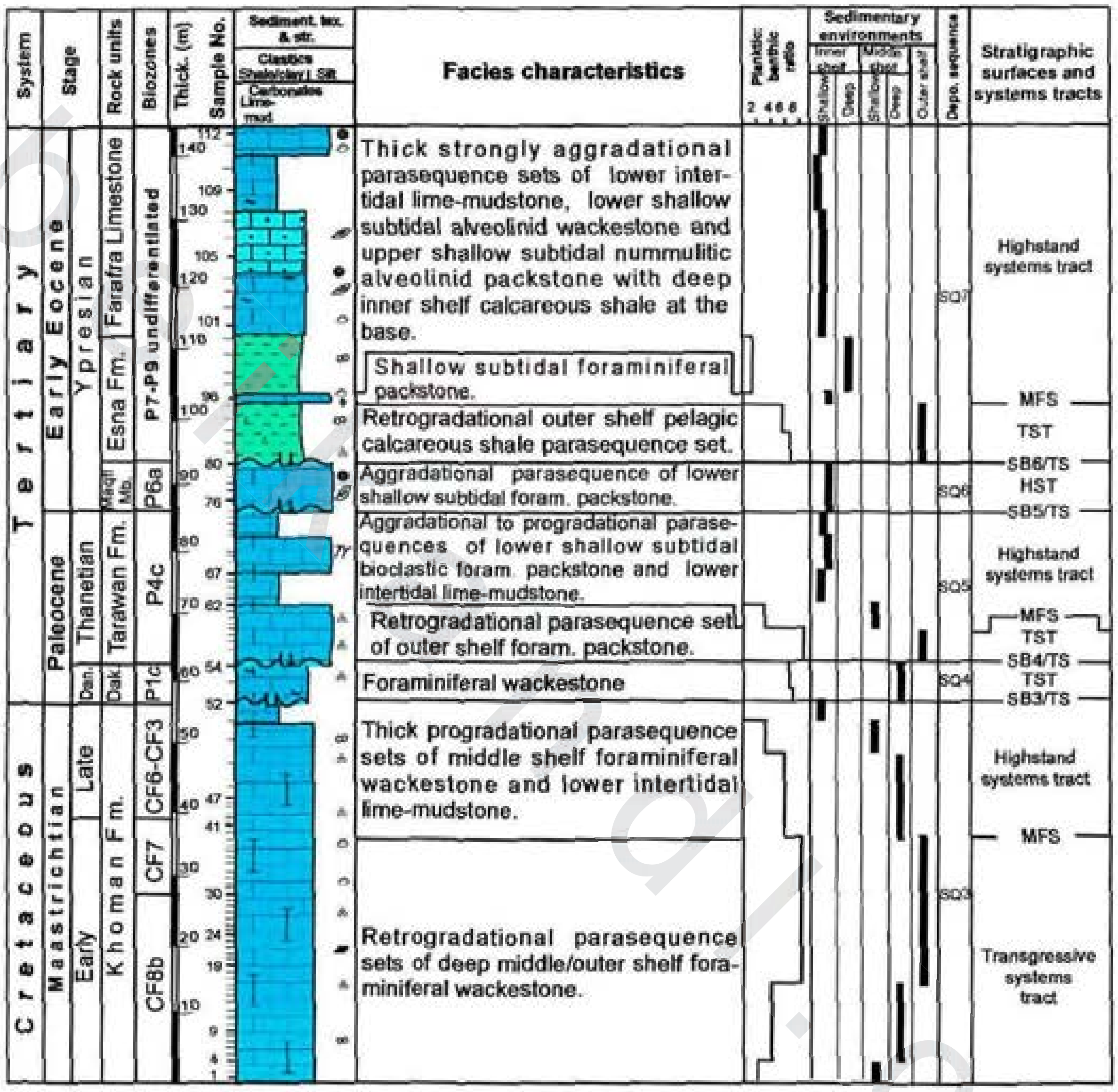
The highstand systems tract is usually formed during the late part of the eustatic rise, eustatic stillstand and the early part of the eustatic fall. This systems tract includes the topmost part of El-Hefhuf Formation. It consists of upper intertidal sandy dolostone due to a marked fall in relative sea level. The presence of dolostone bed at the end of the depositional sequence SB2 indicates a long period of emergence associated with intense dolomitization process which replaced an original sandy lime-mudstone rock when the sea level fall at the end of the depositional cycle.

- The third depositional sequence (SQ3)

The third depositional sequence belongs to the Khoman Formation of Early/Late Maastrichtian age in the Farafra Oasis. It is bounded by clear and sharp unconformity surfaces (sequence boundaries). The lower boundary is an unconformity surface separating between the Campanian part of El-Hefhuf Formation and the chalk of the Khoman Formation, while upper boundary is a paraconformity surface due to the missing of the Latest Maastrichtian and the lower part of the Danian sediments. It includes the following two system tracts (Fig. 5.4).

Transgressive systems tract

This systems tract is composed of retrogradational parasequence sets of deep middle/outer shelf foraminiferal wackestone with a shallow middle shelf foraminiferal wackestone at the base (Fig. 5.4). It forms the lower and middle parts of the Khoman Formation in the Farafra Oasis. The transgressive deposits are bracketed at the base by the transgressive surface (Ts) which points to a rapid increase in accommodation space. This surface is marked by conspicuous environmental changes from upper intertidal to shallow middle shelf indicating a rapid deepening in the depositional regime. This supports the retrogradation of the facies belts. This systems tract is also bracketed at the top by the maximum flooding surface (MFS), where the change in planktic/benthic ratio indicates the beginning of the progradation parasequence. Hence, this surface separates retrograding strata below from prograding strata above. It represents the change to overlying protruding strata of the highstand systems tract. The MFS marks the ultimate marine invasion after which a gradual sea level begins.



Base unexposed

Fig. 5.4 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Maastrichtian-Lower Eocene succession in northwest Ain Maqfi, Farafra Oasis.

Highstand system tract

This systems tract constitutes the upper part of the Khoman Formation which belongs to the Late Maastrichtian in the Farafra

Oasis. It delineates at the base by the maximum flooding surface of the underlying transgressive systems tract (Fig. 5.4) and at the top by the depositional sequence SB3. This systems tract exhibits typical upward shoaling parasequences owing to a gradual decreasing in relative sea level fall. Sediments of the HST are composed of progradational parasequence of middle shelf foraminiferal wackestone at the base and lower intertidal lime-mudstone at the top (Fig 5.4). In Qur Hadida, these deposits are replaced by aggradational trend sets of alternating shallow inner shelf mudstone and upper intertidal dolostone (Fig. 5.5).

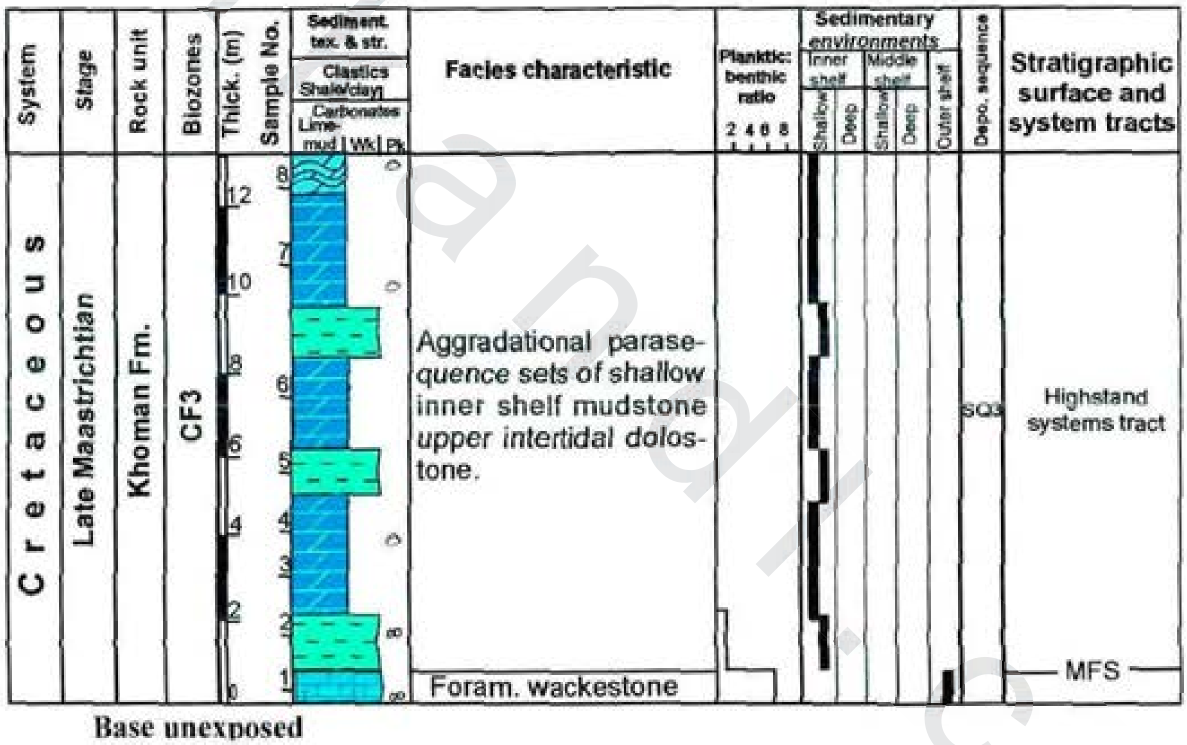


Fig. 5.5 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Maastrichtian Khoman Formation at Qur Hadida, east Farafra Oasis.

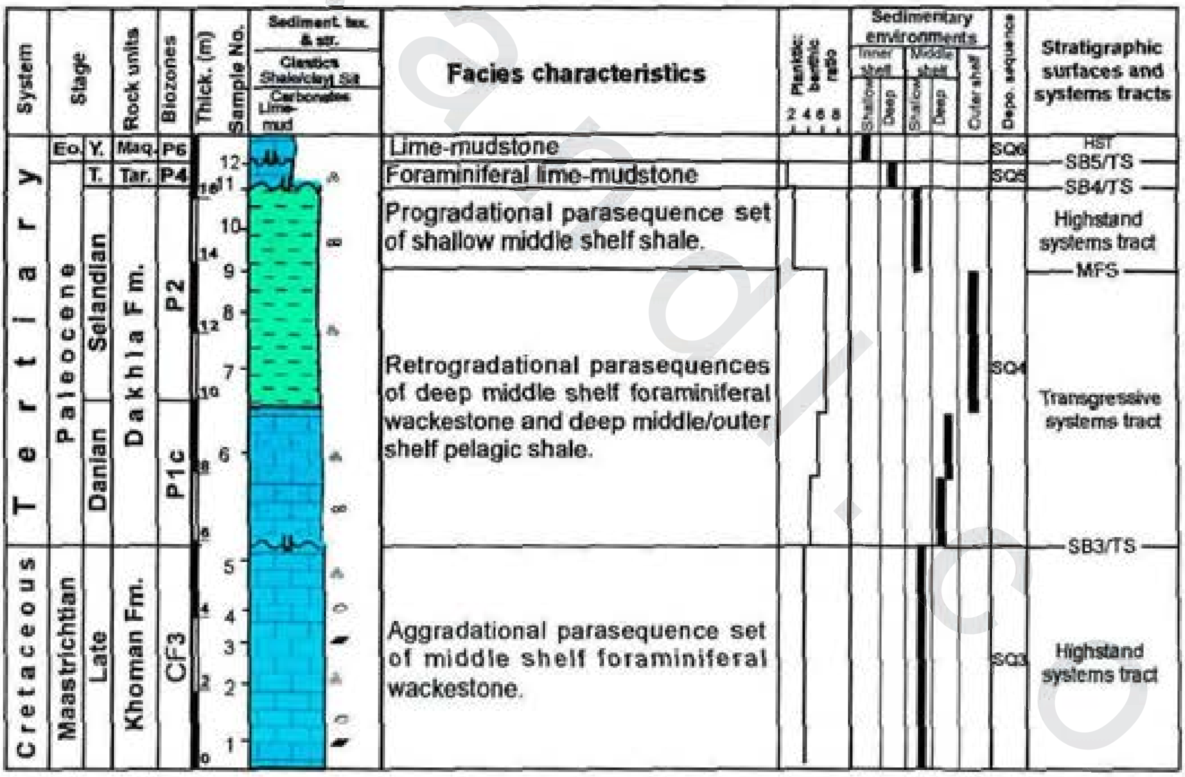
- The fourth depositional sequence (SQ4)

The Dakhla Formation represents the fourth recorded depositional sequence (SQ4). The base of this depositional sequence is defined at the contact between the Khoman and

Dakhla formations due to a submarine break, while the top of the depositional sequence SQ4 marks unconformably contact between the Dakhla and Tarawan formations in the Bir Murr, Ain Maqfi, and northwest Ain Maqfi. Depositional sequence SQ4 includes the following two systems tracts.

Transgressive systems tract

This systems tract demarcates the lower part of the Dakhla Formation in the Farafra Oasis. The shallow conditions which had started by the beginning of the Early Maastrichtian are prevailed again in the Early Paleocene, where the sediments have been deposited under shallower water conditions of deep middle shelf (Fig. 5.6). These transgressive deposits are followed by a



Base unexposed

Fig. 5.6 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Maastrichtian-Lower Eocene succession in Bir Murr, east Farafra Oasis.

retrogradational parasequence of deep middle/outer shelf pelagic shale due to rapid rise in relative sea level. Samples from the lower part of the Dakhla Formation gave a typical Danian fauna with several derived Maastrichtian fauna such as *Globotruncana* species in the basal part of the formation. The maximum flooding surface typifies the top of the deep middle/outer pelagic shale (Fig. 5.6).

Highstand systems tract

This systems tract constitutes the upper part of the Dakhla Formation in Bir Murr and Shakhs El-Obeiyid of *Praemurica uncinata–Morozovella angulata* P2 Zone or *Morozovella angulata-Igorina albeari* P3a Subzone in Ain Maqfi (Table 5.1). The highstand systems tract is characterized by marked drop in the P/b ratios with the increase of the benthic species in the Bir Murr. It is dominated by a shallow middle shelf shale parasequence set (Fig. 5.6). The highstand deposits are not traced in northwest Bir Bidni and Shakhs El-Obeiyid most probably eroded a way during the subsequent sea-level fall and subaerial exposure (Figs. 5.7 & 5.8). Over there, the overlying sequence boundary SB4 is marked by reworked fossils of the Morozovella *angulata-Globanomalina pseudomenardii* (P3) Zone.

- The fifth depositional sequence (SQ5)

This depositional sequence comprises the Tarawan Formation and is bounded above and below by unconformity surfaces of SB5 and SB4 respectively (Figs. 5.4, 5.7 & 5.8). A rapid spread of pelagic carbonates marks the beginning of the depositional sequence SQ5. These pelagic facies of the transgression systems tract is followed by shallower facies of the overlying highstand systems tract (HST) as shown below:

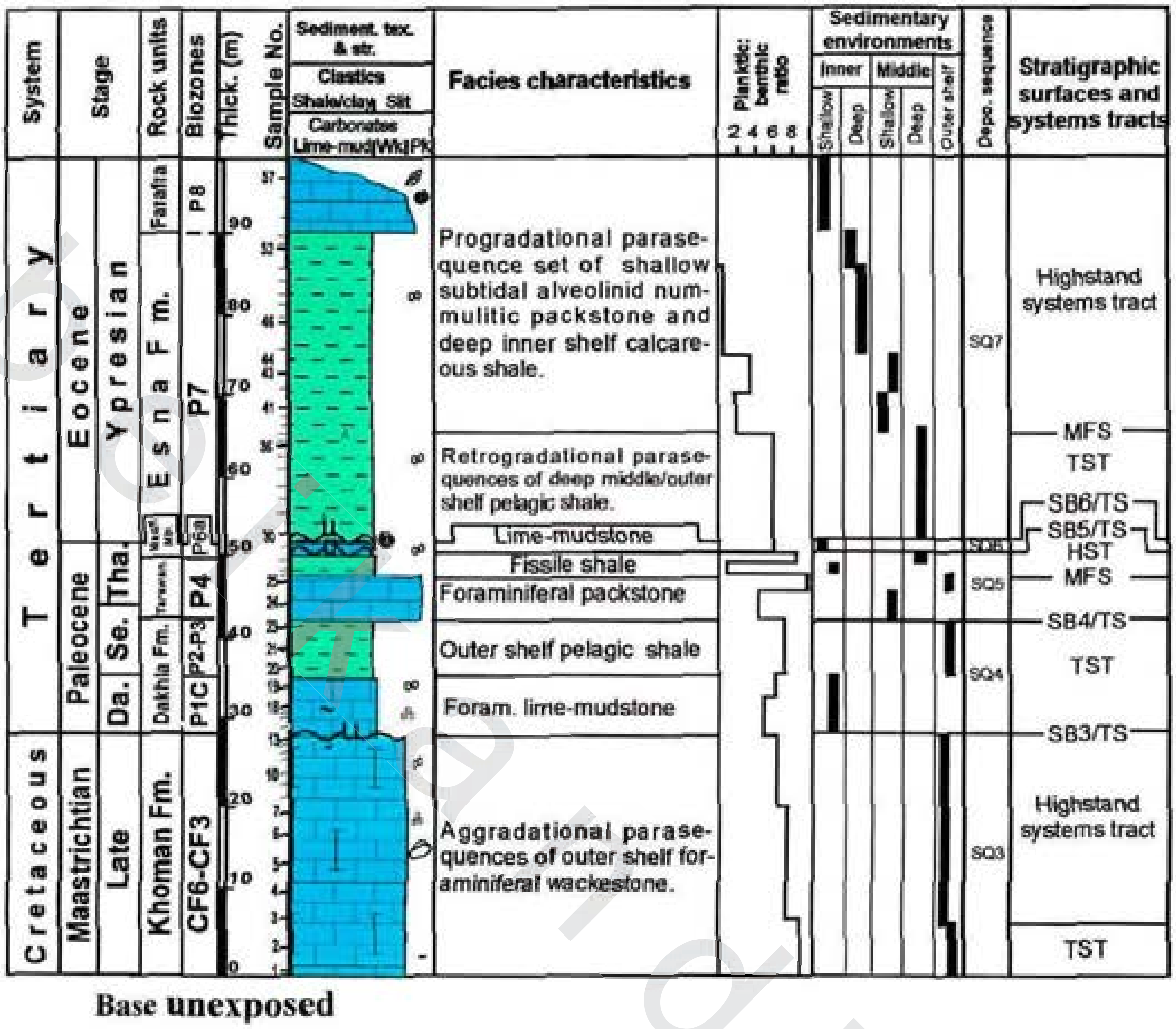
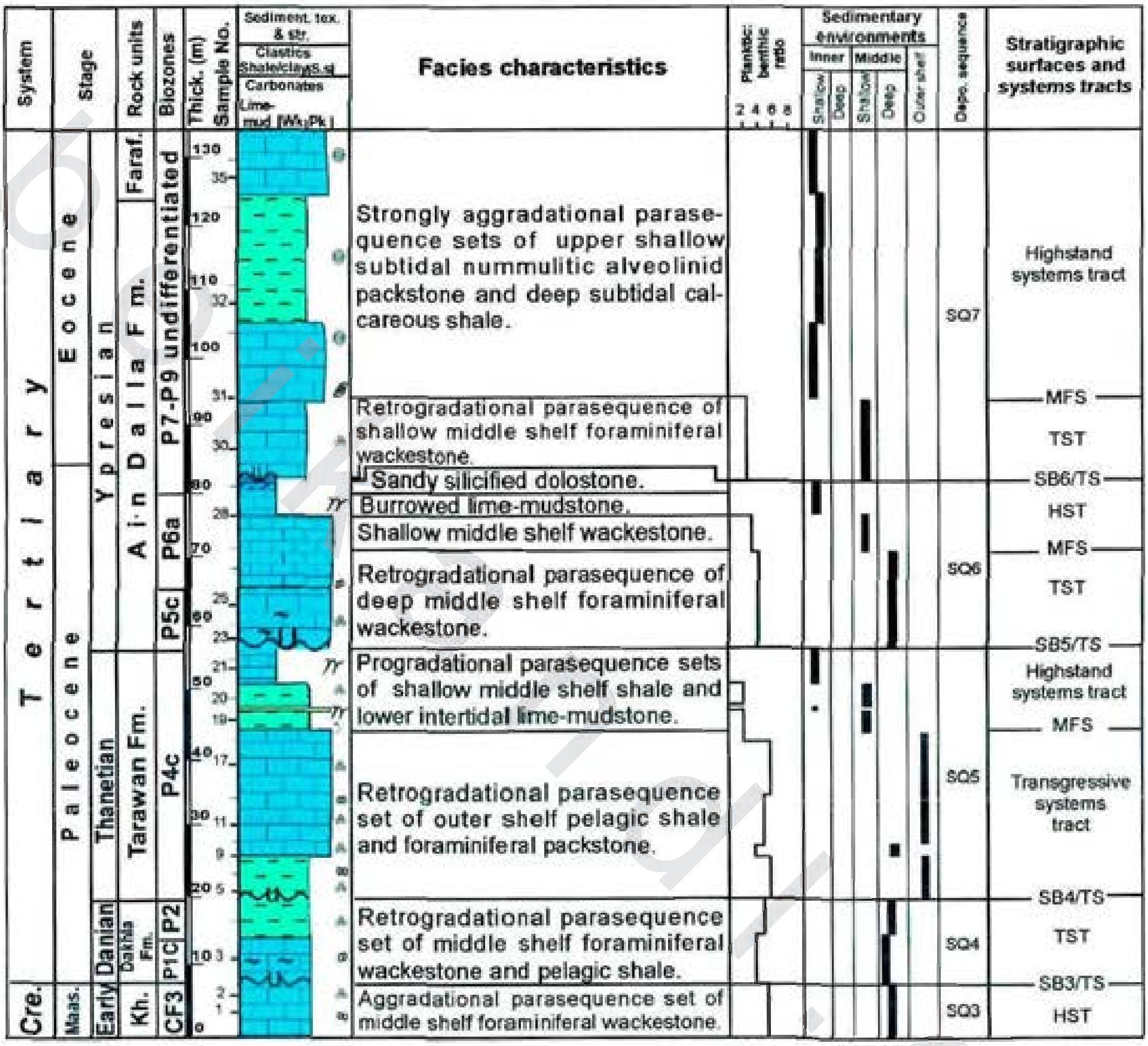


Fig. 5.7 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Maastrichtian-Lower Eocene succession in northwest Bir Bidni (about 30km. in Farafra Ain Dalla road), west Farafra Oasis.

Transgressive systems tract

This systems tract marks the lower part of the Tarawan Formation. The base of the transgressive systems tract is a transgressive surface (TS) which also coincides with the sequence boundary SB4 (Figs. 5.4, 5.7 & 5.8). This systems tract is represented by retrogradational parasequence sets of outer shelf pelagic foraminiferal packstone (Fig. 5.4) with pelagic shale at the base in Shakhs El-Obeiyid (Fig. 5.8).



Base unexposed

Fig. 5.8 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Maastrichtian-Lower Eocene rocks at Shakhs El-Obeiyid, northwest Farafra Oasis.

This systems tract has been deposited during a rapid rise in relative sea level (Jervey, 1988). The maximum flooding depth was obtained during the deposition of this pelagic facies. In northwest Bir Bidni and Shakhs El-Obeiyid, the maximum flooding surface is detected near the upper part of the Tarawan Formation to separate between the lower pelagic facies and the overlying calcareous shale facies with a sharp lithological contact (Figs 2.20, 2.7 & 5.8).

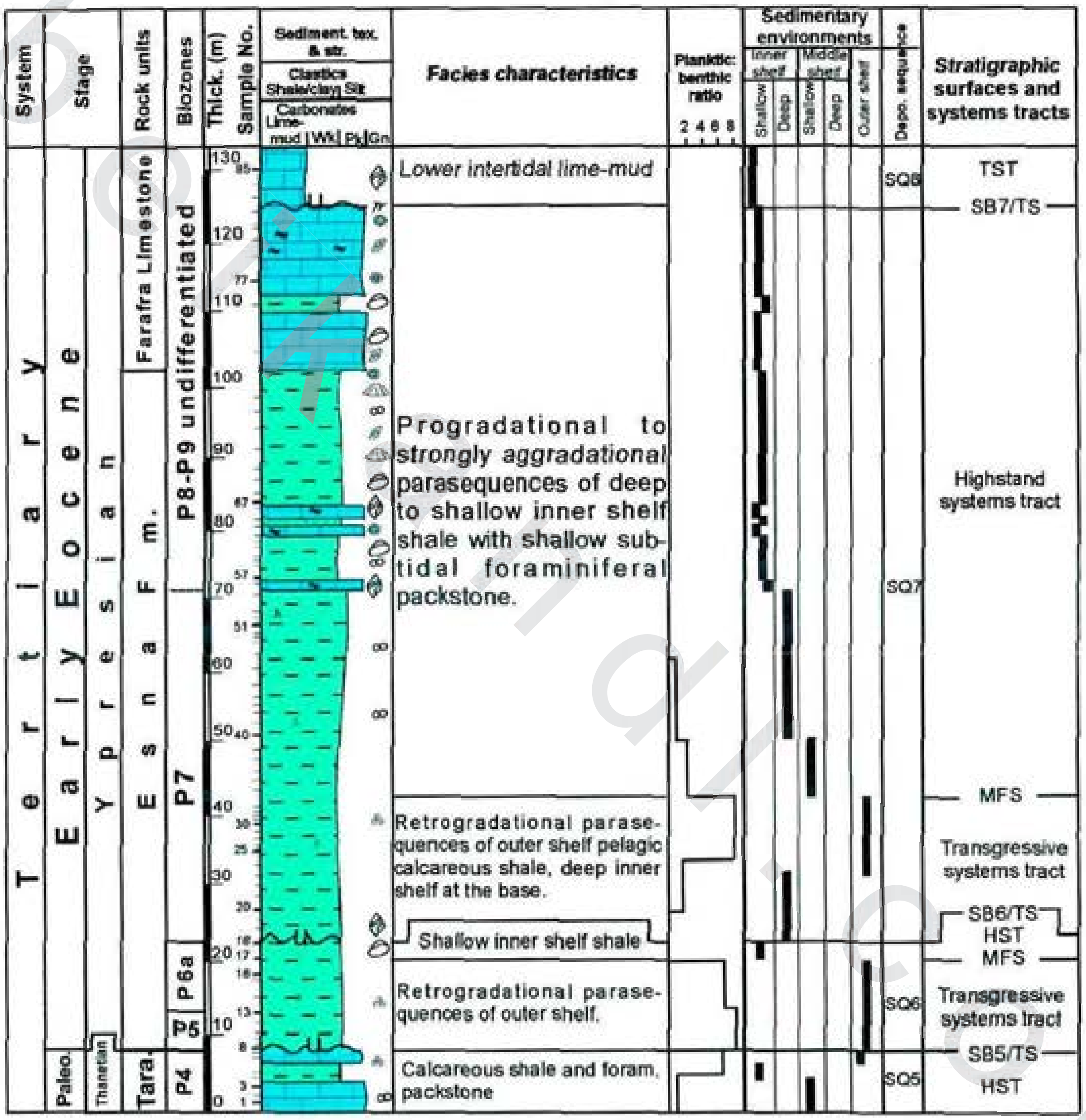
Highstand systems tract

This systems tract covers the upper part of the Tarawan Formation in the Farafra Oasis. It is bounded below by a maximum flooding surface and above by an erossional surface of the sequence boundary SB5. The maximum flooding surface is identified by the change from the homogeneous ratio aggradational carbonate deposits to interbedded progradational deposits. This highstand systems tract consists of aggradational to progradational parasequence sets of shallow middle shelf foraminiferal wackestone and calcareous shale, lower shallow subtidal bioclastic foraminiferal packstone and lower intertidal foraminiferal lime-mudstone (Figs. 5.4, 5.8 &5.9). In northwest Bir Bidni, the highstand systems tract is represented by deep middle shelf calcareous shale which is capped by lower intertidal lime-mud facie of the Maqfi Member (Figs 2.20 & 5.7), while in south Qaret Sheikh Abd Alla it is represented by deep middle shelf foraminiferal packstone.

- The six depositional sequence (SQ6)

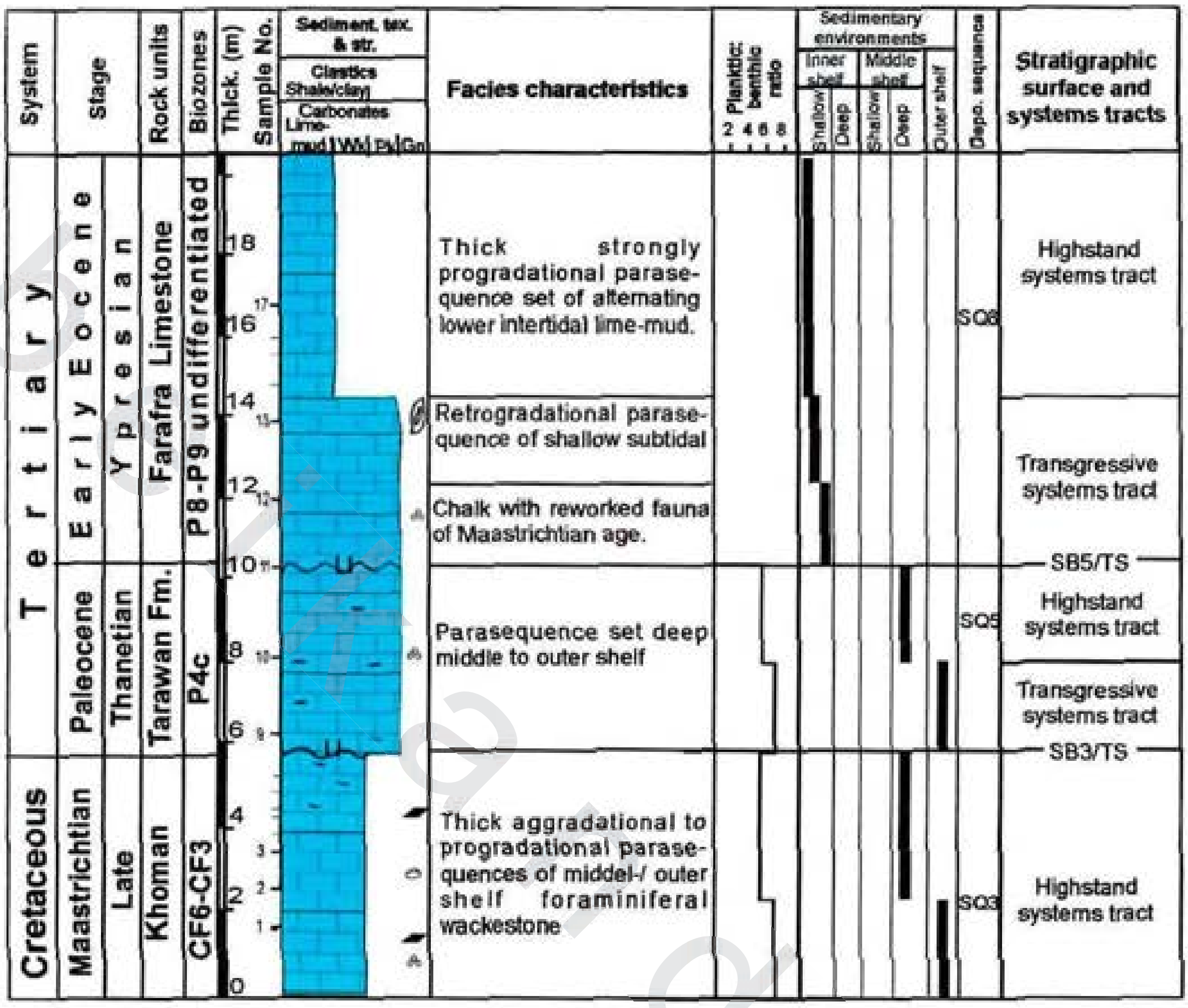
This depositional sequence covers the lower part of the Lower Eocene Esna and Ain Dalla formations in the Farafra Oasis. The base of this sequence is marked by the sequence boundary SB5, while its top is characterized by the presence of a thick evaporate bed in southeast Qur Hadida (Figs. 2.31, 2.32 & 5.11), submarine break in El-Quss Abu Said (Fig. 5.12) or by intense dolomitization at Shakhs El-Obeiyid and Ain Dalla area

(Figs. 5.8 & 5.13) due to the missing of P6b Subzone. The depositional sequence SB6 is not recorded at Qaret Sheikh Abd All (Fig. 5. 10) due to the missing of the whole Esna Formation. This sequence includes the following systems tracts:



Base unexposed

Fig. 5.9 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Paleocene-Lower Eocene succession in northern slopes of El Quss Abu Said, Farafra Oasis.

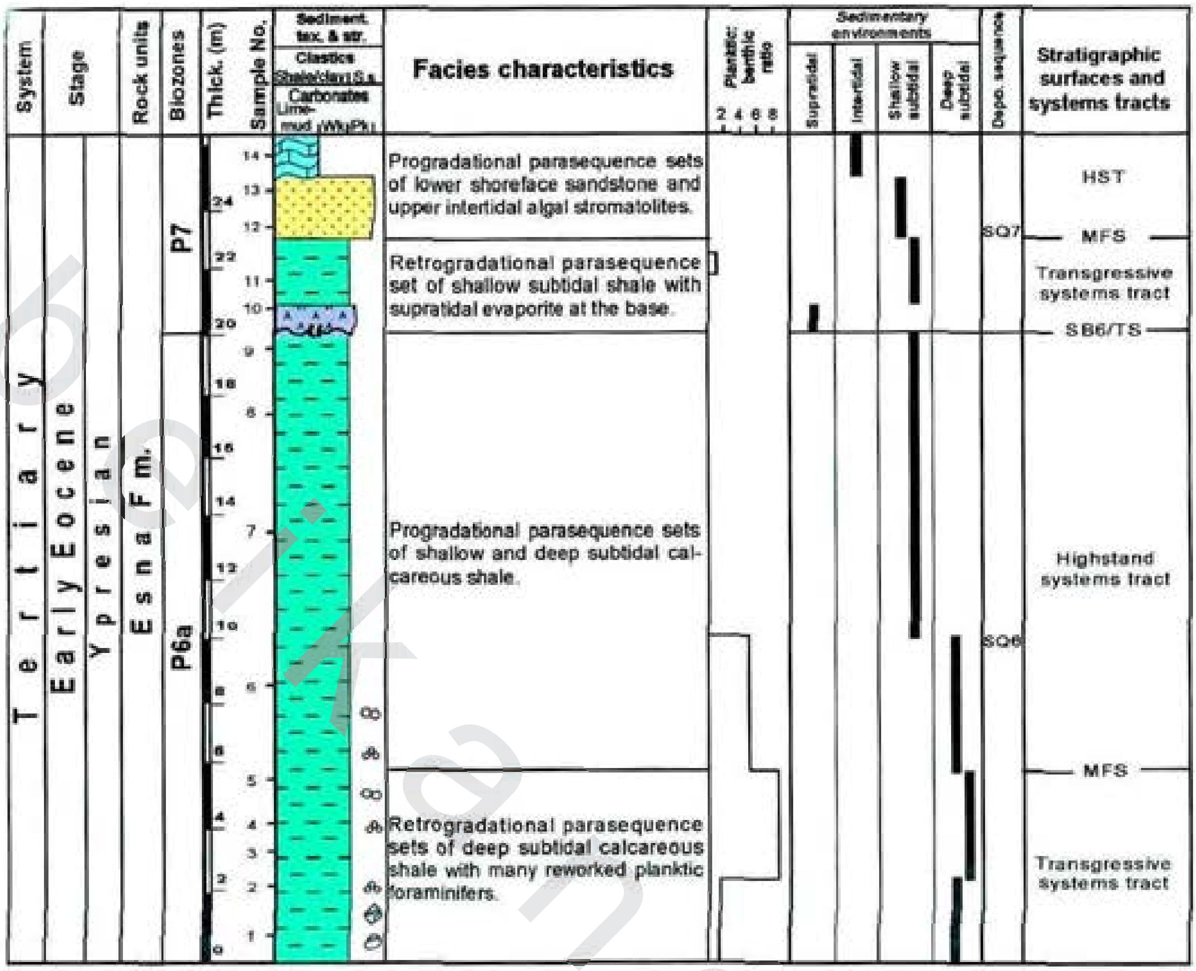


Base unexposed

Fig. 5.10 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Maastrichtian-Lower Eocene succession in south Qaret Sheikh Abd Alla, north Farafra Oasis.

Transgressive systems tract

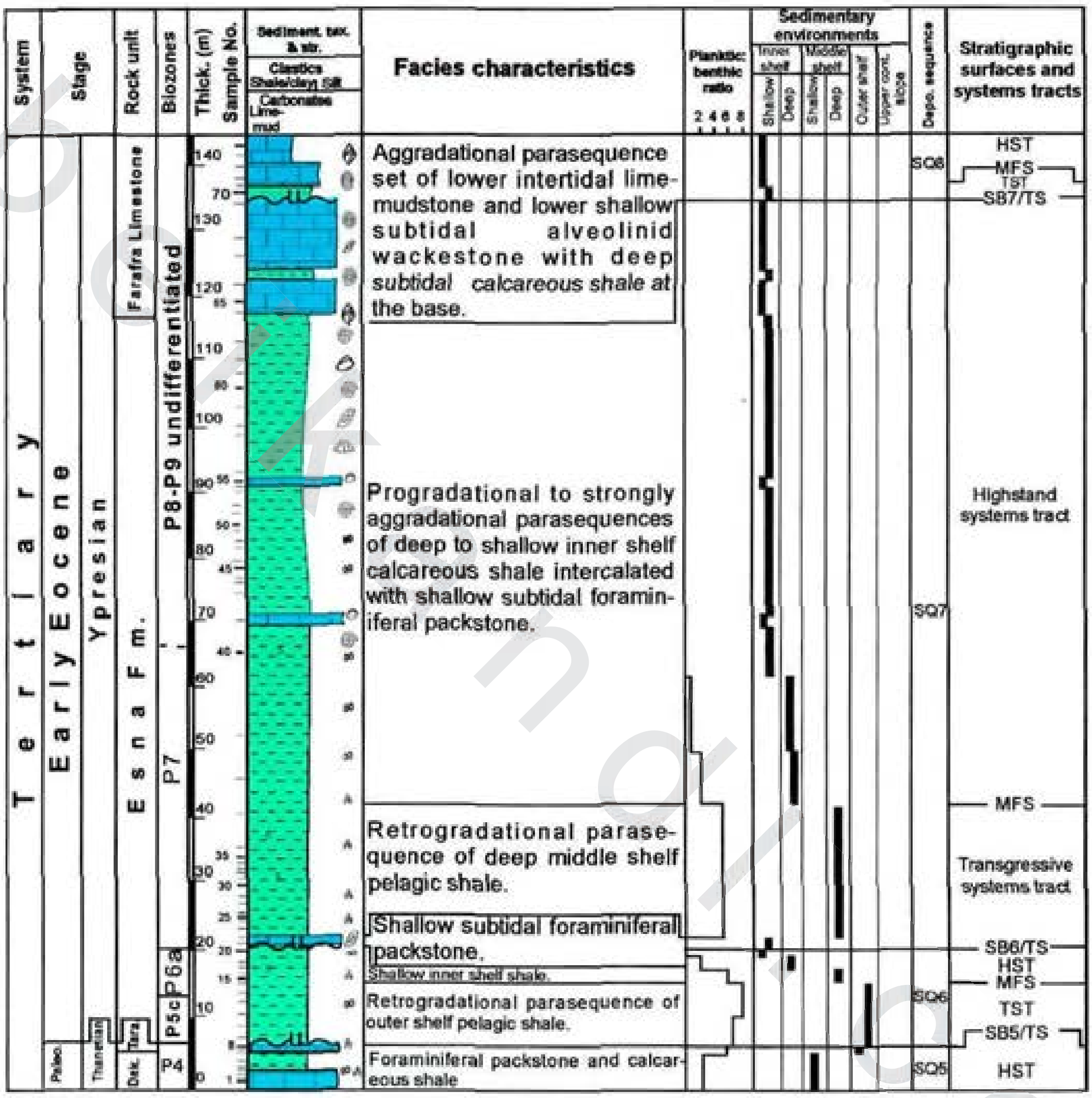
The transgressive systems tract of the depositional sequences SQ6 forms the basal part of the Esna Formation (i.e. Maqfi Member) and its lateral coeval Ain Dalla Formation in the Farafra Oasis. It is bounded at the base by the sequence boundary SB5 and is topped by a maximum flooding surface that represents a change from open marine facies below to deep inner shelf facies (Figs. 5.9 & 5.12). This system tract is composed of a thick,



Base unexposed

Fig. 5.11 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Lower Eocene Esna Formation at southeast Qur Hadida, east Farafra Oasis.

retrogradationally stacked parasequence of outer shelf pelagic shale. In El Quss Abu Said (Figs. 5.9 & 5.12) and deep middle/outer shelf foraminiferal wackestone in Shakhs El-Obeiyid and Ain Dalla (Figs. 5.8 & 5.13) due to an obvious rapid increase in sea level. This caused deposition of pelagic facies enriched in well preserved planktics and benthics. In southeast Qur Hadida, the transgressive systems tract is built of retrogradational parasequence sets of deep subtidal calcareous shale with many reworked planktic foraminiferal (Fig. 11). The transgressive deposits are not traced in Bir Murr, Ain Maqfi and northwest Ain Maqfi, (Figs. 5.6, 5.15 & 5.4) is most probably due to their uplift during the deposition of the Transgressive systems tract.



Base unexposed

Fig. 5.12 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Paleocene-Lower Eocene rocks at the southern slope of El Quss Abu Said, Farafra Oasis.

Highstand systems tract

This systems tract includes the top basal part of the Esna Formation and is bounded below by the maximum flooding surface, which marks the top of the transgressive systems tract, and above by the sequence boundary SB6. It is built of a progradational stacked parasequence of shallow middle shelf calcareous shale and foraminiferal wackestone, shallow inner shelf calcareous shale, lower intertidal lime-mudstone and silicified dolostone due to continuous uplift and relative sea level (Figs. 5.4, 5.6, 5.7, 5.8, 5.9, 5.11, 5.12 & 5.13). These deposits exhibit an overall shallowing-upward tendency. Reworked fauna in this systems tract indicates that the increased rate of accommodation begins to decline just above the maximum flooding surface.

- **The seventh depositional sequence (SQ7)**

This depositional sequence covers the main part of the Esna and Ain Dalla formations as well as the lower part of the overlying Farafra Limestone in the Farafra Oasis. It is bounded at the base by the sequence boundary SB6 due to the absence of the P6b Subzone, while its top is marked by the sequence boundary SB7. This sequence includes the following two systems tracts.

Transgressive systems tract

This systems tract demarcates the middle part of the Esna and Ain Dalla formations. It is bounded at the base by the sequence boundary SB6 and at the top by the maximum flooding surface, which delineates the base of the overlying highstand systems tract. The transgressive systems tract is composed of retrogradational parasequence sets of deep middle/outer shelf pelagic shale in the Farafra Oasis and pelagic shallow middle/outer shelf foraminiferal wackestone in Shakhs El-Obeiyid and Ain Dalla (Figs. 5.8 & 5.13). It starts with an obvious rapid increase the planktic and benthic percentages. The maximum flooding surface that defines the upper boundary of this systems tract is marked by an abrupt decrease in the planktic percentage and the appearance of larger foraminifers.

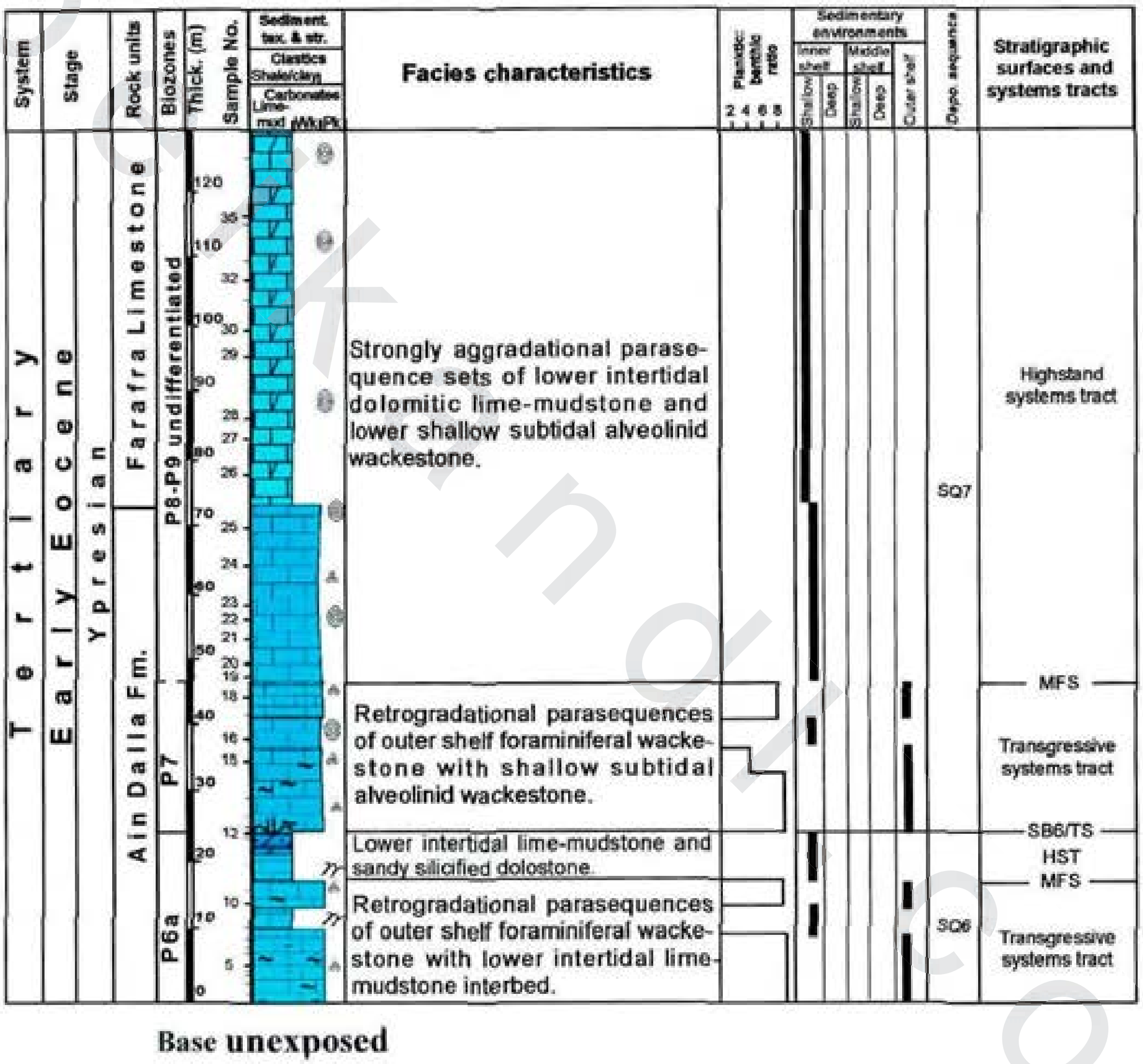


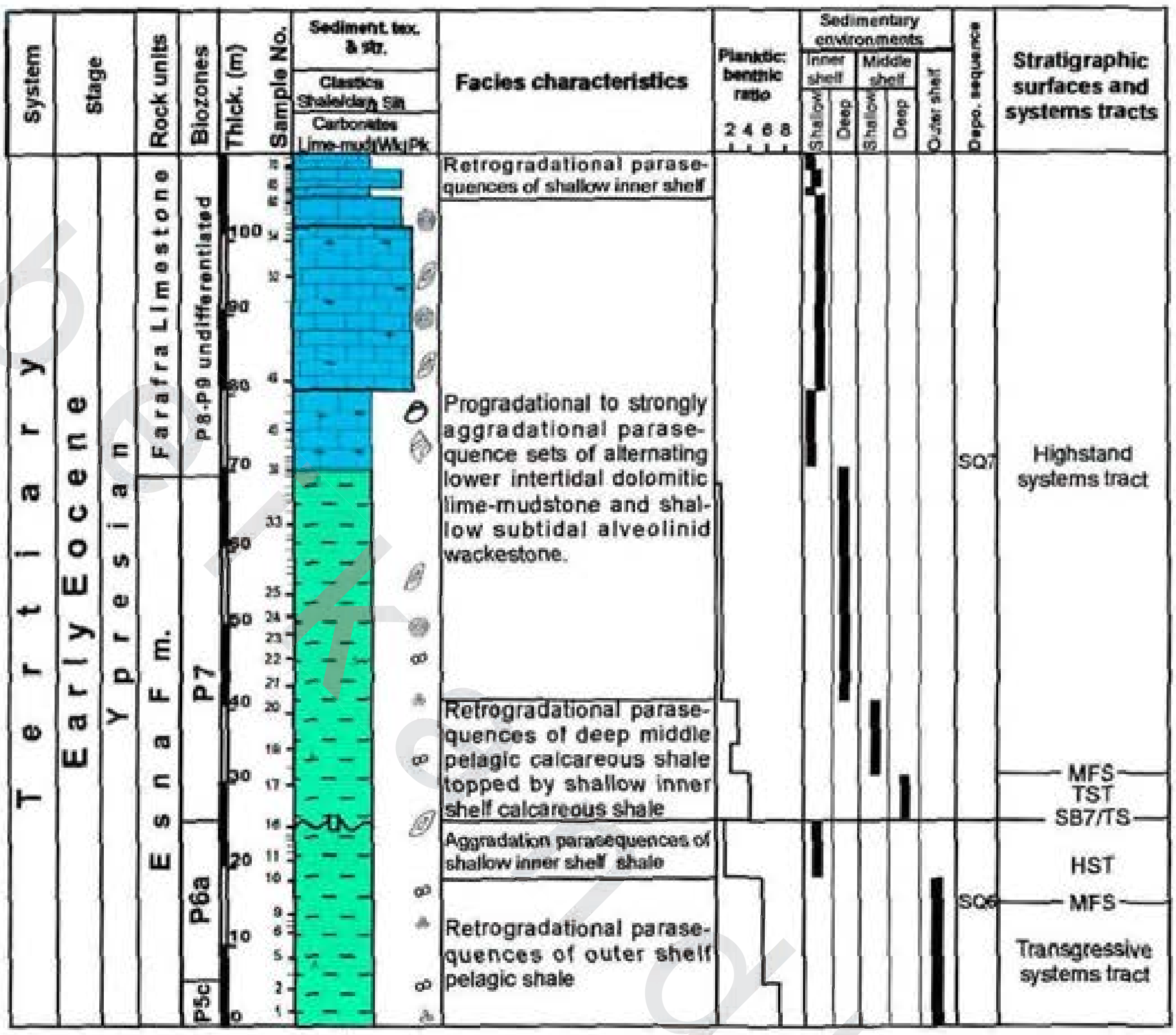
Fig. 5.13 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Lower Eocene succession in northeast Ain Dalla, west Farafra Oasis.

Highstand systems tract

The highstand systems tract represents the upper part of the Esna/Ain Dalla formations and the lower part of the Farafra Limestone in the Farafra Oasis. It is characterized by gradual progradation of the facies patterns depositing thick regressive facies due to a marked relative sea level fall. The planktic percentage is nil in this facies, due to shallowing conditions. The regressive facies are dominated by strongly aggradational to progradational parasequence sets of shallow/deep inner shelf shale, lower shallow subtidal alveolinid wackestone, upper shallow subtidal nummulitic alveolinid packstone and lower intertidal lime-mudstone. The upper highstand deposits are marked by carbonate facies of the Farafra Limestone allover the study area. In southeast Qur Hadida, the highstand deposits are represented by lower shoreface sandstone and upper intertidal algal stromatolites (Fig. 5.11).

- The eighth depositional sequence (SQ8)

The last depositional sequence in the Farafra Oasis corresponds to the upper part of the lower Eocene Farafra Limestone. The upper part of the Farafra Limestone is locally detected in El Quss Abu Said, Gabal Sofra and Ain Maqfi (Figs. 5.9, 5.12, 5.14 & 5.15). The base of the sequence SQ8 is marked by an intensively bored hardground. Sequence SQ8 is composed of shallow-marine carbonate facies enriched in larger foraminifera, while its top is characterized by dolomitic lime-mud, forming the plateau surface of in the Farafra Oasis. It is characterized by the presence of both transgressive and highstand systems tract (Figs. 5.14 & 5.15).

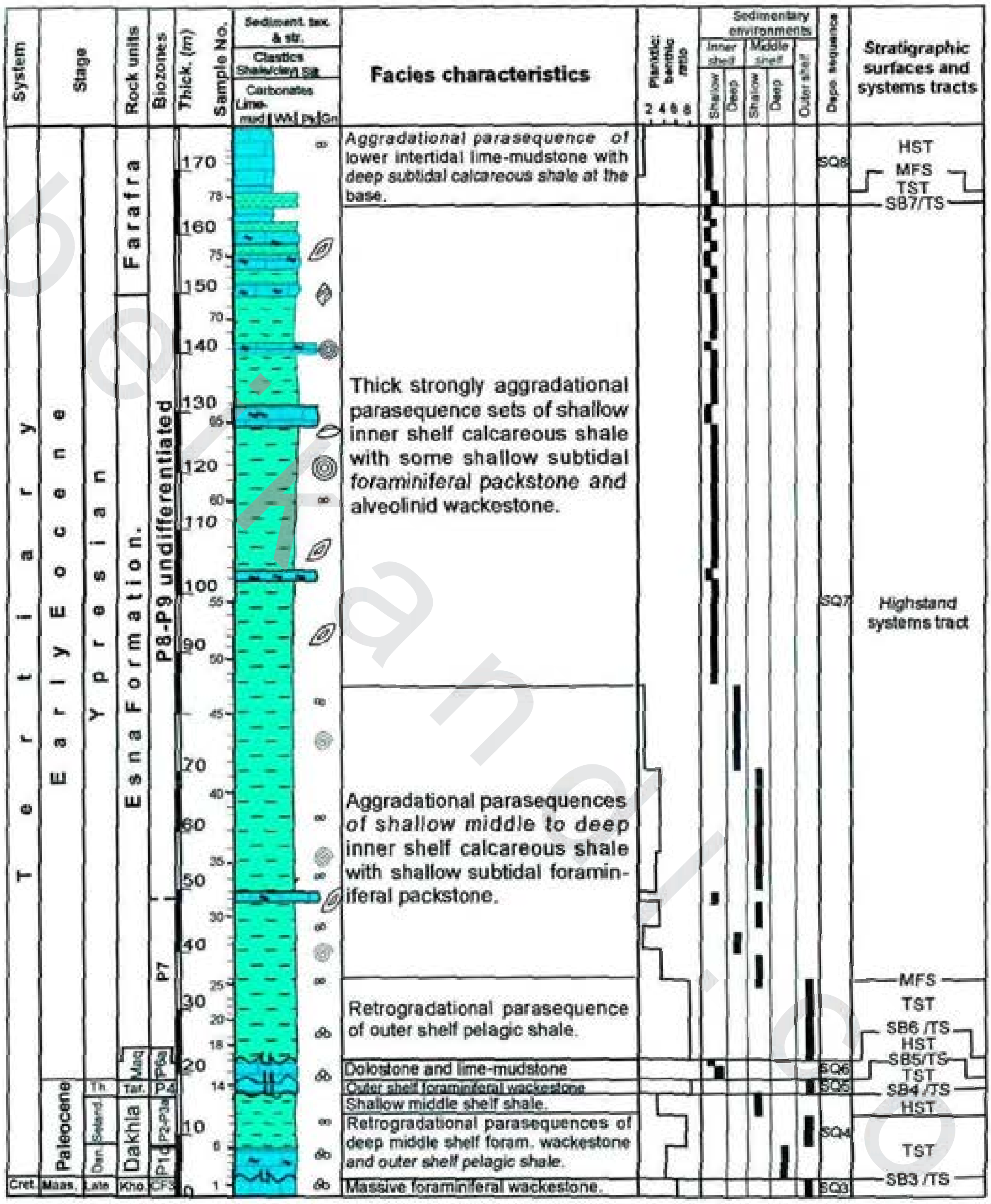


Base unexposed

Fig. 5.14 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Lower Eocene succession in Gabal Sofra, West Farafra Oasis.

Transgressive systems tract

The transgressive systems tract of the depositional sequence SQ8 is bounded at the base by the sequence boundary SB7 and is topped by the maximum flooding surface. It is composed of a retrogradational upper deep subtidal shale parasequence set (Figs. 5.12, 5.14, & 5.15) due to a slight rise in relative sea level. In the northern slope of El Quss Abu Said, the transgressive systems tract is not traced, most probably eroded away.



Base unexposed

Fig. 5.15 Representative stratigraphic section showing the facies characteristics, depositional environments and sequence stratigraphic interpretation of the exposed Upper Maastrichtian-Lower Eocene succession in Ain Maqfi, East Farafra Oasis.

Highstand systems tract

This systems tract represents the upper most part of the Farafra Limestone carbonate dominated facies. It is dominated by lower shallow subtidal alveolinid wackestone and/ lower intertidal lime-mudstone due to a slight fall in relative sea level (Figs. 5.12 & 5.15). To summarizes the combined effects of the tectonics, basin morphology, sediment eustatic sea-level fluctuations and sedimentation rate control the depositional sequences, their internal systems tracts and facies associations.

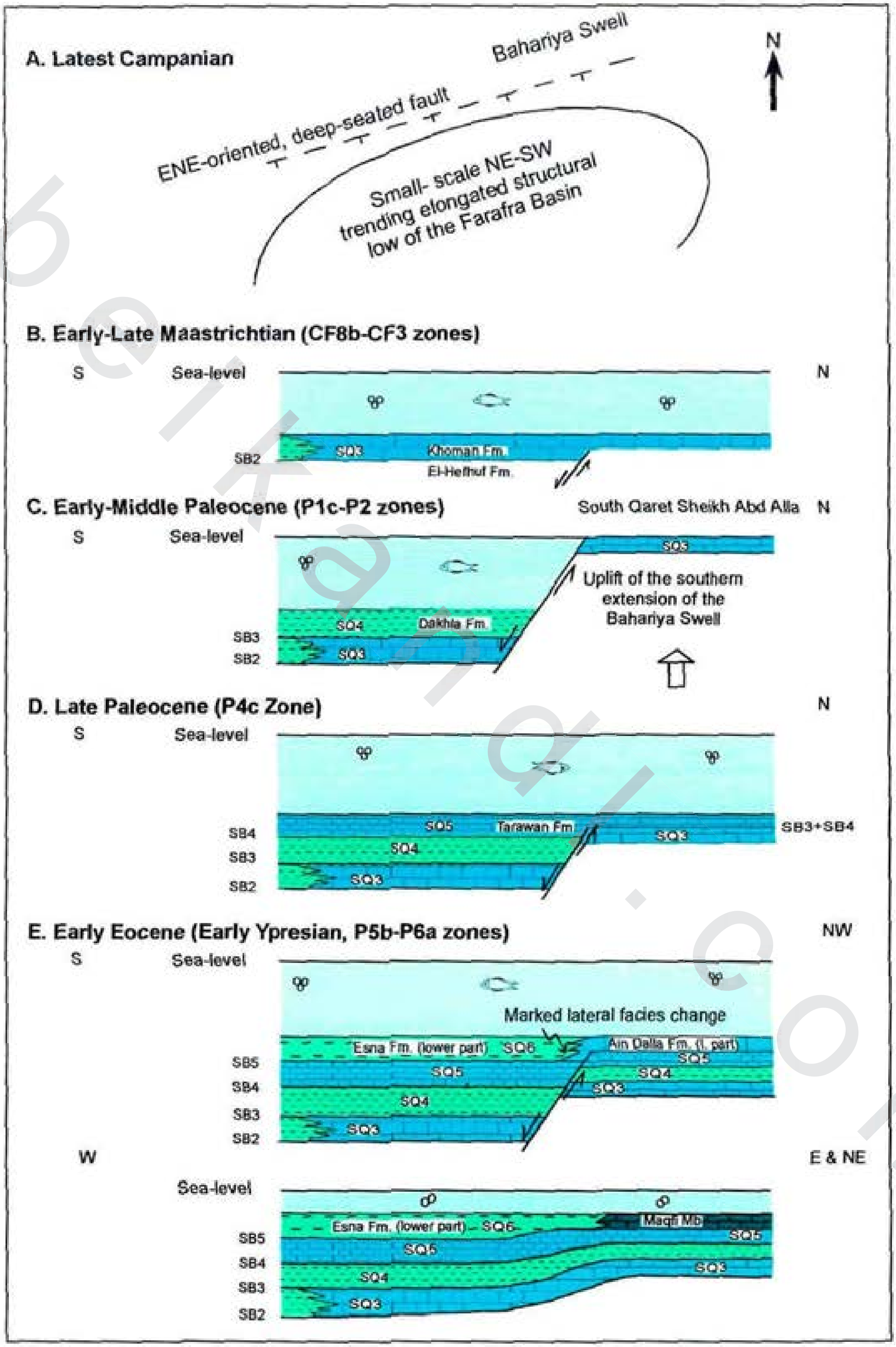
Chapter VI

Geological Histroy

VI Geological History

It is known that the Bahariya Oasis is pushed up after the deposition of the Early Senonian sediments to form a distinct NE-trending structural high aligned parallel to the Syrian Arc fold system; the Bahariya swell of Moustafa *et al.* (2003). It is throught that the northeastern margin of the Farafra Basin was the southern most end of the Bahariya swell. This is evidenced from the marked decrease in thickness of the Upper Cretaceous-Lower Eocene sediments toward the northeast Farafra Oasis. A major ENE-oriented deep-seated fault is deformed by Moustafa *et al.* (op. Cit.) in the plateau between Bahariya and Farafra which extends southwest word to the northern margin of El Quss Abu said. The present author believes that the tectonic pulses along this major fault have strongly affected the sedimentation patterns in the Farafra Basin during the Late Cretaceous-Early Eocene time (Fig. 6.A.1).

During the Santonian time a shallow marine environment prevailed in the Farafra Oasis which resulted in the deposition of thick clastic sediments of El-Hefhuf Formation. In fact, the Cretaceous period witnessed four transgressive cycles in Egypt; these are the Aptian, Cenomanian, Coniacian and Campanian-Maastrichtian transgressive cycles (Said, 1990). The Late Cretaceous transgression was the widest encroachment of the sea over the continents during the Phanerozoic time. This extensive distribution of the Late Cretaceous Sea seems to correspond to a major world-wide rise in relative sea level. During the Campanian, the first marine transgression took place which caused the deposition shallow/deep oyster rudstone with *Pycnodonte vesicularis* followed by lower intertidal phosphatic sandy dolostone due to a rapid sea level fall; the upper unit of El-Hefhuf Formation. These sediments exhibit a marked facies change southwards into a succession of hard siliceous semicrystalline limestone, shale and phosphatic bed of the Duwi Formation.


A. Latest Campanian
Bahariya Swell
N
ENE-oriented, deep-seated fault
Small- scale NE-SW trending elongated structural low of the Farafra Basin
B. Early-Late Maastrichtian (CF8b-CF3 zones)
S
Sea-level
N
SB2
SQ3
Khoman Fm.
El-Hefhuf Fm.
C. Early-Middle Paleocene (P1c-P2 zones)
South Qaret Sheikh Abd Alla
N
S
Sea-level
SQ3
Uplift of the southern extension of the Bahariya Swell
SB3
SB2
SQ4
Dakhla Fm.
SQ3
D. Late Paleocene (P4c Zone)
N
S
Sea-level
SB4
SB3
SB2
SQ5
Tarawan Fm.
SQ3
SB3+SB4
SQ4
SQ3
E. Early Eocene (Early Ypresian, P5b-P6a zones)
NW
S
Sea-level
Marked lateral facies change
Esna Fm. (lower part)
SQ6
Ain Dalla Fm. (l. part)
SQ5
SQ4
SQ3
SB5
SB4
SB3
SB2
SQ5
SQ4
SQ3
W
E & NE
Sea-level
Maqfi Mb.
Esna Fm. (lower part)
SQ6
SQ5
SQ5
SQ3
SQ4
SQ3
SB5
SB4
SB3
SB2

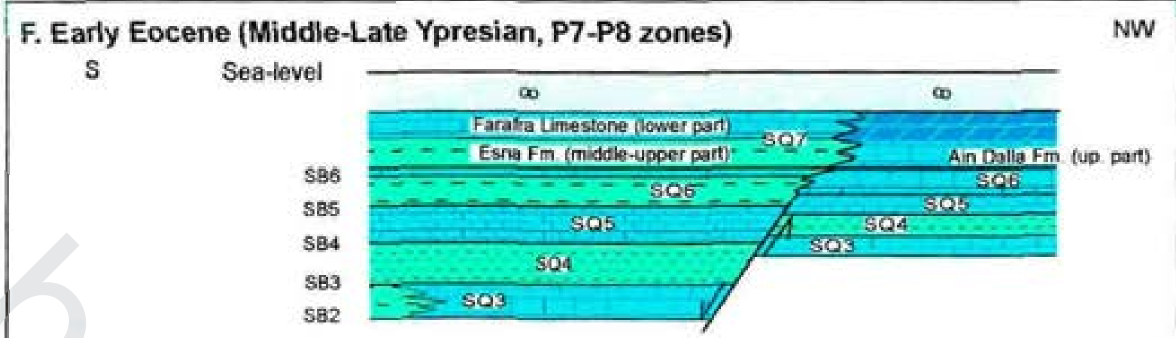


Fig. 6.1 (opposite and above) Tectono-stratigraphic evolution of the Upper Cretaceous-Lower Eocene sequences in the Farafra Basin (not to scale).

During the Latest Campanian, regional tectonic movement took place caused a widespread hiatus between El-Hefhuf Formation and the overlying Khoman Chalk (Fig. 6.B.1) This unconformity is also observed by Barthel and Hermann-Dagen (1981), whereas the upper limestone beds of the Campanian Duwi Formation at Qur El-Malik Member have not been deposited.

At the Early-Late Maastrichtian, a major marine ingression flooded southern Egypt and extended further south, forming an embayment in northern Sudan (Klitzsch and Wycisk, 1987). During the Early Maastrichtian *Rugoglobigerina hexacamerata* CF8b and *Gansserina gansseri* CF7 zones the Farafra Basin became more deeper due to a rapid sea level rise. This led to the deposition of deep middle/outer shelf foraminiferal wackstone. The absence of any clastic supply provides suitable conditions for a growing platform carbonate succession. The carbonate facies represents the lateral equivalent of the clastic-dominated facies of the Dakhla Formation prevailed southward of the Farafra Basin. This change in facies seems to be a regional feature nearly at latitude 27° North. Khalifa and Zaghloul (1989) believed that this area might represent the shelf edge, which separates between the shallow water clastic facies in the south and the deeper facies in the north. They added that the shelf edge conditions prevailed south of Ain El Sheikh Marzouk, while shelf slope conditions prevailed north of this locality. However, the thick sedimentary cover recorded in the subsurface and surface of the Farafra Oasis with respect to Bahariya Oasis might indicate deepening basin toward the Farafra Oasis (Fig. 6.B.1).

During the Late Maastrichtian *Contusotruncana contusa/ Pseudotextularia intermedia/ Racemiguembelina fructicosa/ Pseudoguembelina hariaensis* CF6-CF3 Zones, a regressive phase prevailed over the Farafra Oasis as evidenced from the deposition of middle shelf foraminiferal wackestone, lower intertidal lime-mudstone and upper intertidal dolostone. It is followed by a tectonic uplift with the formation of an unconformity between the Late Cretaceous and Early Paleocene (e.g. Barthel and Hermann-Degen, 1981, Hermina, 1990, Abdel-Kirrem & Samir 1995 and Tantawy 2001) at the top of the Khoman Formation.

A prominent rise in relative sea level took place during the Late Danian *Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* P1c Subzone and *Praemurica uncinata–Morozovella angulata* P2 Zone over the Farafra Oasis causing deposition of deep middle-outer shelf foraminiferal wackestone and pelagic calcareous shale. A minor hiatus with the formation of unconformity surface is recorded in the eastern and western parts of the Farafra Oasis due to the missing of the *Morozovella angulata-Globanomalina pseudomenardii* Interval Zone P3).

The whole sediments of the Dakhla Formation are absent in the extreme northern part of the Farafra Oasis. In the central part of the Farafra Oasis especially in Gunna North and northwest Bir Bidni, this zone is recorded as a result of continuous sedimentation (Fig. 6.C.1).

During the Late Paleocene *Globanomalina pseudomenardii* P4 Zone deep water conditions prevailed once again resulted in the deposition of outer shelf pelagic foraminiferal packstone and shale. This graded upward into shallow middle shelf foraminiferal wackestone, shale, shallow subtidal bioclastic foraminiferal packstone and lower intertidal lime-mudstone due to gradual sea level drop. This regressive phase ended with subaerial exposure over the Farafra Basin with the formation of unconformity surface during the Late Thanetian and Earliest Ypresian (Fig. 6.D.1).

A prominent rise in sea level took place during the Earliest Ypresian P5c Subzone in the Farafra central basin and continued throughout the basal part of the *Morozovella formosa* and/or *Morozovella lensiformis* P6a Subzone. This resulted in accumulation of deep middle/outer shelf pelagic shale and wackestone; basal part of the Esna Formation with abundant large morozovelliods, (about 72%) and less abundant subbotinids (50% to 6%). The immigration of these warm, low-latitude indices (i.e. morozovelliods) marks the warmest period throughout the Earliest Ypresian. While in the uplifted area, the whole P5 Zone has not been deposited as in the central basin. At the marginal or structural high areas, the miliolids alveolinid packstone of the Maqfi Member deposited directly over the Tarawan Formation during the P6b Zone. The Maqfi Member is of local distribution along the eastern and northeastern parts of the Farafra Oasis (Fig. 6.E.1).

The maximum thickness is about 8-10m in northwest Ain Maqfi. The thickness wedges out toward the southeastern part at Bir Murr and northwest Bir Bidni to about 1m thick. It disappears in the extreme northern part of the Farafra Oasis, where the Esna Formation is completely missing in Qaret El-Sheikh Abd Alla and the Farafra Limestone overlies the Paleocene Tarawan Formation. The time coeval is Ain Dalla Formation also overlies the Tarawan Formation in the western part of the Farafra Oasis (Fig. 6.E.1). In fact, the Esna Formation reaches its maximum thickness in the Farafra central basin and decreases gradually in thickness toward the basin margin in the present-day eastern and western reaches of the Farafra Oasis.

At the end of the *Morozovella formosa* and/or *Morozovella lensiformis* P6a Subzone, minor tectonic uplift took place accompanied with subaerial exposure which level fall extended over the Farafra Basin during the *Morozovella formosa/M. lensiformis-M. aragonensis* P6b Subzone. This unconformity recorded within the lower part of the Esna Formation.

During the basal part of the Middle Ypresian *Morozovella aragonesis/M. formosa* Zone P7, a sudden deepening of the basin accompanied with a warming trend tock place, causing the deposition of shallow middle to outer shelf pelagic shale and foraminiferal wackestone; the middle part of the Esna Formation to outer shelf depth. This followed by regressive phase at the top part of *Morozovella aragonesis/M. formosa* Zone prevailed over the Farafra Oasis with the abundance of larger foraminifers and macrofossil fauna rich sediments. These shallowing conditions of the sea continued throughout the Late Ypresian *Morozovella aragonesis/Acarinina aspensis-Hantkenina nuttalli* (P8/P9) undifferentiated Zone; the upper part of the Esna Formation as well as the Farafra Limestone and the lateral facies change.

The Farafra Limestone represents the counterpart and the lateral facies changes of the Lower Eocene Thebes Formation exposed further eastward at the Nile Valley area. The facies change may be largely controlled by the tectonic movement that affected Egypt during the Late Cretaceous and before the deposition of the Lower Eocene sediments (Fig. 6.F.1). Zaghloul (1983) subdivided the Farafra Limestone into three subenvironments namely: 1) Ain Dalla-Qur Hamra and Maqfi-Karawin bank margin, 2) El Quss Abu Said bank interior (shelf lagoon) and 3) Gabal Sofra and Naqb El-Romi off bank facies.

Chapter VII
Summay and Conclusions

VII. Summary and Conclusions

The present work deals with the integrated litho-and biostratigraphy, microfacies associations, depositional environments, sequence stratigraphy and the geological history of the Upper Cretaceous-Lower Eocene succession in the Farafra Oasis.

The Farafra Oasis is one of the most characteristic depressions present in the Western Desert of Egypt. It is located about 560 km southwest of Cairo and about 300km west of Assiut. The floor of the oasis is occupied by the Maastrichtian chalk, while the Lower Paleocene-Lower Eocene clastic/carbonate sediments characterize its scarp faces and plateau surfaces. The Upper Cretaceous-Lower Eocene succession of the Farafra Oasis is invoked by a variety of shallow and deep marine sediments with many distinct lateral variations in facies and thickness. Few studies were published on the eastern and western parts of the Farafra Oasis.

Fourteen surface stratigraphic sections have been measured and sampled in east and west Farafra Oasis. These sections are chosen to represent the whole lateral and vertical facies and thickness changes in the Farafra Oasis. Different lithologies of the same age can be recognized in and around the Farafra Oasis. The age assignment, sequence boundaries and the environmental interpretations of the different sediment types give a clear picture about the aerial distribution of various facies and help in solving the stratigraphic problems in the study area.

The succession cropping out in the Farafra Oasis ranges in age from Santonian to Early Eocene. It is classified into seven rock units; these are from older to younger: El-Hefhuf, Khoman, Dakhla, Tarawan, Esna and its lateral coeval Ain Dalla, and Farafra formations, respectively.

El-Hefhuf Formation is well developed in Wadi Hennis and east Bir El-Obeiyid. It has an exposed thickness ranges from 11-35m thick. El-Hefhuf Formation represents the oldest exposed rocks in the Farafra Oasis. It is composed of two rock units with a sharp contact inbetween. The lower unit is composed of clastic sequence of shale, cross-bedded sandstone, massive sandstone, and siltstone, partly glauconitic. The upper unit starts with oyster bank which is followed by phosphatic sandy dolostone with common shark teeth and burrows. The latter have different straight, bifurcated and flask shapes. The contact between El-Hefhuf Formation and the overlying Khoman Formation is a sharp unconformable contact between the hard dolostone and the chalk of Early Maastrichtian age.

Five dominant facies associations are recognized in El-Hefhuf Formation. These are:

1. Upper deep subtidal shale/mudstone.
2. Shallow subtidal massive/cross-bedded sandstone (ferruginous quartz arenite).
3. Lower intertidal phosphatic sandy lime-mudstone.
4. Shallow/deep subtidal oyster rudstone with *Pycnodonte vesicularis*.
5. Upper intertidal sandy dolostone.

El-Hefhuf Formation seems to have been deposited in a shallow marine environment with oscillations from upper intertidal to upper deep subtidal. The clastic facies of El-Hefhuf Formation represents the first depositional sequence SQ1. The base of this sequence is not exposed while its top is marked at the base of a *Pycnodonte vesicularis* rich bed with many reworked Cenomanian fossils. The upper boundary defines the base of the Campanian and separates between the lower clastic and upper carbonate units by a sharp erossional contact. It is consists of progradational parasequence sets of alternating upper deep subtidal shale/mudstone, subtidal lower shoreface massive-bedded sandstone and subtidal upper shoreface cross-bedded sandstone that define its highstand systems tract. The carbonate facies of El-Hefhuf Formation represents the second depositional sequence SQ2. This depositional sequence includes a lower transgressive deposit of shallow/deep subtidal oyster rudstone, lower intertidal sandy phosphatic dolostone and sandy argillaceous limestone.

The Khoman Formation is widely distributed throughout the floor of the northern Farafra Oasis. It reaches its maximum thickness in the northern escarpment of the Farafra Oasis (50m thick) and is made up mainly of snow-white chalk; moderately hard, massive and fine-grained, While at Qur Hadida, the chalk is topped by dolostone intercalated with mudstone and algal stromatolites especially near top. The Khoman Formation comprises the following four facies associations:

1. Deep middle to upper continental slope foraminiferal wackestone
2. Shallow inner shelf mudstone
3. Lower intertidal lime-mudstone
4. Upper intertidal dolostone

The basal part of the Khoman Formation indicates deposition in a deeper middle shelf environment, whereas the overlying sediments of the upper part of the *Rugoglobigerina hexacamerata* CF8b Zone has been deposited in a relatively deeper sea oscillating between outer shelf and upper continental slope depth. Shallower conditions of deep middle shelf start with the upper part of the *Gansserina gansseri* CF7 Zone and the base of the overlying *Contusotruncana contuse* CF6 Zone. Very shallow conditions of shallow inner shelf dominated in the top part of the Khoman Formation.

The Khoman chalk is highly fossiliferous with planktics and benthics which belong to three planktic foraminiferal zones, namely: *Rugoglobigerina hexacamerata* Interval Zone CF8b and *Gansserina gansseri* Partial Range Zone CF7 which form the lower-middle part of the Khoman Formation and the *Contusotruncana contusa/ Pseudotextularia intermedia/ Racemiguembelina fructicosa/ Pseudoguembelina hariaensis* Interval Zone (CF6-CF5-CF4-CF3 Undifferentiated Zone), which belongs to the upper part of Khoman Formation

The Khoman Formation represents the third depositional sequence SQ3. The lower boundary of this sequence is an unconformity surface separating between the Campanian part of El-Hefhuf Formation and the Khoman Formation, the upper boundary is a paraconformity surface at the top of the formation due to the missing of the Latest Maastrichtian and the lower part of the Danian. The SQ3 consist of retrogradational parasequence sets of deep middle/outer shelf foraminiferal wackestone with a shallow middle shelf foraminiferal wackestone at the base that belong to the transgressive deposits and progradational parasequence of middle shelf foraminiferal wackestone at the base and lower intertidal lime-mudstone at the top of the highstand deposits.

The Dakhla Formation is widely distributed in the central and southern parts of the Western Desert. It is represented in the Farafra Oasis by its uppermost part of its upper Kharga Shale Member. The formation ranges in thickness from 1-10m. It is missing in south Qaret Sheikh Abd Alla; this perhaps reflects uplift of this area during deposition of the Dakhla Formation. This Formation consists of two informal units; a lower argillaceous chalk unit with many reworked foraminiferal fossils of Maastrichtian age at the base, which maintain its basal unconformity surface. While, the upper unit is formed of foraminiferal calcareous shale with many gypsum veinlets.

The formation includes the following three facies associations.

1. Deep middle shelf foraminiferal wackestone
2. Deep middle/outer shelf pelagic shale
3. Shallow inner shelf foraminiferal lime-mudstone

The facies associations and faunal content of the Dakhla Formation indicate a transgressive event of the sea level, which increases upward with the increasing of the planktic foraminifers. The formation however, has been deposited in middle/outer shelf, inner shelf environment.

The Dakhla Formation is fossiliferous with abundant planktics and benthics which belong to the *Globanomalina compressa-Praemurica uncinata* Interval Subzone P1c, *Praemurica uncinata–Morozovella angulata* Interval Zone P2 and *Morozovella angulata-Globanomalina pseudomenardii* Interval Zone P3.

The Dakhla Formation represents the fourth recorded depositional sequence SQ4. The lower boundary is a disconformity surface separating the top part of the Khoman Formation from the basal part of the Dakhla Formation. While, the upper boundary is an erossional unconformity surface due to the missing of the *Praemurica uncinata-Morozovella angulata* P2 Zone and *Morozovella angulata-Globanomalina pseudomenardii* P3 Zone (northwest Ain Maqfi), which represents a time gap of from about 61.2Ma to about 57.1Ma. In Bir Murr and Shakhs El-Obeiyid, this hiatus is recorded due to the missing of the P3 Zone, while in Ain Maqfi, this hiatus recorded due to the missing of the P3b Subzone. In the extreme northern part of the Farafra Oasis at south Qaret Sheikh Abd Alla, the whole Dakhla Formation is missing which equivalent to about 9.0 Ma. This contact (SB4) is conformable in the Bir Bidni due to continuous sedimentation.

The Tarawan Formation is well exhibited in the Farafra Oasis. It is characterized by a marked change in thickness from 1m in Bir Murr to 23m in northwest Ain Maqfi. This formation is composed of chalk and argillaceous limestone with calcareous claystone interbeds at the middle part of El Quss Abu Said; it belongs to the *Globanomalina pseudomenardii* Zone (P4). The top part of the Tarawan Formation is composed of calcareous shale at northwest Farafra-Ain Dalla passage. It is intensively burrowed with *Thalassinoides* in its upper part especially toward the paleohigh areas. The Tarawan Formation includes the following facies associations:

1. Outer shelf pelagic foraminiferal packstone
2. Outer shallow middle shelf pelagic shale
3. Lower shallow subtidal bioclastic foraminiferal packstone

4. Lower intertidal foraminiferal lime-mudstone

The Tarawan Formation is characterized by gradual upward shallowing conditions as evidenced from the rapid vertical variation in the facies associations and decrease upward in planktic/benthic ratio ratios. These shallowing conditions most probably are connected with an episode of tectonic activity in the Egyptian Paleocene called the *Velascoensis* Event by Strougo (1986).

The Tarawan Formation represents the fifth recorded depositional sequence SQ5. Its upper boundary is a sharp erossional surface due to the missing of the Latest Paleocene *Morozovella velascoensis* P5 Zone especially along the eastern part of the Farafra Oasis. The SQ5 is formed of transgressive systems tract and highstand systems tract. The transgressive deposits are followed by the maximum flooding surface, which represents the change from pelagic facies to shallower facies of the overlying highstand systems tract at northwest Bir Bidni, Shakhs El-Obeiyid and northwest Ain Maqfi. The latter is composed of aggradational to progradational parasequence sets of shallow middle shelf foraminiferal wackestone and calcareous shale, lower shallow subtidal bioclastic foraminiferal packstone and lower intertidal foraminiferal lime-mudstone

The Esna Formation is widely distribution in the scarp face of the Farafra Oasis. It is locally absent in south Qaret Sheikh Abd Alla. It exhibits marked lateral facies and thickness changes in the studied area depending on the basin paleotopographic setting. It ranges in thickness from 20-150m and is composed of green shale and mudstone intercalated in its upper part with argillaceous limestone. In the eastern and northern parts of the Farafra Oasis, the Esna Formation starts at the base with the Maqfi Member, while in southeast Qur Hadida the basal part of the Esna Formation consists of evaporite, shale and sandstone which are capped by limestone with algal stromatolites. The formation unconformably overlies the Tarawan Formation.

The Esna Formation is fossiliferous with abundant planktics and benthics especially in its lower part which belong to the *Morozovella velascoensis* Zone P5b-c and *Morozovella subbotinae* Zone P6a in the central and western parts of the Farafra Oasis, while the middle and upper parts of the formation ascribe to the *Morozovella aragonesis/M. formosa* Zone P7 and lower part of the *Morozovella aragonesis/Acarinina aspensis-Hantkenina nuttalli* Zone (P8-P9 undifferentiated)

The Esna Formation includes the following six facies associations:

1. Deep middle/outer shelf pelagic shale
2. Shallow inner shelf calcareous shale
3. Lower shallow subtidal miliolids alveolinid bioclastic packstone
4. Lower shallow subtidal foraminiferal packstone
5. Supratidal sabkha
6. Lower shoreface calcareous quartz arenite

The faunal and lithologic characteristics of the basal Maqfi Member suggest deposition in a lower shallow subtidal environment, while in the paleo-low areas, the basal part of the Esna Formation indicates deposition in a deep middle/outer shelf environment. The overlying sediments of the middle and upper parts of the Esna Formation are deposited under shallower conditions between shallow subtidal to upper deep subtidal setting (shallow inner shelf).

The Ain Dalla Formation has a limited aerial distribution, only found in Ain Dalla and Shakhs El-Obeiyid areas. It is introduced to replace the Esna Formation in Ain Dalla and to represent the well-bedded chalky limestone with chert bands at the top. The formation is found to overlie unconformably the Tarawan Formation and to underlie the Farafra Formation with a sharp lithologic contact.

The formation contains the following microfacies associations:

1. Deep middle/outer shelf foraminiferal wackestone
2. Lower shallow subtidal alveolinid wackestone
3. Deep subtidal calcareous shale
4. Lower intertidal sandy silicified dolostone
5. Lower intertidal lime-mudstone

The lower part of Ain Dalla Formation has been deposited in a deep middle/outer shelf setting. It is interrupted by shallowing conditions to deposit a lime-mudstone and sandy silicified dolostone of lower intertidal regime, while the upper part of Ain Dalla Formation is interpreted to be deposited in a lower shallow subtidal environment. In the upper part of Ain Dalla Formation, the planktics are nil, while the larger foraminifers are frequent indicating a regressive event.

The depositional sequence SQ6 covers the lower part of the Lower Eocene Esna and Ain Dalla formations. The base of this sequence is marked by the sequence boundary SB5 which separated the Thanetian from Early Ypresian, while its top is characterized by the missing of the *Morozovella formosa/M. lensiformis-M. aragonensis* Subzone P6b; this sequence boundary SB6 is characterized by the presence of a thick evaporite bed in southeast Qur Hadida, submarine break in the southern slope of El Quss Abu Said or by intense dolomitization in Ain Dalla and Shakhs El-Obeiyid. It separates between the Early and Middle Ypresian.

Sequence 6 includes both transgressive and highstand systems tracts. The transgressive deposits consist of outer shelf pelagic shale and deep middle/outer shelf foraminiferal wackestone. While, the highstand deposits are formed of shallow middle shelf calcareous shale and foraminiferal wackestone, shallow inner shelf calcareous shale, lower intertidal lime-mudstone and silicified dolostone. The depositional sequence SQ7 on the other hand, represents the main part of the Esna and Ain Dalla formations as well as the lower part of the overlying Farafra Limestone in the Farafra Oasis

The Farafra Limestone has a great extension, forming the cap rock of El-Quss Abu Said Plateau as well as the northern and eastern plateaus of the Farafra Oasis. It is composed of limestone with argillaceous content at base and dolomitic limestone at the top. In the northern reach of the Farafra basin, the Farafra Limestone is composed of dolomitic limestone such as in Ain Dalla and south Qaret Sheikh Abd Alla.

The Farafra Limestone yields the following facies associations:

1. Deep subtidal calcareous shale.

2. Upper shallow subtidal nummulitic alveolinid packstone.
3. Lower shallow subtidal nummulitic wacke/packstone.
4. Lower intertidal lime-mudstone.
5. Lower intertidal dolomitic lime-mudstone.

In general, the lower part of the Farafra Limestone has been deposited in a shallow subtidal environment which became shallower in the upper part of the formation (lower intertidal flat). The contact between the Esna Formation and the Farafra Limestone is gradational in eastern and western escarpments of the Farafra Oasis.

The upper part of the Farafra Limestone corresponds to the last recorded depositional sequence in the Farafra Oasis, the depositional sequence SQ8, due to the detection of an unconformity surface in the middle part of the Farafra Limestone. This surface is characterized by an intensively bored hard ground with *Thalassinoides*.

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Arabic Summary

استراتجرافية تتابع الطباشيري العلوي – الثالث السفلي في واحة الفرافرة – الصحراء الغربية – مصر

رسالة مقدمة

للحصول على

درجة العالمية (الدكتوراه) في العلوم

(چيولوچيا)

من الجيولوجي

شريف فاروق محمد أحمد

بكالوريوس علوم چيولوچيا (جامعة الأزهر 1996)

ماجستير علوم چيولوچيا (جامعة الأزهر 2003)

إلى

جامعة الأزهر

كلية العلوم

قسم الجيولوجيا

2006

بسم الله الرحمن الرحيم

﴿قل سيروا في الأرض فانظروا كيف بدأ الخلق ثم الله ينشئ النشأة الآخرة إن الله على كل شيء قدير﴾

صدق الله العظيم

سورة العنكبوت الآية ٢٠

إهداء

إلى روح أبي الكريم

إلى أرواح شهداء المسلمين

إلى كل نفس تريد أن ترقى بالعلم والإيمان

إلى من يبحثون عن حقائق الكون ليهتدوا من خلالها
إلى عظمة الخالق وحقيقة الوجود

إلى كل هؤلاء...

أقدم هذا العمل المتواضع

الباحث

شريف فاروق محمد ا حمد

الملخص العربي

ظلت أطراف واحة الفرافرة من ناحية الشرق والغرب مناطق يكتنفها الغموض وتحوطها التخمينات نظراً لصعوبة الوصول إلى هذه المناطق حيث تكثر الكثبان الرملية بها, وقد درست المناطق الوسطي من واحة الفرافرة القريبة من الطريق الإسفلتي الرئيسي المتجه إلى واحة الداخلة وبقيت المناطق الشرقية والغربية من واحة الفرافرة غامضة, لذا تم التطرق إلي هذه المناطق لمحاولة كشف جزء من هذا الغموض.

ولإنجاز هذه الدراسة تم اختيار اربعة عشر قاطعا جيولوجيا سبعة منها في الاجزاء الشرقية (وهى قطاعات بئر مر, عين مقفى, جنوب شرق قور حديده, قور حديده, جنوب شرق قارة الشيخ عبد الله, شرق عين مقفى, وادي حنس) وإما السبعة الاخرى فتقع في الاجزاء الغربية من واحة الفرافرة (وهى شمال هضبة القس ابو سعيد, جنوب هضبة القس ابو سعيد, شمال غرب بئر بدني, شرق شخص الابيض, شخص الابيض, عين دالة وجبل سفره). ويمتد التتابع في واحة الفرافرة من عهد السانتوني إلى عهد الايوسين المبكر. وقد امكن تقسيم هذه القطاعات إلى سبعة متكونات وهى

1. **متكون الهفوف:**

يوجد هذا المتكون في منخفض الفرافرة بشكل محدود، حيث ينحصر تواجده في الاجزاء المنخفضة طوبوغرافيا على شكل تلال صغيرة الحجم في وادي حنس وشرق شخص الأبيض. ويتألف من طفل أخضر يتميز بوجود حبيبات من الجلوكونيت متبادل مع حجر رملي عديم الحفريات ينتمي للسانتوني، ويعلوه طبقات من حجر الدولوميت الذي يتميز بوجود حبيبات من الفوسفات التابع للكمباني ويتميز متكون الهفوف بوجود خمس سحنات دقيقة وهي

1. Upper deep subtidal shale/mudstone.
2. Shallow subtidal massive/cross-bedded sandstone (ferruginous quartz arenite).
3. Lower intertidal phosphatic sandy lime-mudstone.
4. Shallow/deep subtidal oyster rudstone with *Pycnodonte vesicularis*.

5. Upper intertidal sandy dolostone.

ويفصل بين السحنات الفتاتية والسحنات الكربونية فاصل طباقي ويستدل على ذلك بوجود حفريات السينوماني الشهيرة مثل *Ceratostreon flabellatum* (Goldfuss), and *Ilymatogyra* (*Afrogyra*) *africana* (Lamarck)

المعاد ترسيبها مع مستعمرات من *Pycnodonte vesicularis* (Lamarck) التابعة للعصر للكمباني. وتمثل السحنات الكربونية أول تقدم بحري حقيقي غطى منطقة الدراسة خلال الكمباني متبوع بتقهقر بحري في نهاية الكمباني المتأخر.

2. متكون الخومان:

ينتشر هذا المتكون في بمساحات شاسعة في أرضية منخفض الفرافرة ويكون أشكالاً سطحية متنوعة أثر تعرضها لعوامل التجوية المختلفة ومن أشهرها الأبراج الكارستية وموائد الشيطان. ويتألف من طباشير ابيض غني بالفورامنيفرا التابعة للمسترختي. وقد تبين أن الحد الفاصل بين الطباشيري العلوي والباليوجين السفلي يقع عند قاعدة النطاق CF6. كما تضح من خلال الدراسة التفصيلية للمحتوي الحفري أن الراوسب تكون اقل عمقا مع تقدم الزمن. وقد امكن تتبع ذلك من خلال دراسة وفرة وتنوع الفورامينفرا الهائمة ذات الحافة الحادة (keeled) المنتشرة في الأجزاء السفلية لهذا المتكون والتي تقل كلما اتجهنا لأعلي, وكذلك أفراد heterohelicids المنتشرة بوفرة في أواخر الطباشيري العلوي. وقد سجل وجود دولوميت متبادل مع طفل في الأجزاء السفلية فقير في المحتوى الأحفوري في منطقة قور حديدة.

وقد أمكن تقسيم متكون الخومان إلى ثلاثة نطاقات حيوية كالأتي من أسفل لأعلي:

- *Rugoglobigerina hexacamerata* (CF8b) Zone
- *Gansserina gansseri* (CF7) Zone
- *Contusotruncana contusa*/ *Pseudotextularia intermedia*/ *Racemiguembelina fructicosa*/ *Pseudoguembelina hariaensis* Interval Zone (CF6-CF5-CF4-CF3 Undifferentiated).

ويتميز متكون الخومان بوجود أربع سحنات دقيقة وهي

1. Deep middle to upper continental slope foraminiferal wackestone
2. Shallow inner shelf mudstone
3. Lower intertidal lime-mudstone
4. Upper intertidal dolostone

ويفصل بين متكون الهفوف والخومان فاصل طباقي عبارة عن طبقة من الدولوميت ينحصر سمكها في منخفض الفرافرة إلي متر واحد فقط مقارنة بسمكها في منخفض البحرية الذي يصل إلي ٢٦ متر.

٣. متكون الداخلة:

يظهر هذا المتكون في واحة الفرافرة متمثلا بعضو الخارجة الذي يختفي تدريجيا كلما اتجهنا ناحية الشمال ويتألف الجزء السفلى منه من حجر طفلي طباشيري بينما الأجزاء العلوية تتألف من طفل اخضر غنى بالفورامنيفرا. وترسب متكون الداخلة تحت بيئة شاطئية ضحلة تميل للعمق كلما اتجهنا لاعلى وقد امكن تقسيم هذه المتكون إلي اربعة نطاقات حيوية كالاتي من اسفل لاعلي:

- *Globanomalina compressa-Praemurica uncinata* Interval Subzone (P1c)
- *Praemurica uncinata–Morozovella angulata* Interval Zone (P2)
- *Morozovella angulata-Globanomalina pseudomenardii* Interval Zone (P3).

ويتميز متكون الداخلة بوجود سحنات دقيقة وهى

1. Deep middle shelf foraminiferal wackestone
2. Deep middle/outer shelf pelagic shale
3. Shallow inner shelf foraminiferal lime-mudstone

كما تبين ان الحد الفاصل الداني /والسيلاندي (Danian/Seldanian)يقع عند قاعدة تحت النطاق P3b للفورامنيفرا الهائمة. ويحد هذا المتكون من اعلى فاصل طباقى تم تحديده في الاجزاء الشرقية والغربية من منخفض للفرافرة، وذلك بسبب غياب النطاق

الحيوي P3 مما يدل على إن هذه المناطق تمثل حوافف حوض الترسيب.

٤. متكون الطروان:

يتمثل هذا المتكون في الهضبة الشرقية لمنخفض الفرافرة من حجر جيري وحجر جيري طباشيري، يتغير إلي حجر جيري يتخلله بعض الراقات من الطفل في منطقة القس أبو سعيد، بينما تتغير أجزاؤه العلوية في طريق الفرافرة – عين دالة إلي طفل، وكذلك أجزاؤه السفلية في منطقة شخص الأبيض مما يدل على النشاط التكتوني للمنطقة في تلك الفترة الزمنية والتي تتميز بوجود نطاق *Globanomalina pseudomenardii* Zone.

وقد ترسب متكون الطروان في بيئة عميقة مرورا بالرصيف القاري العميق حتى المنحدر القاري العلوي خاصة في الأجزاء العلوية من متكون الطروان.

ويتميز متكون الطروان بوجود سحنات دقيقة وهي:

1. Outer shelf pelagic foraminiferal packstone
2. Outer shallow middle pelagic shale
3. Lower shallow subtidal bioclastic foraminiferal packstone
4. Lower intertidal foraminiferal lime-mudstone

ويحد هذا المتكون من أعلى فاصل طباقي في منخفض الفرافرة وذلك لغياب ثغره طباقية صغيرة (minor hiatus) متمثلا بغياب تحت نطاق P5a في منطقة القس ابو سعيد وغياب ايضا تحت النطاق P5a & P5b في معظم اجزاء الفرافرة.

٥. متكون إسنا:

ويتألف من طفلة فاتحة اللون تحتوى على بعض التداخلات من الحجر الجيري خاصة في الاجزاء العليا لهذا المتكون، وتتغير الاجزاء السفلي لمتكون الإسنا في الاطراف الشرقية من منخفض الفرافرة إلي حجر جيري غني بالالوفيولينيات ويسمى عضو المقفى الذي ترسب في بيئة بحرية ضحلة. ويترسيب الجزء السفلى من متكون الإسنا في بيئة بحرية عميقة إلي متوسطة العمق، اما الجزء العلوي فيرجع ترسيبه في

بيئات ضحلة، وقد استدل على ذلك من الانتشار الواسع لمجموعة المحاريات والفورامنيفرا الكبيرة.

ويتميز متكون إسنا بوجود ستة سحنات صخرية كالاتي:

1. Deep middle/outer shelf pelagic shale
2. Shallow inner shelf calcareous shale
3. Lower shallow subtidal miliolids alveolinid bioclastic packstone
4. Lower shallow subtidal foraminiferal packstone
5. Supratidal sabkha
6. Lower shoreface calcareous quartz arenite

ولقد اسفرت الدراسة الحالية عن تحديد الوضع الاستراتجرافي لعضو المقفى Maqfi Member في منخفض الفرافرة حيث ثبت إنة يمثل بداية الإيوسين ويتغير إلى طفل في منطقة القس ابو سعيد. ويحد هذا الطفل وعضو المقفى فاصل طباقي من اعلى وذلك لغياب *Morozovella formosa/M. Lensiformis-M. aragonensis* Subzone P6b

كما تبين ان الحد الفاصل بين الإيوسين المبكر والمتوسط يقع عند قاعدة النطاق الحيوي *Morozovella aragonesis/M. formosa* Zone (= P7) المتمثل بالسطح السفلى لطبقة المتبخرات التي سجلت لاول مرة في الدراسة الحالية في متكون الإسنا بمنطقة قور حديده التي تضاهى السطح السفلي لتجمعات النيموليت في منطقة جنوب القس أبو سعيد.

٦. متكون عين دالة:

يتواجد هذا المتكون في منخفض عين دالة، ويتألف من حجر جيري طباشيري غنى بالفورامنيفرا الهائمة في الاجزاء السفلي و بالفورلمنيفرا الكبيرة في الاجزاء العليا. ولقد أثبتت الدراسة الحالية أن منطقة شخص الأبيض تمثل منطقة تداخلات بين متكون الإاسنا و عين دالة، وان هذه التداخلات والتغيرات في السحنات الصخرية تدل على النشاط التكتونى لهذه المنطقة وتتراوح بيئة ترسيب متكون عين دالة بين بيئة بحرية عميقة و ضحلة.

ويتميز متكون عين دالة بوجود خمس سحنات صخرية كالاتي:

1. Deep middle/outer shelf foraminiferal wackestone
2. Lower shallow subtidal alveolinid wackestone
3. Deep subtidal calcareous shale
4. Lower intertidal sandy silicified dolostone
5. Lower intertidal lime-mudstone

ويحد هذا المتكون من اعلى فاصل طبقي يقع ايضا بين P6a, P7 فوق طبقة من الحجر الدولوميتى الرملي السليكاتى المميزة لمتكون عين دالة.

٧. حجر جيري الفرافرة:

ويتألف من حجر جيري وحجر جيري دولوميتى مع قليل من الطفل التابع ل Late Ypresian الذي يحتوي على النطاق الحيوي *Morozovella aragonesis/Acarinina aspensis-Hantkenina nuttalli* Zone (= P8-P9 Undifferentiated). سيطرت بيئة الرصيف القاري الضحل على هذا المتكون وذلك للانتشار الواسع للالفيولنيات والنيمو ليتات وايضا الحفريات الكبيرة

يتميز متكون الفرافرة بوجود خمس سحنات دقيقة وهى:

1. Deep subtidal calcareous shale.
2. Upper shallow subtidal nummulitic alveolinid packstone.
3. Lower shallow subtidal nummulitic wacke-/ packstone.
4. Lower intertidal lime-mudstone.
5. Lower intertidal dolomitic lime-mudstone.

ويحد هذا المتكون من اعلى فاصل طباقى تم تحديده في منطقة القس ابو سعيد والهضبة الشرقية من منخفض الفرافرة، وذلك بسبب الانتشار الواسع ل *Thalassinoides* بين الحجر الجيري والحجر الجيري الدولوميتي.