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DEPOSITIONAL HISTORY OF THE LOWER EOCENE DROWNED CARBONATE PLATFORM (DRUNKA FORMATION), WEST OF ASSIUT-MINIA STRETCH, WESTERN DESERT, EGYPT

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ABSTRACT

The Lower Eocene Drunka Formation that exposed along the western margin of the Nile Basin in Assiut and Minia stretch is a thick carbonate platform consisting of two units. The Lower one measures 34 m in thickness and comprises four emergence carbonate cycles that range in thickness from 4 m to 10.75 m. Each cycle commences with thin lime mudstone and / or algal skeletal wackestone and capped with thick oolitic-peloidal grainstone. These cycles represent non-gradual cycles that signify no regular balance between subsidence and sedimentation rates. They indicate high frequency sea level fluctuation and / or short time sea level oscillations, accompanied with high production of carbonates. The upper unit measures 99.75 m in thickness, and also comprises emergence carbonate cycles. The cycle begins with thick lime mudstone, followed by algal wackestone / packstone and capped by a thin bed of nummulitic algal packstone or peloidal grainstone (0.5 m to 5 m thick). These cycles represent gradual cycles that denote regular vertical increase in sea level concurrent with increase in sedimentation rate. They resemble low frequency sea level fluctuations with high rate of subsidence outpacing the increase in sea level rise. The drowning of carbonate platform is evidenced by: 1) Increase in thickness of emergence carbonate cycles upward especially in the upper unit. 2) The increase of thickness in the lower parts of cycles (lime mudstone and wackestone) at the expense of cycle cap (packstoneand grainstone) and 3) The decreases of skeletal particles that provide fine-grained carbonate e.g. benthonic foraminifera and algae in the upper unit. Nineteen microfacies associations are recorded and distributed as: lime mudstone, bioclastic wackestone, echinoidal wackestone, nummulitic wackestone, dasycladacean algae wackestone, peloidal wackestone, orbitolites wackestone, miliolidae wackestone, bioclastic packstone, codiacean algae packstone, peloidal packstone, echinoidal packstone, dasycladacean algae packstone, orbitolites bioclastic packstone, miliolidae packstone, peloidal grainstone, siliceous oolitic grainstone and codiacean algae grainstone. According to lithologic characters, geometry, stratigraphic position, sedimentary structures, facies associations, fossil content and cyclic sequences, the environmental deposition of the Drunka Formation reflects a restricted shelf lagoonal facies

INTRODUCTION

The mapped area skirts the Nile Valley from the west in the vicinity of Assiut between south of Abu-Tig till the latitude of El-Qussiya in the north (Fig.1). It lies between the following co-ordinates: Latitudes 26˚ 23´ & 27˚ 27´ N and Longitudes 30º 32´ & 31º 15´ E. The area under investigation is a part of the limestone plateau that bounds the cultivated area from the west.. The exposed limestone rocks in this area belong to the Early Eocene.

MATERIAL AND METHODS

Three stratigraphic columnar sections were measured and about 250 thin sections representing the different limestone types in these sections were prepared and examined under the petrographic microscope for their composition, texture, macro and microfaunal assemblage. To differentiate between limestone and dolostone facies (especially in the very fine grained rocks), about sixty samples were treated with Alizarine Red-S and potassium ferricyanide. The procedure is adopted from Dickson (1965).

STRATIGRAPHY

The Drunka Formation has a distinct entity. It is characteristized from all the Lower Eocene carbonates by its massive, fossiliferous (especially the algal elements), bioturbated, porous and cavernous limestones.

The term "Drunka Formation" was introduced by El-Naggar (1970) to substitute the "Upper Libyan" substage of Zittel (1883). He (op.cit) proposed the type locality of this formation at Gebel Drunka, southwest of Assiut (200 m thickness). The equivalent succession in the eastern side of the Nile Valley was called as "Manfalut Formation" by Said (1971). The rank of the Drunka Formation of El-Naggar (1970) was lowered by Omara *et al.* (1970) and Aref (1982) who used the term "Drunka Member" to describe the carbonate succession that exposed in the area to the southwest of Assiut and that outcropped between Assiut and Beni Suef on the eastern part of the Nile Valley respectively. Here, the authors agree with El-Naggar (1970), Youssef *et al.* (1982),

Mansour and Philobbos (1983), Keheila (1983), Hassaan *et al.* (1990), Helal (1996) and Sheleby *et al.* (2000) in raising the rank of the Drunka Member of Omara *et al.* (1970) to the formation status.

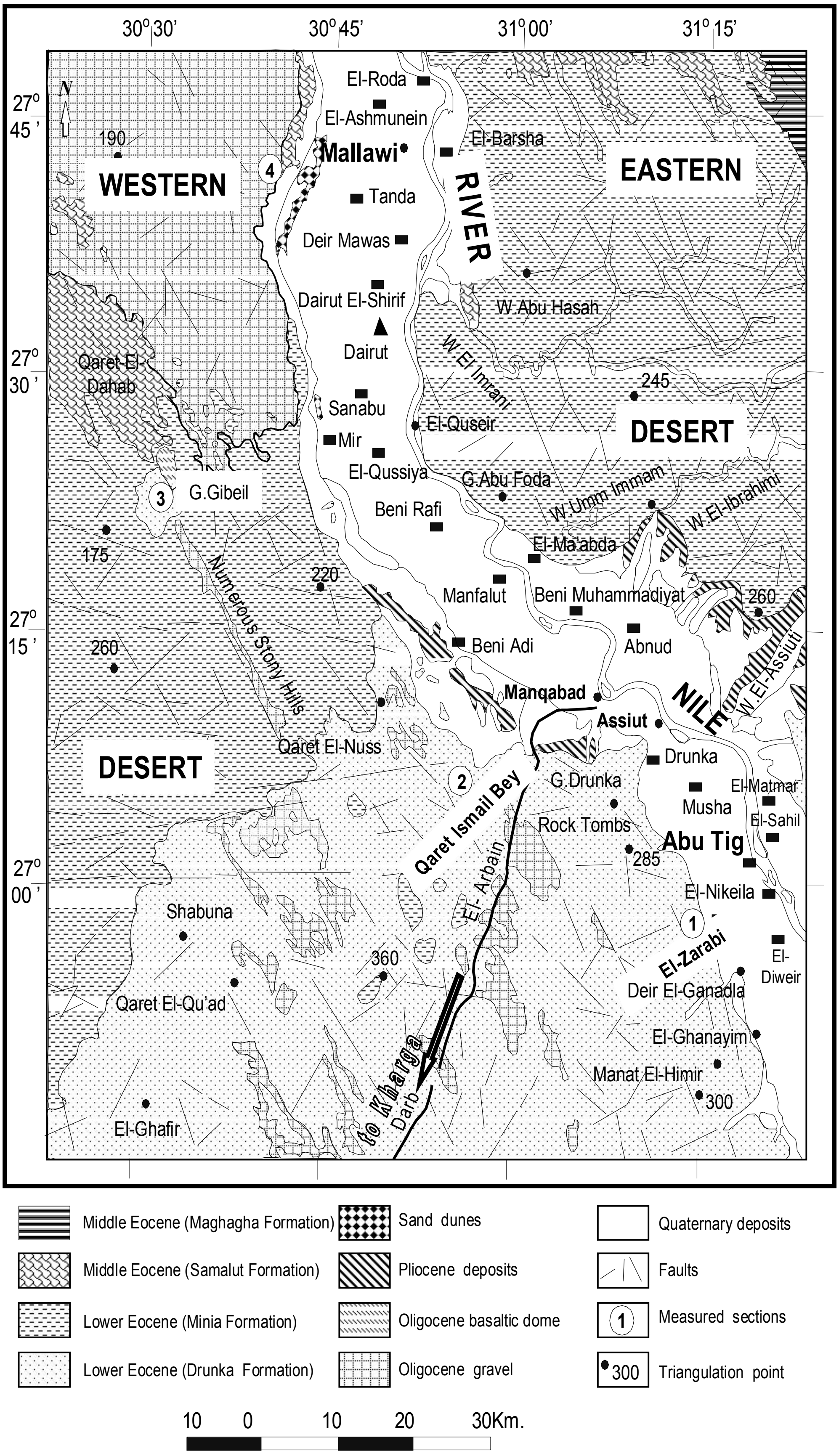


Fig.(1) Geological map of the study area (modified after EGPS and Conoco, 1987)

In the studied area, the Drunka Formation is well represented at El-Zarabi section (section 1) (133.75m), Ismail Bey section (section 2) (35.5m) and Gebel Gibeil section (section 3) (48.5m). The maximum thickness of the Drunka Formation in the present area is about 133.75 m at El-Zarabi section, opposite El-Zarabi Village (south Abu-Tig) (Fig. 2A&B). The Drunka Formation is also recorded at Ismail Bey section (35.5 m), southwest of Assiut (Fig.3) and the lower two-thirds (48.5 m) of the section measured at Gebel Gibeil section, west El-Qussiya (Fig.4).

The Drunka Formation in the present area is composed of hard, crystalline, thick-bedded to massive limestone with greyish white, yellowish white, white and snow-white colours. The limestone is locally chalky and / or argilliceous, highly bioturbated and highly fossiliferous. It contains chert concretions and bands in numerous horizons. (Pl.1A-D). The base of the Drunka Formation is unexposed, while its upper contact is conformable with the overlying Minia Formation at Gebel Gibeil section. This contact is placed between the rosy white chalky, argillaceous, algal limestones of the upper unit of the Drunka Formation and the chalky white alveolinid limestones of the Minia Formation.

Generally the limestone is very rich in calcareous green algae (both codiacean and dasycladacean), miliolids (*Quinqueloculina* sp.) and peloidal grains (fecal peloids and micritized skeletal grains). It also contains an appreciable amount of nummulites and orbitolites besides, the echinoderms, molluscs and the fragmental skeletal particles.

According to the variations in the lithologic characteristics and the fossil content, the Drunka Formation exposed at El-Zarabi section can be subdivided into two distinct units, lower and upper units. The lower unit is represented by the lower 34 m of the section whereas the upper unit is represented by its upper 99.75 m. The discrimination between the two units is depending upon the variation in lithology from grey, yellowish grey, massive, hard, mainly crystalline, poorly fossiliferous, algal limestone with a few silicified bands and concretions that characterize the lower unit whereas the upper unit is made of yellowish white, white and snow white, chalky, thin-laminated, algal, foraminifera limestone with abundant chert bands and large chert nodules.

The limestone of the Drunka Formation yielded the following algal flora: *Ovulites pyriformis* Schwager, *Ovulites arabica* (Pfender), *Ovulites morelleti* Elliott, *Ovulites marginulata* (Lamarck), *Ovulites elongata* Lamarck, *Ovulites* sp., *Halimeda praemonilis* L & J.Morellet, *Halimeda tuna* (Ellis and Solander) and *Halimeda* sp., *Acicularia robusta* Dragastan and Soliman, *Niloporella subglobosa* Dragastan and Soliman, *Cymopolia* sp., *Clypeina occidentalis* (Johnson and Kaska) and *Neomeris* sp. The nummulites (mainly *Nummulites planulatus* (Lamarck) and *Nummulites* sp.), miliolids (*Quinqueloculina* sp.) and *Orbitolites complanatus* Lamarck represent the foraminifera of the Drunka Formation. Pelecypods, gastropods, echinoderms and bryozoan bioclasts are also recorded in high percent.

According to its stratigraphical setting and faunal content, the Drunka Formation is assigned to the Ypresian, This agrees with the opinions of El-Naggar (1970), Youssef *et al.* (1982), Mansour and Philobbos (1983), Keheila (1983), Helal (1996) and Sheleby *et al.* (2000).

MICROFACIES ANALYSIS

Mudstone microfacies association:

1. Lime mudstone microfacies:

The term lime mudstone is used here to describe the mud-supported limestone which is composed mainly of micrite with fossil fragments range from 1-9% of the rock. The lime mudstone is usually overlain by either wackestone or packstone forming a base of an emergence cycle (Khalifa, 1996). In the rocks of the lower unit of the Drunka Formation outcropping at El-Zarabi section, this microfacies is recorded in three beds with a thickness ranges from 0.5-1.5 m (Fig.2A). It rock is yellowish grey to grey, very hard and massive. This microfacies is also recorded in the rocks of the upper unit of the Drunka Formation outcropping at El-Zarabi section (0.5-5 m) (Fig.3B). It reaches about 5 m at the topmost part of Ismail Bey section (Fig.3) and it forms the main bulk of this unit at Gebel Gibeil section with a total thickness of about 22.5 m (about 45% of the total thickness of the unit) (Fig.4). The lime mudstone of the upper unit of the Drunka Formation is represented by white, chalky, fine-grained, poorly fossiliferous, thin laminated limestones, which are sometimes cracked with finely crystalline calcite.

Petrographically, the lime mudstone is mainly composed of micrite and microspars that formed by the aggrading neomorphism. The are represented by randomly distributed skeletal particles of bioclasts (up to

5.5%) of bivalvia, echinoderms, foraminifera, green algae, bryozoa and nummulites (2.5%) (Pl.2A). These allochems are commonly recrystallized to sparry calcite crystals.

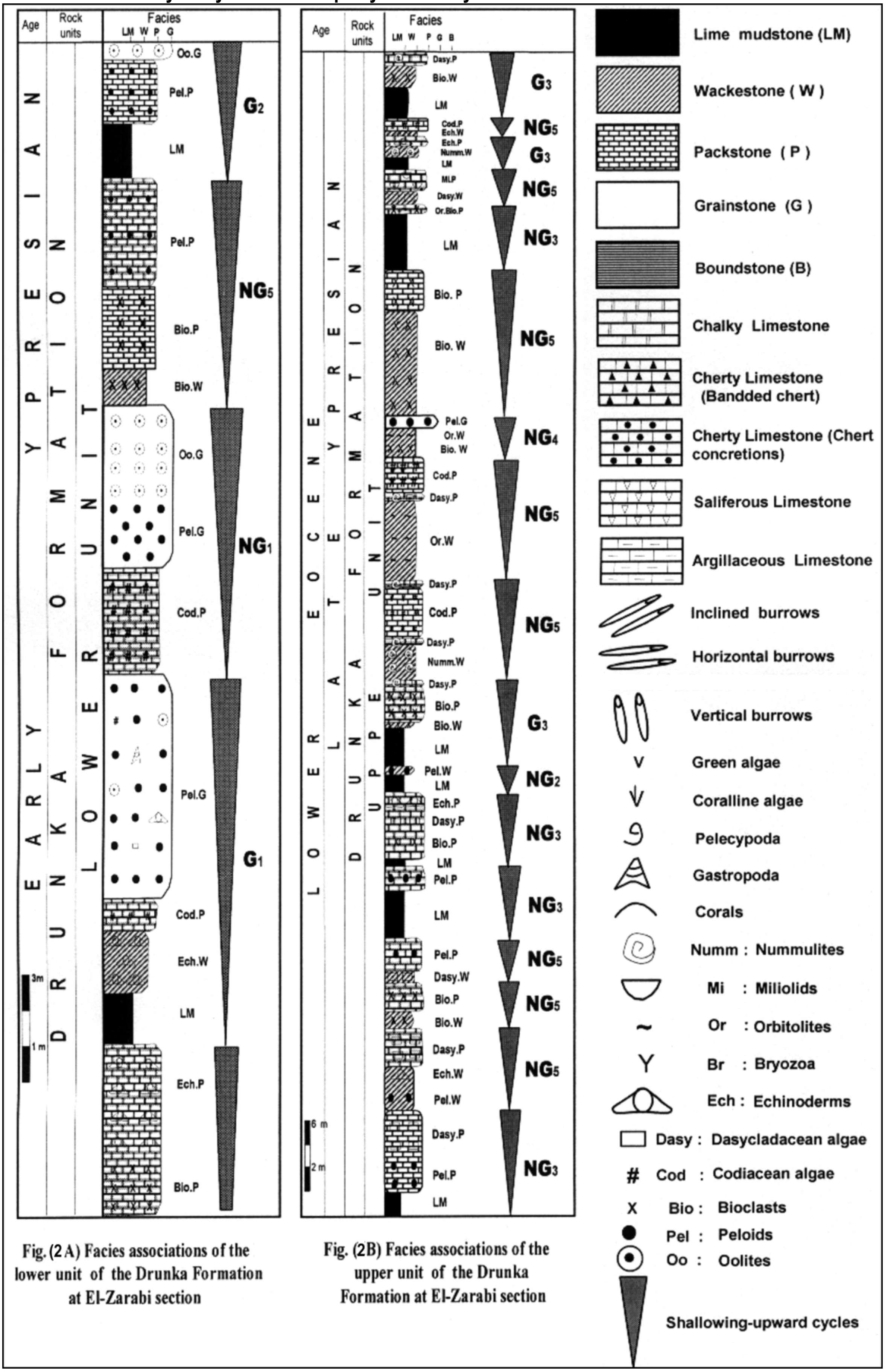


Fig. (2A) Facies associations of the lower unit of the Drunka Formation at El-Zarabi section

Fig. (2B) Facies associations of the upper unit of the Drunka Formation at El-Zarabi section

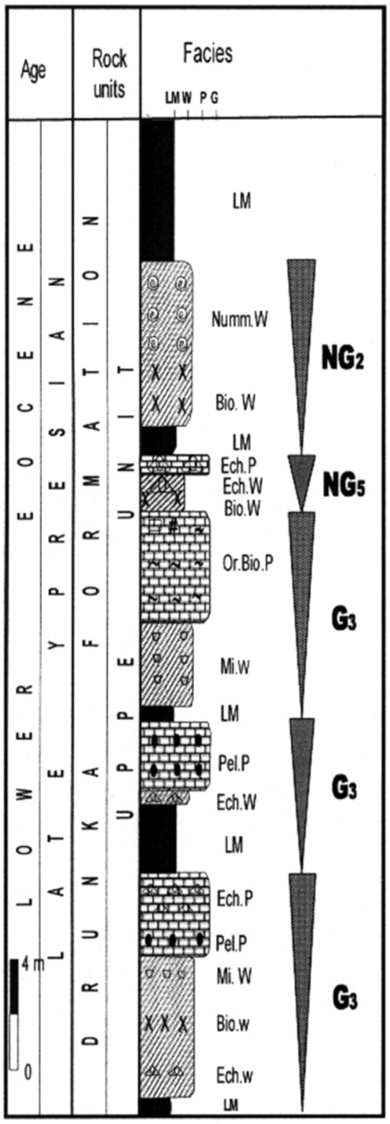


Fig. (3) Facies associations of the Lower Eocene rocks of the upper unit of the Drunka Formation at Ismail Bey section

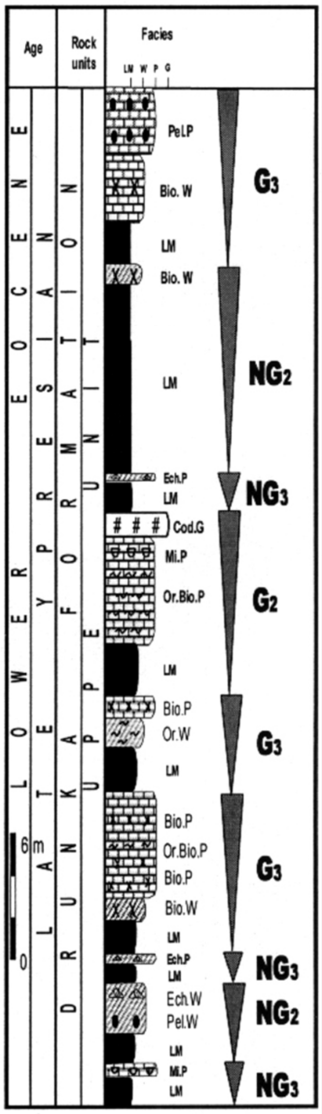


Fig. (4) Facies associations of the Lower Eocene rocks of the upper unit of the Drunka Formation at G.Gibeil section

Legend shown on Fig. 2A & 2B

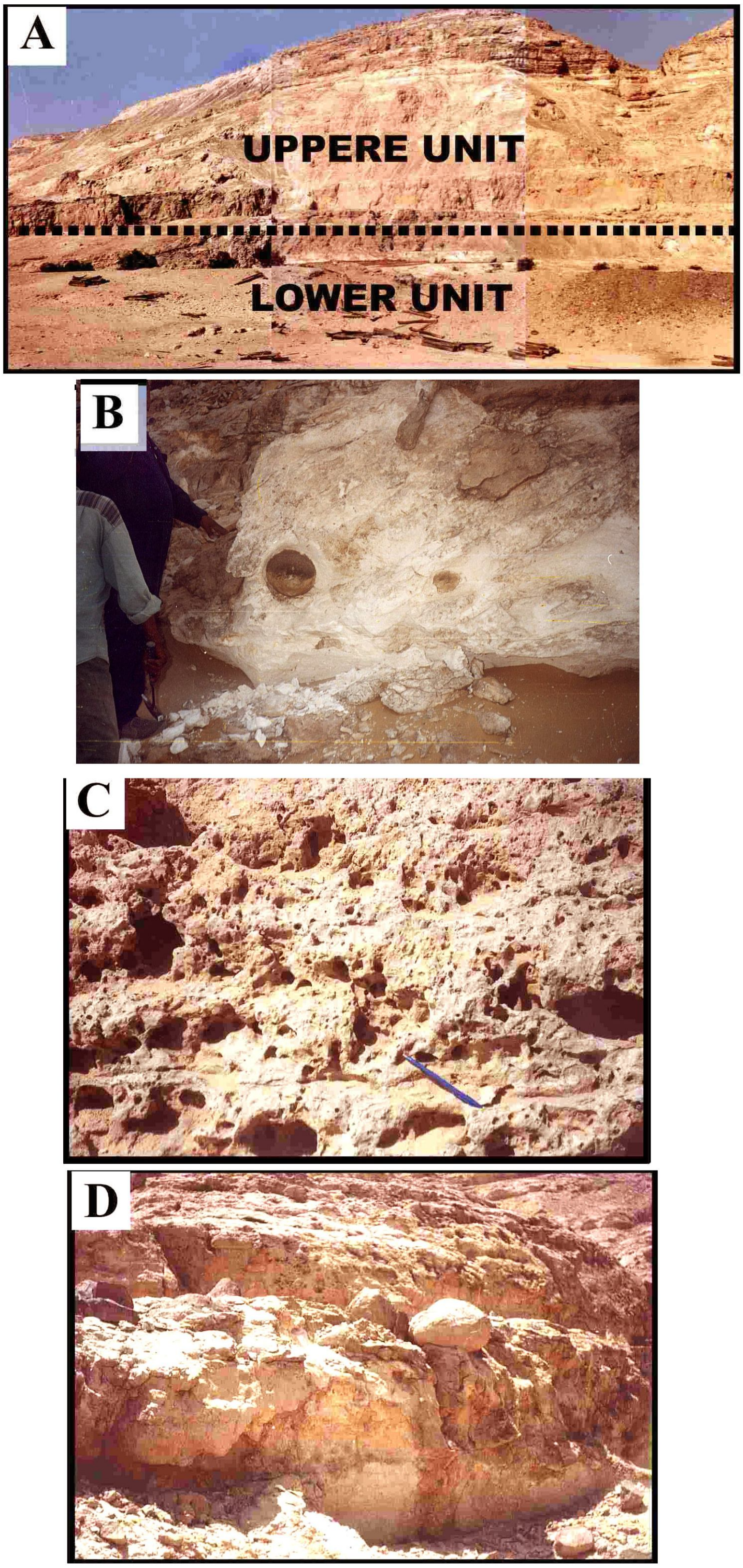
Wackestone microfacies associations:

The wackestone microfacies associations are mostly overly the lime mudstone microfacies in the emergence cycles. They occur in the middle part of this type of cycle but in some cases they form the lowermost part of the cycle. They are mainly overlain by the packstone or grainstone textures.

1. Bioclastic wackestone microfacies:

This microfacies is typified by the lithology of both the lower and upper units of the formation. In the lower unit, it is recorded in its upper part at El-Zarabi section with about 1 m thick at which it is composed of grey, hard, crystalline, massive and fossiliferous limestone (Fig.2A). This microfacies is also recorded in the upper unit of the Drunka Formation that exposed at El-Zarabi, Ismail Bey and Gebel Gibeil sections with a total thickness of about 27.25 m. At El-Zarabi section, it is recorded in several horizons from the lower to the upper part of the unit with a maximum thickness of about 5.5 m at its upper part (Fig.2B). At Ismail Bey section, it is recorded in three horizons attain a maximum thickness of about 3.5 m at the upper part of the section (Fig.3). The bioclastic wackestone microfacies is recorded in five horizons at the lower and upper parts of Gebel Gibeil

section with a thickness ranges from 0.5-1.5 m (Fig.4). The rock is white to greyish white, chalky and fossiliferous limestone.



<u>Plate 1:</u>

A. A panoramic view of the Drunka Formation (El-Zarabi section). The dashed line represents the contact between the two units of the Drunka Formation. B. Field photograph showing the chert nodules within the carbonate rocks of the upper unit of the Drunka Formation at Gebel Gibeil section. C. Field photograph showing the numerous pores (may be

due to burrowing) and the cavernous nature of the lower unit of the Drunka Formation at El-Zarabi section. D. Field photograph showing the yellowish grey, burrowed limestone with chert concretions of the lower unit of the Drunka Formation at El-Zarabi section.

The bioclastic wackestone of the Drunka Formation is formed of bioclasts (10-15%), miliolids (5%), dasycladacean algae (4%), codiacean algae (3-5%), pellets and coprolites (2.5-3.5%), reworked nummulites (up to 8%, only in the upper unit of the Drunka Formation), bryozoa (2%), micrite (40-60%) and neomorpohic spar replacing the matrix (up to 2.5%) (Pl.2B). The bioclasts of the lower unit of the Drunka Formation are chiefly composed of codiacean algal fragments (mainly *Ovulites* spp.), while those of the upper unit are mainly of echinodermal and foraminiferal fragments (nummulites and miliolids) and to less extent green algae.

2-Echinoidal wackestone microfacies:

In the lower unit, this microfacies is recorded in two successive beds at the lower part of El-Zarabi section with a thickness of about 0.75 m and 1 m respectively (Fig.2A). The rock is grey to white, very hard, massive, porous, cavernous and fossiliferous. In the upper unit of the Drunka Formation, this association occurs at the lower part (1 m) and upper part (0.5 m) of El-Zarabi section (Fig.2B). At Ismail Bey section, it has a maximum thickness of 0.75 m at its base (Fig.3). It is recorded at the lower part of the unit exposed at Gebel Gibeil section with about 1 m in thickness (Fig.4). The rock is represented by chalky, white and fossiliferous limestone. In thin section, the rock consists of echinoidal plates and spines (15-25%), bryozoa (6%), pelecypods (2.5%), nummulites (2%) and miliolids (0.5%). The fine to coarse sand-sized and moderately sorted echinodermal particles show preferred orientation and speckled appearance due to the effect of micritization process (Pl.2C).

3. Dasycladacean algae wackestone microfacies:

This microfacies is observed in the upper unit of the Drunka Formation. It constitutes two beds in the lower and upper parts of this unit at El-Zarabi section attaining a thickness of 0.5 and 1.5 m respectively (Fig.2B). Lithologically, the rock is formed of yellowish to greyish white, crystalline to argillaceous and burrowed limestones. In thin section, this microfacies is composed of dasycladacean green algae (20%), fecal peloids (5%), mollusca (2.5-5%), foraminifera (2-4% mainly miliolids and to less extent nummulites), bioclasts (2-5%, of green algae, foraminifera, echinoderms and bryozoa), micritized grains (1%), intraclasts (1%), coralline algae (1%) and ostracods (<1%). The dasycladacean algal content of the upper unit of the Drunka Formation is mainly represented by the *Niloporella subglobosa* Dragastan and Soliman (Pl.2D).

4. Nummulitic wackestone microfacies:

The nummulitic wackestone microfacies is only recorded in the upper unit of the Drunka Formation. Two beds at the middle and upper parts of El-Zarabi section represent this facies with a thickness of 3.5 and 1 m (Fig.2B). It also occurs at the topmost part of Ismail Bey section (2.5 m) where it is underlain by the bioclastic wackestone and overlain by the lime mudstone (Fig.3). The rock is white, chalky and fossiliferous.

In thin section, the rock is composed of nummulites (15-20%), bioclasts (8%), green algae (2.5%), foraminifera (2%, miliolids and benthonic forams) and bryozoa (1%). The nummulites of this microfacies belong mainly to the *Nummulites planulatus* (Lamarck), whichare mainly affected by the aggrading recrystallization process (Pl.2E).

5. Orbitolites wackestone microfacies:

This microfacies is only recorded in the upper unit of the Drunka Formation. It is recorded at the middle and upper parts of El-Zarabi section with a thickness of about 7 and 0.5 m respectively, where it overlies the dasycladacean algae packstone and the bioclastic wackestone and underlies the dasycladacean algae packstone and the peloidal grainstone (Fig.2B). In the middle part of Gebel Gibeil section, its thickness is about 1.5 m and overlies the lime mudstone and underlies the bioclastic packstone (Fig.4). The rock is usually white, chalky, hard and fossiliferous. This microfacies is comoposed of poorly preserved orbitolinid particles embedded in a micrite matrix. The allochems are represented by orbitiolites (10-12.5%), miliolids and benthonic forams (2%), molllusca (2.5-4%, mainly bivalvia), echinoderms (2.5%, mainly echinoid plates which exhibit a syntaxial overgrowth), micritized grains (5%), ostracoda (up to 1%) and green algae (up to 1%) (Pl.2F).

6. Peloidal wackestone microfacies:

This microfacies is confined to the lower part of the upper unit of the Drunka Formation that outcrops at El-Zarabi section. It is recorded in two horizons each measures an average thickness of about 80 cm (Fig.2B). Also, this association is recorded in two horizons at the lower and uppermost parts of the upper unit of the Drunka Formation at Gebel Gibeil (Fig.4) with a total thickness of about 3.5 m. Rock of this microfacies is greyish to rosy white, chalky, argillaceous and shows thin-lamination in the lower bed. The rock consists of fine-grained micrite with peloidal micritized grains and/or fecal pellets (mainly coprolites) (15%), echinoids (3%, plates and spines), green algae (2.5-5%), foraminifera (1-3%) and skeletal debris (2%) (Pl.3A).

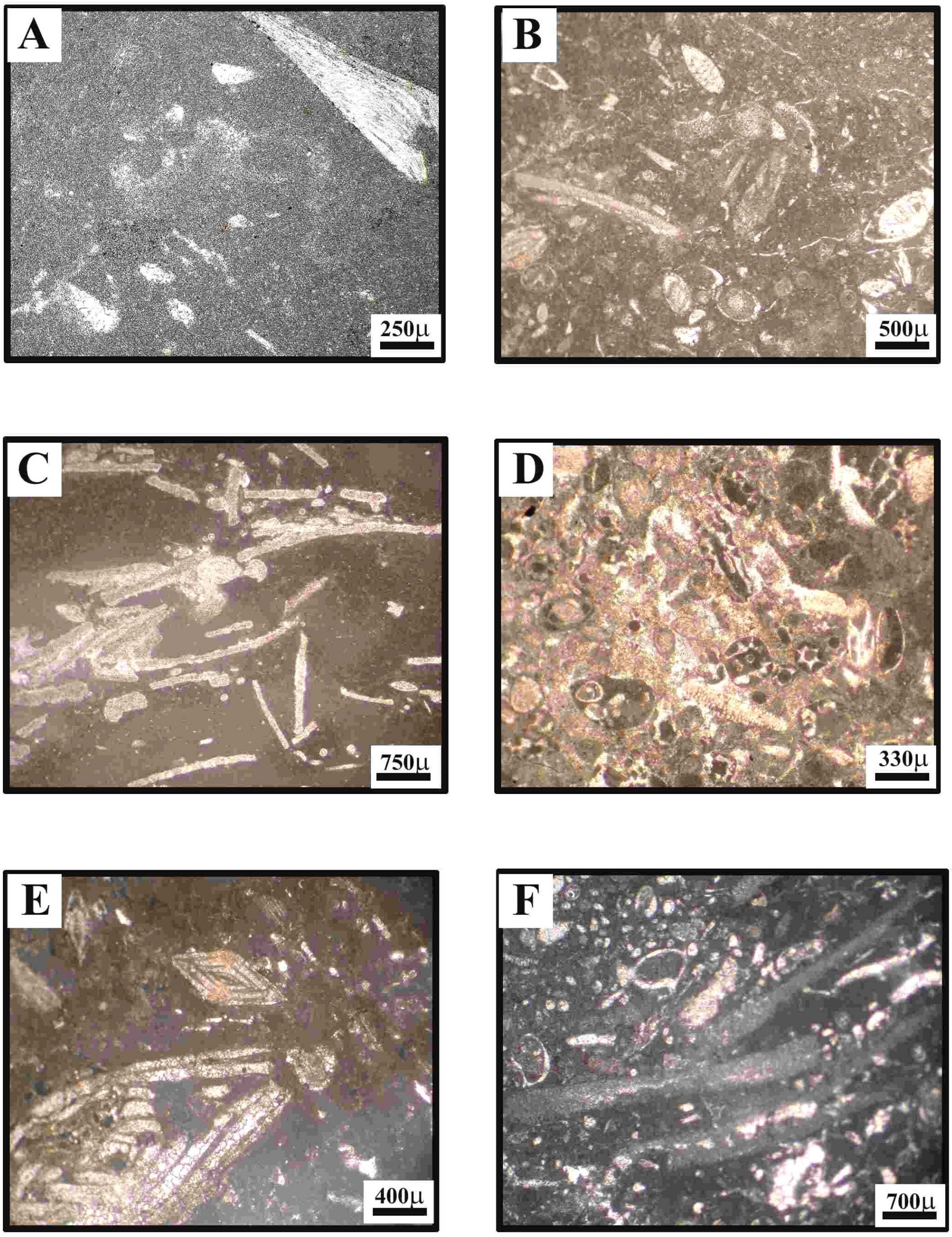


Plate 2:

A. Photomicrograph showing the lime mudstone microfacies. Notice: the pelecypod fragment at the upper right hand part of the photo and the other bioclasts. Lower unit, Drunka Formation, El-Zarabi section. O.L. B. Photomicrograph showing the bioclastic wackestone with skeletal debris of echinoderms, nummulites, molluscs and codiacean green algae embedded in a micrite matrix. Upper unit, Drunka Formation, El-Zarabi section. O.L. C. Photomicrograph showing the echinoidal wackestone consists of echinoid plates showing parallel orientation in lime mud. Notice: the syntaxial calcite overgrowth around the echinoid plates. Lower unit, Drunka Formation, El-Zarabi section. O.L. D. Photomicrograph showing the dasycladacean algae wackestone. The particles are composed of *Niloporella subglobosa*,

nummulites and bioclasts of the echinodermal grains embedded in a micrite matrix. Upper unit, Drunka Formation, El-Zarabi section. O.L.
E. Photomicrograph showing the nummulitic wackestone. The allochems are formed of nummulites (*N. planulatus* (Lamarck)), echinoderms and skeletal debris embedded in a micrite matrix. Notice: the recrystallization masking the internal structure of the nummulitic grain at the lower left part of the photo. Upper unit, Drunka Formation, El-Zarabi section. O.L. F. Photomicrograph of the orbitolites wackestone. The framework is composed of badly preserved orbitolites and bioclasts embedded in a lime mud matrix. Upper unit, Drunka Formation, Gebel Gibeil section. O.L.

7. Miliolidae wackestone microfacies:

This microfacies is observed in the upper unit of the Drunka Formation exposed at Ismail Bey section attaining a thickness of 4.7 m (Fig.3). It is underlain by the bioclastic wackestone and the lime mudstone and overlain by the peloidal packstone and the orbitolites bioclastic packstone microfacies. The rock is yellowish white, hard, crystalline, burrowed and thin laminated. Under the microscope, this association is composed mainly of miliolids (up to 20%) in addition to shell fragments (up to 7%) embedded in a microcrystalline calcite matrix, which is partially recrystallized to neomorphic sparry calcite (Pl.3B).

Packstone microfacies associations:

Packstone microfacies mostly represents the cap of the emergence cycles. It usually overlies the wackestone microfacies but it sometimes overlies the lime mudstone microfacies in the non-gradual emergence cycles. It is also overlain by the grainstone microfacies.

1. Bioclastic packstone microfacies:

This microfacies is represented by three beds at the basal and upper parts of the lower unit of the Drunka Formation at El-Zarabi section with a total thickness of 4.25 m (Fig. 2A). It increases in thickness up to 16 m in the upper unit of the Drunka Formation at both El-Zarabi (Fig.2B) and Gebel Gibeil sections (Fig.4).

These rocks are grain-supported in which the debris of skeletal particles is the most predominant components. It is composed of bioclasts (30-50%), peloids (12%), nummulites (5%), codiacean green algae (2.5-7%), miliolids (2.5-4%), dasycladacean green algae (2.5%), bryozoa (2.5%), coralline algae (2%) and ostracods (<1%)(Pl.3C).

2. Codiacean algae packstone microfacies:

This microfacies is encountered in two beds at the lower (1 m) and middle (3 m) parts of the lower unit of the Drunka Formation (Fig.2A) and by three beds at the middle and topmost parts of the upper unit of the Drunka Formation at El-Zarabi section with a total thickness of 13 m (Fig.2B). The rock in the lower unit is yellowish grey, hard, compact, highly fossiliferous and burrowed, while that of the upper unit is formed of yellowish to greyish white limestone, chalky, hard, massive, burrowed, fossiliferous and contains chert bands in the upper bed. The rock consists of microcrystalline calcite with codiacean algae (50-60%, mainly of *Ovulites* spp. and *Halimeda* spp.), miliolids (5-7.5%), echinoids (2.5-3.5%), peloids (3%), nummulites (2.5%, only in the rocks of the upper unit), molluscs (2%) and intraclasts (1%) (Pl.3D).

3. Peloidal packstone microfacies:

This microfacies is repeated in several horizons throughout the Drunka Formation at El-Zarabi section with a total thickness of about 17.75 m (Fig.2A&B). The rock is formed of whitish grey to white, crystalline and burrowed limestone with chert bands and concretions. It is also recorded in two beds at the lower and middle parts of the upper unit of the Drunka Formation at Ismail Bey section measuring a thickness of 1 and 2.5 m from base and above (Fig.3).Also, this associatios is recorded in the topmost part of Gebel Gibeil section with a total thickness of about 3.5m (Fig.4). In thin section, the peloids (micritized grains, fecal peloids and coprolites) are the most abundant allochemical grains where they form about 30-40% of the rock. Other components are noticed e.g. miliolids (5%), orbitolites (2-4%), molluscs (3%), calcareous algae (2%, both the green and red ones) and echinoderms (1%, echinoidal plates and spines sometimes show syntaxial overgrowth) (Pl.3E).

4. Echinoidal packstone microfacies:

This microfacies is recorded inthe basal part of the lower unit at El-Zarabi section with an average thickness of 3 m (Fig.2A). Moreover, it occurs in six horizons in the upper unit of the Drunka Formation (two beds at El-Zarabi section (Fig.2B), two beds at Ismail Bey section (Fig.3) and two beds at Gebel Gibeil section

(Fig.4) with a total thickness of 5.5 m. Lithologically, the echinoidal packstone is usually white to reddish grey, argillaceous and burrowed with chert bands and concretions at Gebel Gibeil section and with chert concretions at Ismail Bey section. Petrographically, this microfacies consists of a fine-grained micritic matrix with echinodermal fragments (50-58%), foraminifera (4%), green algae (4%), micritized grains (3%), recrystallized bivlavia (2%) and bryozoa (2%) (Pl.3F).

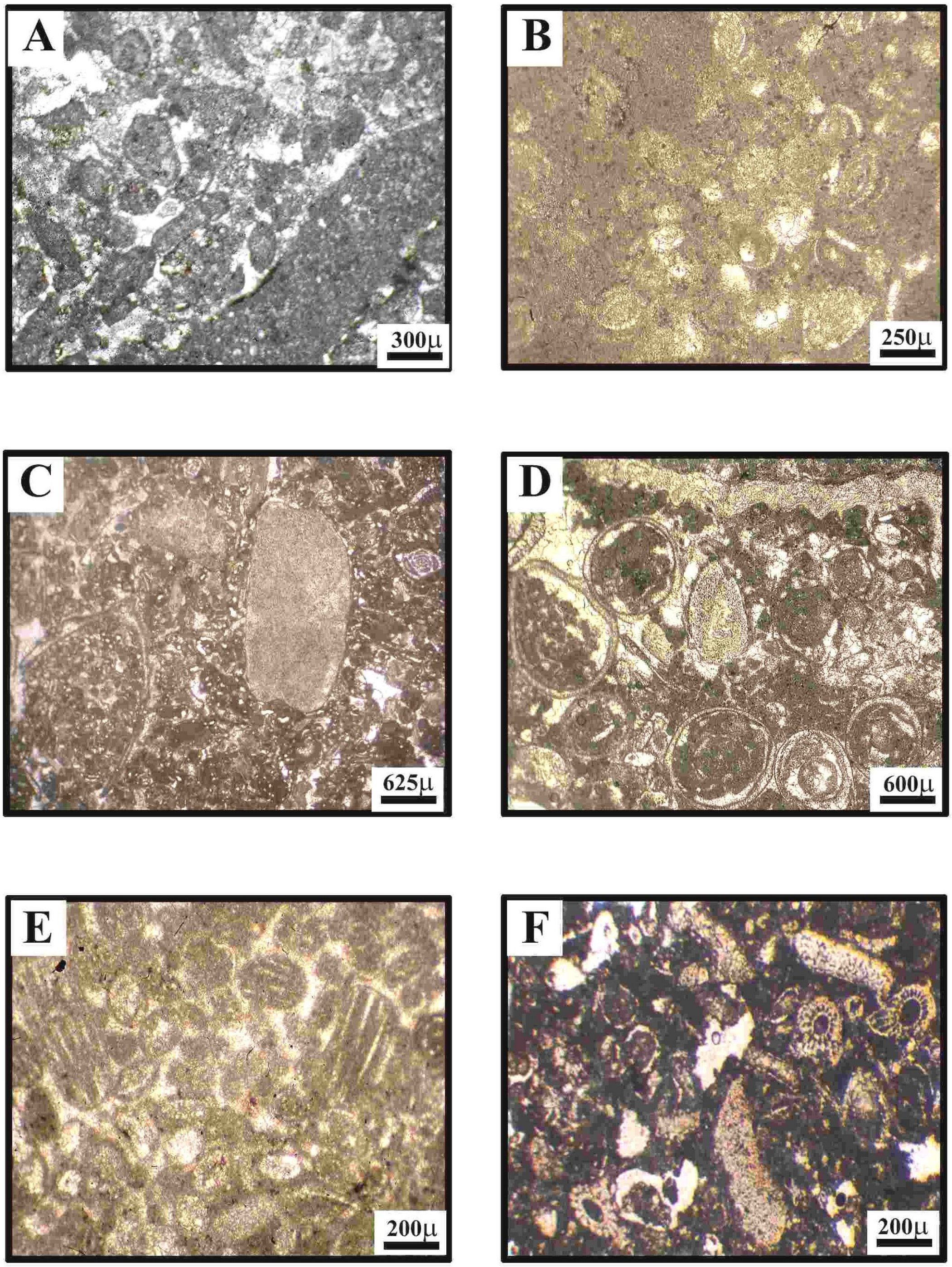


Plate 3:

A. Photomicrograph showing the peloidal (micritized grains) wackestone. The rock is formed mainly of completely micritized grains embedded in a recrystallized micrite. Upper unit, Drunka Formation, Gebel Gibeil section. O.L. B. Photomicrograph of the miliolidae wackestone. The main components are miliolids (mainly *Quinquelculina* sp.) embedded in a micrite matrix. Notice: The miliolidae grains are exposed to intense micritization. Upper unit, Drunka Formation, Ismail Bey section. O.L. C. Photomicrograph showing the bioclastic packstone microfacies, in which the

shell debris are composed mainly of echinodermal, algal, foraminiferal fragments and micritized grains embedded in a lime mud matrix. Upper unit, Drunka Formation, Middle part of El-Zarabi section. O.L. D. Photomicrograph of the codiacean algae packstone. The main framework is formed of codiacean green algae (*Ovulites arabica* (Pfender)), peloids and micritized bioclast of bivalvia embedded in a recrystallized matrix. Upper unit, Drunka Formation, El-Zarabi section. O.L. E. Photomicrograph showing the peloidal packstone microfacies. The framework is composed of well-sorted and closely packed coprolites in a recrystallized micrite matrix. Upper unit, Drunka Formation, El-Zarabi section. O.L. F. Photomicrograph of the echinoidal packstone microfacies, in which the echinoidal plates and spines are tightly packed in a micrite matrix. Upper unit, Drunka Formation, El-Zarabi section. O.L.

5. Dasycladacean algae packstone microfacies:

The dasycladacean algae packstone microfacies is observed in four beds at the lower, middle and upper parts of the upper unit of the Drunka Formation at El-Zarabi section with a thickness ranges from 0.5-3.5 m (Fig.2B). The rock is white to whitish grey, cherty, thin-laminated, hard, burrowed, algal and highly fossiliferous.

In thin section, the rock is composed of grain-supported texture with skeletal particles reaching up to 90% embedded in a micritic matrix. The main constituents are the dasycladacean green algae (30-40%) mainly represented by the *Niloporella subglobosa* Dragastan and Soliman, bioclasts (12%), echinodermal plates and spines (10%), recrysallized fecal pellets (10%), codiacean green algae (8%), foraminifera (5%), micritized grains (4%) and bryozoa (1%) (Pl.4A).

6. Orbitolites bioclastic packstone microfacies:

In the upper unit of the Drunka Formation, this microfacies is recorded in three beds; one at the upper part of El-Zarabi section with 1 m thickness (Fig.2B), one bed at the middle part of Ismail Bey section measuring 4 m in thickness (Fig.3) and two beds at the lower part of Gebel Gibeil section attaining a thickness of 1.5 m and 3.5 m respectively (Fig.4). This microfacies is composed of bioclasts (30%) mainly of foraminiferal, echinodermal and molluscan fragments, orbitolites (25-30%), green algae (4-8%), miliolids (2.5-5%), nummulites (2.5%), micritized grains (2.5-8%), mollusca (5%), echinoids (2.5%) and fecal peloids (1%) (Pl.4B).

7. Miliolidae packstone microfacies:

This microfacies occurs in the upper unit of the Drunka Formation at the upper part of El-Zarabi section (Fig.2B) with an average thickness of 1.75 m. It overlies the dasycladacean green algae wackestone and underlies the lime mudstone microfacies. Also, it is recorded in two beds in the lower part of Gebel Gibeil section with a thickness of 0.5 and 1.5 m (Fig.4). The rock is white to yellowish white, massive, compact and burrowed. In thin section, this microfacies is made up of miliolidae grains (20-25%), fossil algae (8%), bioclasts (8%), nummulites (7.5%), micritized grains (6%) and intraclasts (1%) embedded in microcrystalline calcite crystals forming the matrix (Pl.4C).

Grainstone microfacies associations:

The grainstone microfacies usually represents a cap of both gradual and non-gradual emergence cycles. They are overlying the packstone and wackestone microfacies respectively.

1. Peloidal grainstone microfacies:

The peloidal grainstone is considered as one of the most distinct microfacies of the lower unit of the Drunka Foramtion. It is repeated in several horizons vertically throughout the lower unit at El-Zarabi section with a total thickness of about 9 m (about 26% of the total thickness of this unit) (Fig.2A). It also occurs as one bed in the upper part of the upper unit at El-Zarabi section with a thickness of about 0.5 m (Fig2B). The rock is grey, cavernous, massive, very hard, burrowed and contains some chert concretions. Petrographically, the rock consists of non-skeletal particles (75%), skeletal grains (9%) and sparry calcite cement (16%). The fecal peloids (coprolites) represent the most abundant non-skeletal particles. They range in size from medium to coarse-grained and are micritized with rod-like (longitudinal sections) or reticulate (transverse sections) sparitic internal structure (Pl.4D). Generally, peloids are moderately sorted, well rounded and are represented mainly by the *Favreina* sp. The other non-skeletal particles are represented by the superficial oolites (5%).

2. Siliceous oolitic grainstone microfacies:

This microfacies is recorded in two beds at the middle and uppermost parts of the lower unit of the Drunka Formation where it represents a cap of the emergence (shallowing-upward) cycles. It is recorded from El-Zarabi section with an average thickness of 2.25 and 0.5 m respectively (Fig.2A). The rock is grey, porous, cavernous and hard.

The rock is composed of allochemical constituents embedded in sparry calcitic cement. The general feature of this microfacies is that most of allochems are well rounded with micrite rinds. The most important allochemcial grains are oolites (65%), green algae (10%) and fecal peloids (2.5%) (Pl.4E). The ooids are well sorted and are mostly of the superficial type, however very few amount of these ooids are of the composite type. The nuclei of both types of ooids are mainly composed of fecal peloids. The green algae are the second in abundance. They are formed of *Ovulites arabica* and *Ovulites pyriformis* and their bioclasts beside the

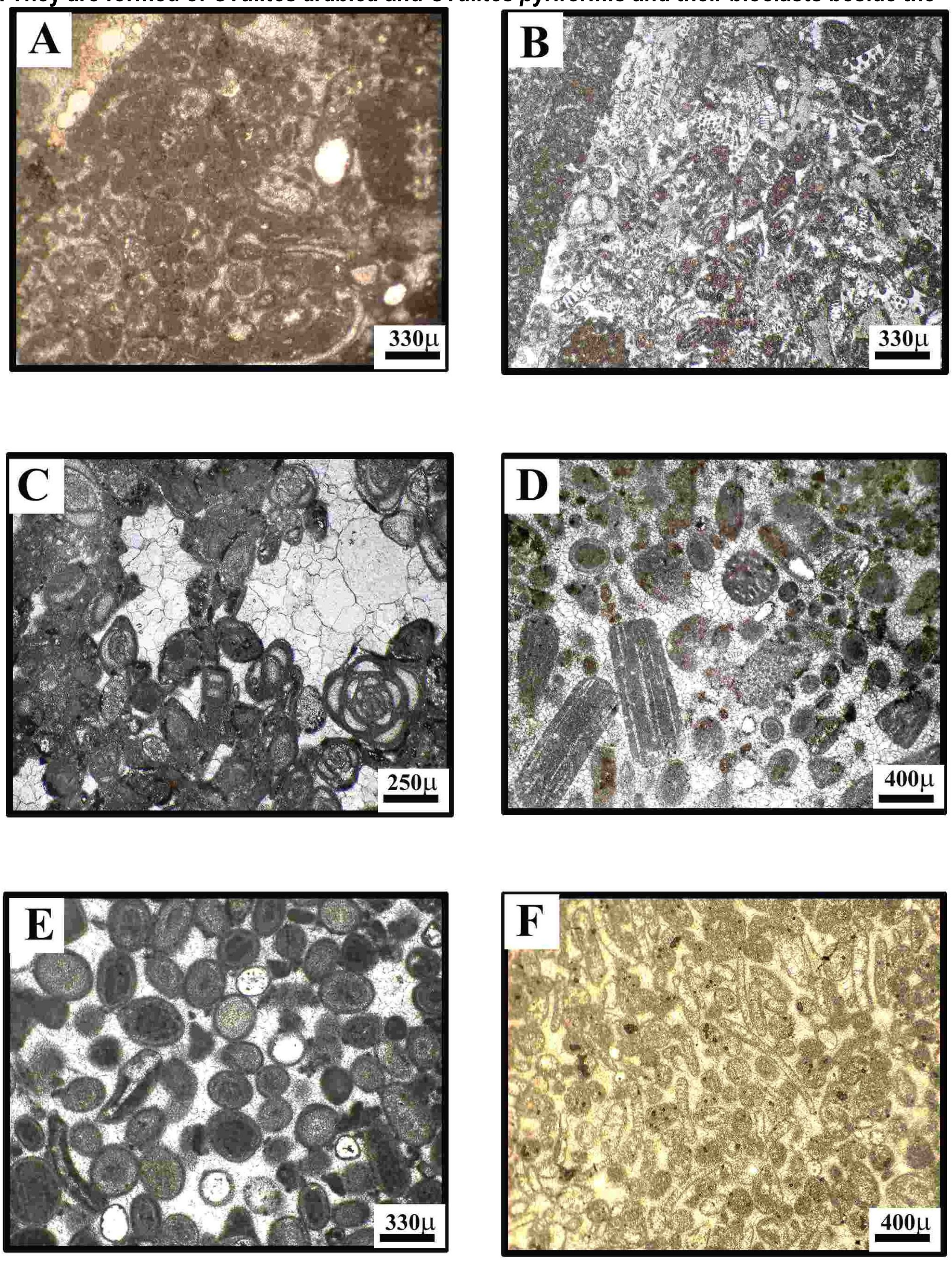


Plate 4:

A. Photomicrograph showing the dasycladacean green algae packstone microfacies. The main components are *Niloporella subglobosa* and micritized grains embedded in a micrite matrix. Upper unit, Drunka Formation, El-Zarabi section. O.L. B. Photomicrograph of the packed orbitolites bioclastic packstone. The main particles are the orbitolites and bioclasts of green algae (codiacean and dasycladacean types) embedded in a micrite matrix, which is influenced by the silicification process. Upper unit, Drunka Formation, Ismail Bey section. O.L. C. Photomicrograph of the miliolidae packstone. The components are mainly formed of miliolids cemented by micritic matrix. Notice: the micritic matrix is influenced by the aggrading neomorphism process. Upper Unit, Drunka Formation, Gebel Gibeil section. O.L. D. Photomicrograph showing the well-washed peloidal grainstone. The allochems are formed of coprolites (*Favreina* sp.) and superficial oolites with nuclei composed of fecal peloids. The cement between the grains is sparry calcite crystals. Lower unit, Drunka Formation, El-Zarabi section. O.L. E. Photomicrograph showing the normally packed oolitic grainstone. The allochems are formed of superficial ooids embedded in sparitic cement. The rock is influenced by silicification. Lower unit, Drunka Formation, El-Zarabi section. O.L. F. Photomicrograph of the codiacean algae grainstone. The rock is composed of fragments of *Ovulites* grains cemented by sparry calcitic cement. Upper unit, Drunka Formation, El-Zarabi section. O.L.

Niloporella subglobosa that are encircled by micritic envelops. The fecal pellets and coprolites represent the fecal peloids. The silicification that affects both the calcite cement and the oolitic grains is the main diagenetic feature.

3. Codiacean algae grainstone:

This association is recorded only in one bed at the middle part of the upper unit of the Drunka Formation at Gebel Gibeil section with an average thickness of 1 m (Fig.4). It is underlain by the miliolid packstone and is overlain by the lime mudstone. Rocks belonging to this microfacies are white, hard, massive and crystalline with chert concretions.

Petrographically, this microfacies is composed of codiacean green algae (50%), micritized grains (10%), foraminifera (2.5%), bryozoa (1%) and ostracoda (1%) embedded in an equant sparry calcite cement (Pl.4F). The codiacean algal grains are formed mainly of *Ovulites* spp. and *Halimeda* spp. The *Ovulites* occur as fragments with recrystallized internal structure. The foraminifera are recorded here as nummulites and miliolids. The neomorphic processes are the main diagenetic features that are observed in this microfacies.

DEPOSITIONAL CYCLES

According to the petrographic analysis of each bed within the cycle supported by the field observation, one mode of deposition is suggested to interpret the depositional mechanism of the sedimentary cycles of the studied rock units. This is the emergence (regressive) cycles of pure carbonates which represent a shallowing-upward sequence. These cycles correspond to Wilson's (1975) "asymmetric shoaling upward shelf cycles". In general, it is suggested that these cycles are formed by the eustatic sea-level fluctuations between the deep subtidal to shallow subtidal depths.

Generally the recorded emergence cycles begin with subsidence during which the deep subtidal facies is deposited and thus most of the sediments are of the mud-supported nature (lime mudstone or wackestone). Under the effect of the uplifting and / or the lowering of the sea level, these cycles are topped by the coarse-grained shallow subtidal (grain-supported) deposits (packstone or grainstone).

On the basis of the relation of cycles with the sea-level changes, the sedimentary cycles were classified by Khalifa (1996) into gradual and non-gradual cycles. The term "gradual cycles" is equivalent to the term "complete cycles" of Grotzinger (1986) which is used to denote the gradual transition from one environment to another, either shallowing or deepening upward without an abrupt change in facies. The non-gradual cycles were termed as condensed cycles by Grotzinger (1986). Khalifa (1996) used the term "non-gradual" cycles to describe those cycles that are reduced in number of beds as compared with the gradual cycles (e.g. the cycle can begin with deep subtidal facies and ends with supratidal facies without passing through the intertidal facies in between.

In the present work, the facies arrangement within a cycle in relation to the oscillation of the sea level can be represented by the terms "gradual" and "non-gradual" cycles of Khalifa (1996).

1. Gradual cycles:

The gradual emergence cycles are generally reflecting a balance between the rate of sea-level fall, subsidence rate and sedimentation rate (Grotzinger, 1986). They mark the gradual transition from one subenvironment to another without abrupt change from deep to shallow facies (Khalifa, 1996). Three types of gradual cycles are recorded in the Lower Eocene rocks of the Drunka Formation.

The first type of the gradual cycles (G1) is only recorded from the lower unit of the Drunka Formation at El-Zarabi section. It exhibits a thickness of about 10.75 m. It comprises four microfacies associations that indicate the change in the subenvironment vertically (Fig.5A). The cycle from base to top consists of: (1) Lime mudstone (1.5 m). (2) Echinoidal wackestone (1.75 m). (3) Codiacean algae packstone (1 m). (4) Peloidal grainstone (6.5 m). The facies numbers (1) and (2) indicates deep subtidal facies, while that of numbers (3) and (4) represents shallow subtidal facies.

The second type of gradual cycles (G2) is composed of deep subtidal facies at the base (lime mudstone) and ends with shallower subtidal facies (packstones and grainstones). It is represented here by one cycle in the rocks of the lower unit of the Drunka Formation at El-Zarabi section. measures about 4 m in thickness (Fig.5B). The basal part of this cycle is composed of dark grey lime mudstone (1.5 m) representing the deep subtidal facies grades upward into well-sorted peloidal packstone (2 m). The cap of this cycle is represented by the oolitic grainstone facies (0.5 m), which is composed mainly of cleanly washed, well-sorted and well-rounded oolites representing the shallowest facies of this cycle (shoaling accreting during regressive phase off the shelves). Also, this type is represented by one one cycle in the middle part of the upper unit of the Drunka Formation at G.Gibeil section, where the cycle begins with lime mudstone (2.5 m) and ends with codiacean algae grainstone (1 m) passing through the orbitolites bioclastic packstone (3.5 m) and miliolidae packstone (1.5 m). As the thickness of the cap of these cycles is thinner than its base, we can deduce that the sedimentation rate is high relative to the submergence rate that causes the deposition of thicker lime mudstone at the base and thinner oolitic grainstone at the top of the cycle.

The third type (G3) is only recorded in the rocks of the upper unit of the Drunka Formation. It comprises the deep subtidal facies (lime mudstone at the base overlain by the wackestones) and capped by the shallow subtidal facies (packstones). At El-Zarabi section, this type is represented by two gradual cycles begin with lime mudstone (1 m and 3.5 m), overlain by bioclastic and nummulitic wackestone (0.5 m and 1 m) and capped by dasycladacean algae and echinoidal packstone (0.5 m and 1 m) (Fig.5C). At Ismail Bey section, this type of cycle is composed of lime mudstone at the base overlain by bioclastic, echinoidal or miliolidae wackestones and capped by peloidal, echinoidal or orbitolites bioclastic packstones (Fig.5D). At Gebel Gibeil section, this type of gradual cycle is represented by three cycles. The first begins with lime mudstone (1.5 m) and capped by bioclastic packstone (2 m) passing through the bioclastic wackstone (1 m). The second cyclebegins with lime mudstone (2 m), overlain by orbitolites wacksetone (1.5 m) and ends by bioclastic packstone (1 m). The total thickness of the third cycle is about 6.5 m, it begins with lime mudstone (2 m), overlain by about 3 m of bioclastic wackestone, which are representing the deep subtidal facies. This cycle is capped by 1.5 m of peloidal packstone (Fig.5E).

2. Non-gradual cycles:

The origin of the non-gradual cycles was generally owed by Grotzinger (1986) to be occurred in cases of which the sedimentation rate is low relative to the rate of the sea-level fall and this results in omission of facies from cycles due to the receding of the sea faster than sediment supply. Khalifa (1996) revealed that the presence of the non-gradual emergence cycles indicates that there is no regular relationship between the subsidence rate and the sedimentation rate. Five types of non-gradual cycles are encountered in the Lower Eocene Drunka Formation of the studied area.

The first type (NG1) is composed of two facies (packstone at the base and grainstone at the top) representing the shallow subtidal facies with absence of the deep subtidal facies (lime mudstone or wackestone). This cycle is recorded at the middle part of the lower unit of the Drunka Formation at El-Zarabi section where it begins with codiacean algae packstone (3 m) at the base, overlain by peloidal grainstone (2.5 m) and capped by oolitic grainstone (2.25 m) which are representing the shallow subtidal facies (Fig.6A). The origin of this cycle is attributed to the eustatic sea-level fall without any marks of subsidence. In this cycle, it is noticed that there is a complete absence of the lime mudstone or wackestone textures that representing the deeper subtidal facies, thus this cycle is described as "non-gradual" cycle as suggested by Khalifa (1996). The origin of this cycle is suggested by Grotzinger (1986) who stated that this cycle occurs where the sedimentation rate is low relative to the rate of sea-level fall. This may lead to the omission of the basal lime mudstone or wackestone forming the base of the cycle. Similar non-gradual cycles were described from the Middle Triassic of both Egypt and Saudi Arabia (Khalifa, 1996 and Abu El-Ghar, 1997).

The second type of non-gradual cycles (NG2) is observed only in the upper unit of the Drunka Formation exposed at El-Zarabi, Ismail Bey and Gebel Gibeil sections. It consists only of deep subtidal facies (lime mudstone at the base and wackestone at the top) with absence of the shallow subtidal facies (packstone or grainstone). At El-Zarabi section, this type is represented by one cycle at the middle part of the unit. It begins with 1.75 m of lime mudstone and capped by about 0.5 m of peloidal wackestone representing the deep subtidal facies (Fig.6B). At Ismail Bey section, this cycle is recorded at the upper part of the section where it is composed of thin lime mudstone (1 m) and thick bioclastic and nummulitic wackestone (6 m) (Fig.6C). At Gebel Gibeil section, this cycle is observed at the lower and upper parts of the upper unit of the Drunka Formation. The lower cycle (4.5 m) begins with lime mudstone and capped by echinoidal wackestone. The upper cycle exhibits a total thickness of about 3.5 m. It consists of lime mudstone (2.5 m) at the base and topped by bioclastic wackestone (1 m) (Fig.6D). The absence of the packstone or grainstone in this cycle is owing to the increasing rate of the sea-level fall with no sediment supply that leads to the non-deposition of the upper beds (caps) representing the shallower subtidal facies (packstones and grainstones). This indicates that the rocks of this cycle were affected by submergence for long period without any fall in the sea level.

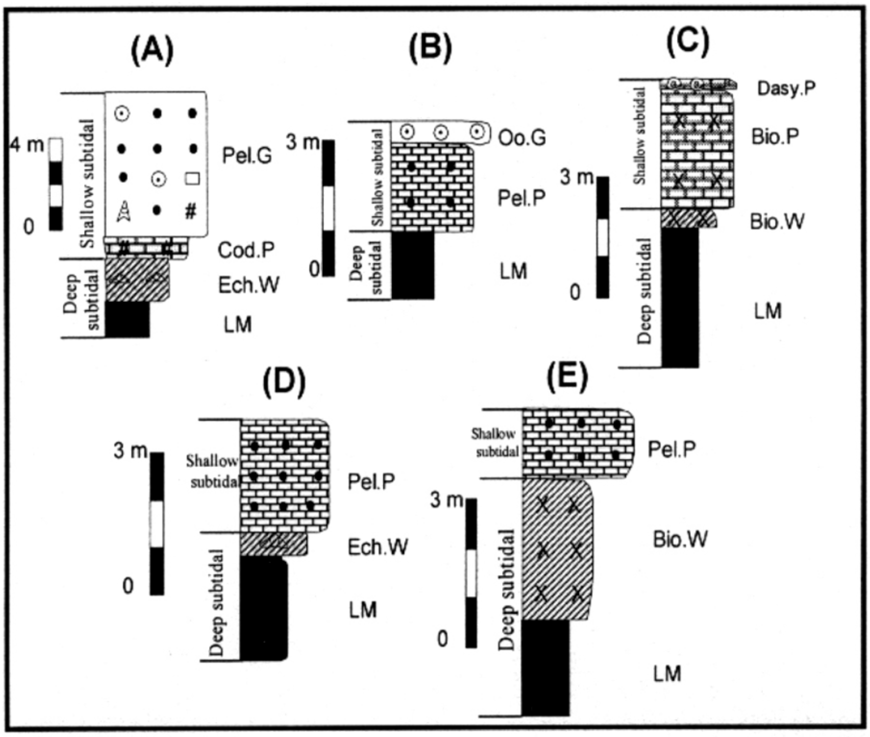


Fig.(5) Showing the different types of the gradual emergence cycles of the Drunka Formation

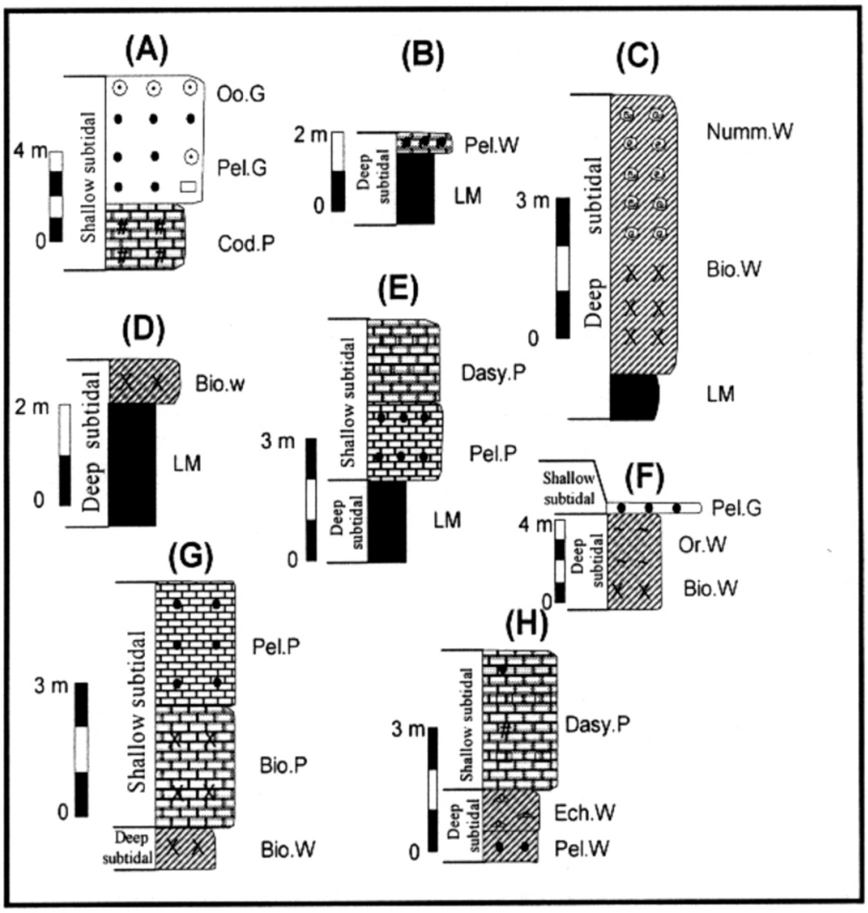


Fig.(6) Showing the different types of the non-gradual emergence cycles of the Drunka Formation

The third type (NG3) is confined to the upper part of the Drunka Formation outcropping at El-Zarabi and G.Gibeil sections. It commences the deep subtidal facies (lime mudstone) at the base, followed by the shallow subtidal packstone. Four cycles were recorded from El-Zarabi section. They begin with the lime mudstone (0.5 m to 5 m) and end with packstone texture (1 m to 6 m). The packstone here is represented by peloidal packstone, dasycladacean algae packstone, bioclastic packstone, echinoidal packstone and orbitolites bioclastic packstone (e.g. Fig.6E). Three cycles were identified from the lower and upper parts of G.Gibeil section. They begin with the lime mudstone and capped by miliolidae and echinoidal packstones.

The fourth type of the non-gradual cycles (NG4) is represented only by one depositional cycle (3.25m) at the upper part of the Drunka Formation exposed at El-Zarabi section. It begins with bioclastic wackestone (2.25 m), orbitolites wackestone (0.5 m) representing the deeper subtidal facies and capped by 0.5 m of peloidal grainstone representing the shallower subtidal facies (Fig.6F).

The fifth type is the most common type (NG5). It commences with the wackestone textures and topped by the packstone texture. In the lower unit of the Drunka Formation, this type is composed of one with a total thickness of about 6.5 m. It commences with bioclastic wackestone (1 m) and ends with peloidal packstone passing through the bioclastic packstone (2.25 m) (Fig.6G). At El-Zarabi section, the upper unit of the Drunka Formation exhibits eight cycles commences with wackestone (0.5 m to 7 m) and capped by packstone (0.5 m to 5 m). The wackestone texture of these cycles is represented by peloidal wackestone, echiniodal wackestone, bioclastic wackestone, dasycladacean algae wackestone, nummulitic wackestone and orbitolites wackestone, while the packstone capping these cycles are dasycladacean algae packstone, bioclastic packstone, peloidal packstone, dasycladacean algae packstone, codiacean algae packstone, and miliolidae packstone (e.g. Fig.6H). At Ismail Bey section, this type is represented by one cycle. It begins with bioclastic and echinoidal wackestones (1.5 m) and ends with bioclastic packstone (0.5 m).

3. Mechanism of cyclicity and discussion:

The mechanism responsible for the development of the above described cycles (meter-scale shallowing-upward gradual and non-gradual cycles) was discussed by many workers (e.g. Ginsburg, 1971; Wilkinson, 1982; James, 1984; Cisne, 1986; Grotzinger, 1986; Hardie and Shinn, 1986; Wright, 1986; Koerschner and Read, 1989; Algeo and Wilkinson, 1988; El-Rick and Read, 1991, Osleger, 1991; Osleger and Read, 1991; Satterley, 1996 a&b and Khalifa, 1996). The most important postulations are the Milankovitch orbital forcing theory, autocyclic and allocyclic mechanisms.

The allocyclic mechanism has an extrinsic control depending upon the forcing effect of external factors such as changes in sea level caused by intrabasinal tectonic activity (episodic subsidence and / or faulting) and eustatic sea-level changes (Goldhammer and Elmore, 1984; Goodwin and Anderson, 1985; Cinse, 1986; Grotzinger, 1986 and Hardie and Shinn, 1986).

The allocyclic mechanism responsible for the sea-level fall causes the subareial exposure of the carbonate platform and hence allowing varying degrees of vadose diagenesis (Grotzinger, 1986). Koerschner and Read (1989) explained the origin of the allocyclic model in terms of two mechanisms: the Jerky subsidence and the sea-level fluctuation and considered that the sea-level fluctuation as the main cause of the cycles.

Khalifa (1996) revealed that the cycles originated by the allocyclic mechanism are characterized by the variation of the thickness and microfacies types within the individual cycle. He stated that these cycles could be correlated laterally along widespread regions.

In the present study, the detailed analysis of the depositional cycles reflects a wide carbonate platform affected by successive periods of transgression phases at the base due to differential subsidence, overlain by facies indicating a sea-level fall due to emergence during the regressive phases. Thus it is seemed that the origin of the recognized shallowig-upward gradual and non-gradual cycles is attributed fundamentally to the oscillation of the sea level due to eustatic sea-level changes or intrabasinal tectonics (episodic subsidence and / or faulting) (allocyclic mechanism) caused the generation of these cycles and their vertical repetition in a rhythmic manner. These processes may provide an adequate space to allow the deposition of more than one shallowing-upward facies types. The variation in sea level here is evidenced by: (1) The deposition of the lime mudstones or wackestones (deep subtidal facies) at the base of the cycles during the periods of submergence. (2) The deposition of the packstone and grainstones at the top of the cycles reflecting the shallow subtidal facies. (3) The sea-level fall can account for diagenesis by active meteoric water and hence causing the dominance of the aggrading neomorphism process and the increasing of its degree as going upward towards the caps of these cycles. (4) Ferrugination can be an indication about the sea level fall. (5) SEM studies of

grainstone facies show that the evaporite mineral (gypsum) occupies the interstices between the calcite cement, this indicates the sea-level fall.

In the studied cycles, it is seemed that it is easier to fluctuate the sea level up and down with a high frequency of oscillation than evolution of a lithospheric plate or local-faulting oscillation with such a frequency. The lack of clastics and having no criteria about regional tectonic considerations in the study interval favor that. And hence, we believe that the formation of the recognized allogenic cycles is formed by the eustatic fluctuations in the sea level. Most workers favor the eustatic sea-level mechanism over the episodic subsidence in formation of the carbonate shelf cycles (e.g. Goldhammar and Elmore, 1984; Grotzinger, 1986; Koerschner and Read, 1989).

DEPOSITIONAL ENVIRONMENT

The restricted shallow shelf lagoonal facies is the chief mode of sedimentation of the Lower Eocene (Late Ypresian) deposits building up the Drunka Formation. The principal mode of the carbonate sedimentation of the rocks of the Drunka Formation is depending upon the accumulation of organically derived particles (e.g. green algae, benthonic large foraminifera, echinoderms and mollusks) and the inorganically derived particles (e.g. oolites and pellets). The restricted shelf lagoonal facies of the Drunka Formation is located at the extreme southern part of the study area (El-Zarabi section) with a thickness of about 133.75 m, southern part of the area (Ismail Bey section) with about 35.5 m thick and at the extreme western part of the area under investigation (core of Gebel Gibeil section) with about 48.5 m thick. Mansour *et al.* (1982 & 1987) interpreted the facies of the Drunka Formation in the areas west and southwest of Sohag, northwest of Assuit and northeast of Sohag respectively to be deposited on an algal bank margin and slope. Keheila and El-Ayyat (1990) studied the Drunka Formation exposed at the area east of Sohag and interpreted it to be deposited in an open shelf lagoon environment. In the present work, the environmental conditions that originally prevailed during the deposition of the limestone of the Drunka Formation are based on its geometry, facies associations, cyclic sequences, primary sedimentary structures, fossil content and paleoecological factors.

1. Geometry:

The geometry of the Drunka Formation describes its stratigraphic position and its lateral relationship with the adjacent formations on the shelf zone. The Drunka Formation overlies the Thebes Formation and occupies a lensoid shape within it at the outer shelf and rimmed from the north by the dolostone facies of the Nashfa Formation (Fig.7). It exhibits a lenticular geometry, in which the maximum thickness occurs at El-Zarabi section (south of Assiut) and wedges out southwards until it changes to the coeval Lower Eocene Thebes Formation at latitude south of Sohag (Mansour *et al.*, 1982). Also, it tapers northwards towards the shelf edge where it changes to the Nashfa Formation at the latitude of Maghagha. At the latter locality geophysical studies indicated the presence of paleo-high (Khalifa, 1981). This opinion was documented later after drilling the Nashfa well no.1, where the basement intrusion appears at 1200 m depth. This nature of occurrence of the Drunka Formation suggests that this formation was restricted between the Lower Eocene Thebes Formation in the south and the Nashfa Formation in the north. The above geometry of the Drunka Formation proves that it was deposited in a restricted shelf lagoon environment.

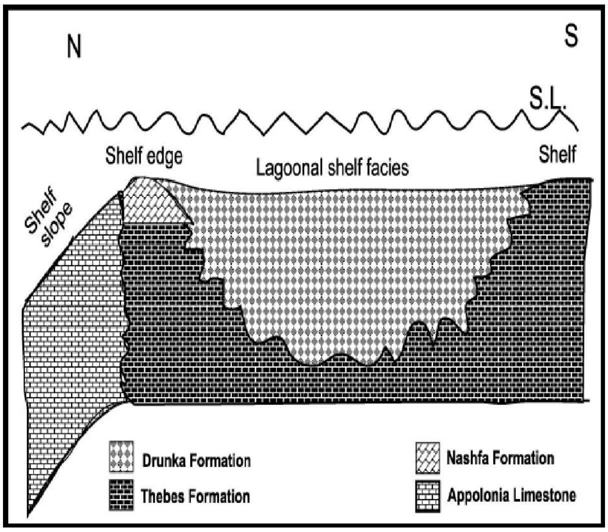


Fig.(7) Schematic diagram showing the possible depositional environment of the Drunka Formation in the study area

Also, the term "restricted shelf marine environment" was used by many workers such as Flugel (1982), Milliman (1974), Wilson (1975) and Tucker (1981). The restricted shelves are defined as any part of a continental or island shelf with slow water circulation resulting in abnormal salinity, depleted nutrients or temperature extremes. The restriction that reduces the normal wave or current energy may result from any physical barriers such as reefs, islands, skeletal or oolitic sand shoals or from the damping effect of vast exposures of shallow water (Enos, 1983).

The most important diagnostic criteria of the restricted platform lagoonal sediments can be concluded as follows: they are common in the back-reef and back-barrier environments passing shoreward into the tidal flat facies (Tucker, 1981). The restricted subtidal back-reef lagoonal sediments are characterized by a limited number of grain types where the fecal pellets, peloids of diverse origin, grapestones, intraclasts and a limited range of skeletal material are the most common grain types (Wilson, 1975). Most sediments of the present environment are composed of lime mud, grainstone is rare, clotted pelleted mudstone or wackestone are most common (Wilson, 1975).

2. Microfacies associations:

The microfacies associations identified in the restricted lagoonal facies of the Drunka Formation in the area under study include the following types: lime mudstone, bioclastic wackestone, echinoidal wackestone, peloidal wackestone, dasycladacean algae wackestone, nummulitic wackestone, orbitolites wackestone, peloidal wackestone, miliolidae wackestone, bioclastic packstone, codiacean algae packstone, peloidal packstone, peloidal packstone, echinoidal packstone, dasycladacean algae packstone, orbitolites bioclastic packstone, miliolidae packstone, peloidal grainstone, siliceous oolitic grainstone and codiacean algae grainstone.

The common presence of peloids (micritized grains) and fecal pellets in the upper unit of the Drunka Formation indicates a more restriction toward the end of this formation and the activation of the burrowing algae, fungi that prevailed in the restricted water. Purdy (1963) studied the lagoonal facies in the Great Bahama Bank and recorded that this facies consists mainly of non-skeletal particles (82.7%), while the percentage of the skeletal particles plus the finer debris is about 17.2%. Flugel (1982) revealed that the fecal pellets are a dominant constituent of the recent subtidal and shallow marine intertidal settings of low energy water. The peloidal facies is usually common in the shallow marine protected, low energy, back-bank lagoonal environments (Enos, 1983; Goldhammar and Elmore, 1984; Tucker and Wright, 1990 and Gischler and Lomando, 1999). The peloidal packstone to grainstone facies was recorded from the lagoonal carbonate sediments (Evans *et al.,* 1995).

In the present facies, the oolites constitute about 1.75% of the whole rock of the Drunka Formation. They are confined to the beds at which the grainstone texture is deposited where they are associated with the peloids. This indicates that the water energy levels were high enough to form the oolites and cause the winnowing of the micrite matrix. Therefore, the oolitic facies here represents higher energy than found during the deposition of the peloidal or skeletal wackestone or packstone. Thus, the author believes in that the present

oolites are of authochthonous type (according to Flugel, 1982) and owes their presence to the change of water energy from the most dominant low energy to higher energy (less dominant) on sporadic periods during the deposition of the Drunka Formation. This view can be supported stratigraphically by the formation of the shoaling-upward cycles in this facies. Flugel (op.cit) stated that the marine ooids originate in the tropical and subtropical environments that influenced by wave action and regarded that the quiet water energy-oolites are formed in a relatively confined environments. He considered that the presence of algae, warm water supersaturated with $CaCo_3$ and normal or increased salinity are important factors that help in the deposition of ooids. The recorded oolites are mainly of the superficial type. The scarcely fossiliferous calcareous mudstones reflect deposition in a moderately shallow, low-energy subtidal setting on carbonate shelf (Gevirtzman and Mount, 1986). Restricted lagoons are typically areas of lime mud deposition (Nichols, 1999).

The lagoonal limestone facies with high percentages of foraminifera, calcareous green algae and peloids is common in lagoonal environments (Tucker, 1981). The mixed peloidal and molluscs-foraminifera-Halimeda facies is deposited in the shallow lagoonal environments (Gischler, 1994). The presence of bioturbation, muddiness, poorly sorted sediments, micritizatioin and high percentage of the calcareous green algae suggests low energy shallow marine shelf lagoon facies (Simpson, 1985).

3. Sedimentary structures:

The non-laminated sediments (massive sediments) are the common features that widely distributed throughout the rocks of the Drunka Formation. (i.e. most of the beds show massive to poorly bedded limestones). The massive nature of the Drunka Formation indicates that the sedimentary structures were probably destroyed by the effect of bioturbation.

The most common biogenic effect was determined in restricted platform lagoonal environment is the burrowing (Milliman, 1974; Wilson, 1975; Bathrust, 1975; Blatt *et al.*, 1980; Enos, 1983; Blatt, 1992; Prothero and Schwab, 1996 and Raymond, 2002). Generally, the the shelf lagoonal facies of the Drunka Formation is characterized by the predominance of burrowing where most beds have no physical sedimentary structures even in the grainstone lithofacies. Consequently, the bioturbation is the most predominant phenomenon in the Drunka Formation. It is represented by burrows, which belong mainly to the inclined type, while the vertical and horizontal burrows are also recorded but with lower abundance. They are more abundant in the lower part of the succession and show average diameter of about 1 cm.

4. Fossil content:

The restricted platform lagoonal sediments are characterized by their low faunal diversity. These sediments are populated by the burrowing gastropods, bivalvia-oyster and rudists, benthonic foraminifera, ostracods, green algae, echinoids, serpulid worms, algal oncoids, peloids and grapestones (Flugel 1982; Logan *et al.*, 1974; Milliman, 1974; Bathrust, 1975; Wilson, 1975; Enos, 1983; Prothero and Schwab, 1996 and Raymond, 2002).

In the Drunka Formation, the average percentage of fossils (fauna and flora) reached about 28% of the whole rock. The calcareous algae and their fragments dominate the biota of the present facies. The most conspicuous forms are the green ones (both the codiaceans and dasycladaceans).

The less dominant fossils are represented (in decreasing order of abundance) by echinoderms, nummulites (mainly *Nummulites planulatus*), miliolids (*Quinqueloculina* sp.), molluscs (mainly bivalvia), orbitolites (*Orbitolites complanatus*), bryozoa and red algae. The skeletal debris consists mainly of algae, nummulites, bivalvia, echinoderms and foraminifera. This skeletal debris is formed as a result of the relatively high water energy in this environment.

The abundance of the benthonic fauna and flora in the rocks of the Drunka Formation suggests that the sedimentation took place in shallow waters on restricted shelves (Garrison and Fischer, 1969). Generally, the green algae inhabit the shallow marine warm water of the intertidal and restricted shelf environments within the photic zone (Neumann and Land, 1975 and Wilson, 1975). The low-energy lagoon (back-reef) environments are dominated by the green algae (Ghose, 1977; Wray, 1977 and Genot, 1991). Ott (1972) recorded the green algae from the Tethys shelf lagoon. The calcareous green algae (both codiaceans and dasycladaceans) dominate the lagoon and back-reef facies (Wray, 1977). Flugel (1977) recorded the calcareous green algae from the Florida Keys marine lagoons. The calcareous codiacean green algae live in sheltered environments having the same

characters of a tropical shelf lagoon (Strougo *et al.*, 1990). Johnosn (1961) stated that the *Halimeda* sp. developed in the lagoonal facies protected by reef. *Halimeda* sp. is bound to marginal marine, often micritic limestone of very shallow water restricted environment. This alga is abundant in the shallow portion of the lagoon environments (Wray, 1977 and Gerhard *et al.*, 1978). The dasycladacean green algae flourish in shelf lagoons (Wray, 1977 and Flugel, 1982). Dasycladacean green algae prefer sheltered waters as back-reef lagoons and usually associated with shallow water foraminifera such as miliolids and large forams (El-Gamal and Youssef, 2000).

The large benthonic foraminifera are also used to reconstruct the paleoenvironmental conditions prevailed during the deposition of the Drunka Formation. Generally, the benthonic foraminifera are miliolids, orbitolites and nummulites. Henson (1950) stated that the miliolids occur in shallow water of barrier-reef lagoons. Wilson (1975) and Freeman-Lynde *et al.* (1981) have found that the miliolids are the most common foraminiferal particles representing the shallow, restricted lagoon environments. Ghose (1977) stated that the orbitolites are recorded in the sheltered water on the reef flat and in the back-reef environments.

Gerhard *et al.* (1978) recorded the echinoid from the shallow lagoon environments of the King Shill limestones, U.S. Virgin Island. The bivalvian particles are common in the shallow lagoon facies (Gerhard *et al.*, 1978). Gischler (2003) recorded the mollusca from the lagoon facies. The bryozoa are recorded from the shelf lagoon environment (Purdy, 1963 and Hoffmeister *et al.*, 1967).

SUMMARY AND CONCLUSIONS

The detailed fieldwork in the area west of Assiut-Minia stretch revealed that the recorded Drunka Formation is composed of hard, crystalline, massive to thin laminated, algal, burrowed and sometimes chalky limestones with numerous chert concretions and bands. Accoding to the lithologic variation and fossil content, the Drunka Formation can be subdivided into two units: the “lower” and “upper” units.

The microfacies analysis of the Drunka Formation in the area under study exihibits that the limestones of this formation are very rich in calcareous green algae (both codiacean and dasycladacean), miliolids and peloidal grains (fecal pellets and micritized skeletal grains) and contain an appreciable amounts of nummulites and orbitolites besides the echinodermal, molluscan and skeletal debris particles. Nighnteen carbonate microfacies associations have been recognized belonging to the lime mudstone, wackestone (nine microfacies associations), packstone (twelve microfacies associations), grainstone (three microfacies associations) and bounstone (one microfacies association).

The carbonate succession of the Drunka Formation is composed of successive emergence (shallowing-upward) cycles. On the basis of the relation of cycles with the sea-level change, the present depositional cycles can be subdivided into gradual and non-gradual cycles. These cycles may be formed by an allocyclic mechanism as evidenced by:

(1) The deposition of the lime mudstones or wackestones at the base of the cycles during the periods of submergence and the deposition of the packstone and grainstones at the top of the cycles reflecting emergence conditions.

(2) Dominance of the aggrading neomorphism process.

(3) Ferrugination affecting some rocks.

(4) Presence of gypsum in the interstices between the calcite cement in some grainstones.

(5) Development of the recrystallized lime mudstone due to the subaerial exposure.

The deduction of the paleoenvironmental conditions during which the Drunka Formation has been deposited depends upon their lithologic characters, geometry, stratigraphic position, sedimentary structures, facies associations, fossil content and cyclic sequences. Detailed sedimentological analysis shows that the Drunka Formation reflects a restricted shelf lagoonal facies.

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