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Bryozoan Nodules as a Frame-Builder of Bryozoan-Microreef, Middle Miocene Sediments, Egypt

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ABSTRACT: Bryozoan nodules, coralline algae, scleractinian corals and oysters form an important organic buildup, 1.2–4.5 m thick in the Langhian-Serravaliann sediments of Egypt. Based on type, shape and size of the substrate, bryozoan nodules take tree-like and globular morphologies. Tree-like specimens reach 10 cm in maximum height and 3 cm in diameter, while Globular ones attain 9 cm in maximum diameter. Most tree-like nodules are perforated with wide or narrow pores, few are non-perforated. Globulars and few tree-like forms are with mamelon-like structures. Perforations on the outer surfaces may indicate a symbiotic relationship between bryozoans and a live plant substrate. Nodules from Homiera and Gharra areas of the Cairo-Suez District with wider perforations may indicate growth in slightly lighter or turbid areas of the continental shelf than those of North Western Desert of narrower perforations. Non-perforated nodules may assume an incrustation on ephemeral substrate.
KEY WORDS: Miocene, bryozoa, frame builder, microreef, paleoecology, Egypt.

0 INTRODUCTION

Bryozoans are small benthic aquatic invertebrates growing as colonies of connected zooids on submerged substrates (Massard and Geimer, 2008). Although bryozoan zooids and fragments are small enough to be used for example in micropaleontological approaches (Lagaaij and Gautier, 1965), they contribute to reef construction in different ways: as principal frame builders, accessory frame encrusters, sediment formers and sediment-movement inhibitors (Hageman et al., 2013, 2003; Ernst and Königshof, 2008; Cuffey, 1977).

Numerous studies were carried out on the Miocene bryozoans of the Cairo-Suez District (e.g., El-Safori and El-Sorogy, 1999; Ziko et al., 1994, 1992) and in the Northwestern Desert (e.g., Ziko et al., 2001; Zalat et al., 1995; Ziko, 1994, 1991; Abbass and El-Senoussi; 1976; Canu, 1912; Fuchs, 1883). Studies on the role of modern and fossil bryozoa in mound, microreef and reef formation in Egypt are very rare (El-Sorogy, 2002; Ziko, 1996; Hamza, 1988). Many abroad studies include Ernst and Königshof (2008), Holcová and Zágoršek (2008), Scholz and Hillmer (1995), Pillar and Vavra (1991), McKinney and Jackson (1989), Cuffey (1985, 1977), Malecki (1980), Bradstock and Gordon (1983), Jackson (1979).

The purpose of the present paper is to study the morphology of the Middle Miocene bryozoan nodules in Cairo-Suez District and Western Desert, Egypt and to examine the paleoecological parameters controlled the growth of such large bryozoan nodules.

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1 MATERIAL AND METHODS

The materials include 115 nodule bryozoans (*Turbicellepora*, *Celleporina*, *Cellepora*, *Tretocycloecia* and some may belong to Cerioporidae) are collected through three field trips, from six stratigraphic sections (Fig. 1). Two of them are from Middle Miocene Marmarica Formation at Matruh and Siwa areas, northern Western Desert and four from Miocene Genefe Formation at Gharra, Geneifa, Homiera and Sadat areas, Cairo-Suez District. Specimens cleaned by tape water to remove adherent sediments for identification and photography by normal light and SEM. SEM photos are taken on the JSM-6380 LA of the College of Science, King Saud University. Representative nodules are polished with transverse and longitudinal orientations to examine their internal substrates. The studied nodules are deposited in the Geological Museum, Zagazig University, El-Sorogy's collection, Zagazig, Egypt.

2 GEOLOGIC SETTING

Miocene deposits cover about 11% of the Egyptian territories. They exhibit great facies variation and distributed in four tectonic provinces: Delta embayment, north Western Desert, Cairo-Suez District and Gulf of Suez-North Red Sea (Said, 1990). Each has its own paleoenvironmental and paleogeographical configuration, which consequently influenced the distribution of its fauna in general, and the bryozoans characterize each of these in particular.

The studied Middle Miocene sediments may correlate Middle Miocene climatic optimum (Langhian/Serravallian boundary, Badenian local stage) which correlated with the large transgression over the Central Paratethys in Europe (Zágoršek, 2010a, b; Holcová and Zágoršek, 2008). The studied bryozoan nodules were collected from the following two provinces.

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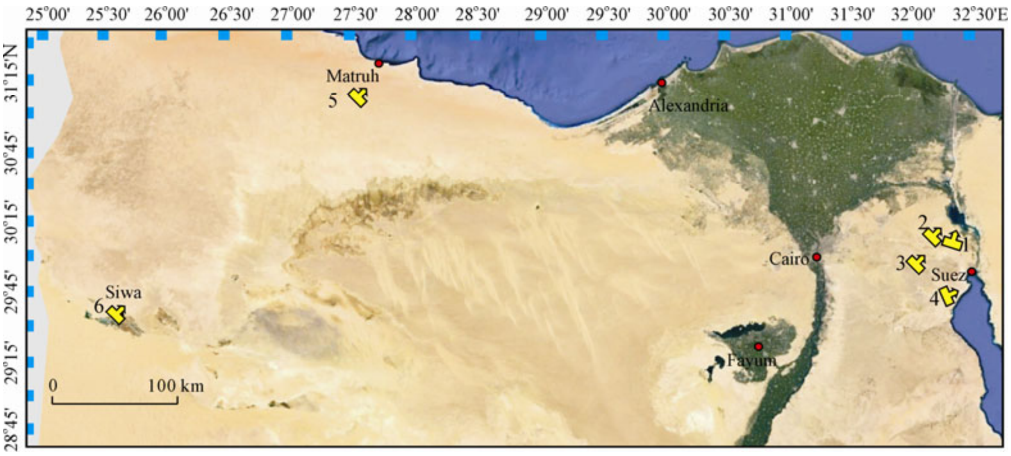

Figure 1. Location map of the studied areas. 1. Gebel Geneifa Section; 2. Gebel Gharra Section; 3. Gebel Homeira Section; 4. Sadat area; 5. Matruh area; 6. Siwa area.

2.1 North Western Desert

This basin is developed to the south of the Mediterranean coastal high. During the Early Miocene, clastic sedimentation prevailed. A change of the climate and a reactivation of the coastal high during the Middle Miocene left the northwestern Desert a distinctive basin in which clastics were deflected and organogenic carbonate deposits accumulated (Said, 1990).

The Marmarica Formation covers almost the entire northern stretch of the western Desert, and forms the white limestone cap of the Qattara wall. It is mostly made up of limestones and marls with a number of oyster banks with *Borelis melo* Fichtel and Moll, 1798; *Ostrea virleti* Deshayes, 1832; *O. frondosa* De Serres, 1829; *Cardium multicostatum* Brocchi, 1814 (Ziko et al., 2001). The Marmarica Formation overlies the clastics of the Moghra Formation and caped in places by Pliocene sediments (Zalat et al., 1995).

The studied materials collected from a buildup, 1.5–4.5 m thick as globular and tree-like nodules act as frame-builder and sediment bafflers by trapping the sediment among branches (Figs. 2a, 2b), in the upper part of the Middle Miocene Marmarica Formation at Matruh (27°42′E and 31°22′N) and Siwa (25°37′E and 29°40′N) areas (Fig. 1). The associated fauna with bryozoan nodules are scleractinian families (Clavularidae, Pocilloporidae, Acroporidae, Calamophylliidae, Poritidae, Faviidae), oysters, lithothamnids, dascycladceans, echinoderms, large benthic foraminifera and balanids (El-Sorogy, 2002). The studied buildup is of Langhian–Serravalian age (Ziko et al., 2001; Said, 1990).

2.2 Cairo-Suez District

This district forms a neritic marginal zone, which was intermittently covered by the sea as it advanced toward the south (Said, 1990). The sediments are thin and are made up mostly of shallow organogenic carbonates with numerous diastems.

Samples here are collected from a massive buildup, 1–2.5 m thick, belongs to Langhian–Serravalian Genefe Formation (El-Sorogy et al., 2005), at Geneifa (32°21′E and 30°12′N), Gharra (32°12′E and 30°02′N), Sadat (32°26′E and 29°47′N), and Homiera (32°17′E and 30°11′N) areas (Fig. 1).

The massive buildup is made up of reefal limestones, marls and sandy marl intercalations, partly siliceous at the base, and rich in bryozoans nodules interfingering locally with oyster shell beds (Figs. 2c, 2d). The following invertebrates are identified from studied buildup: *Ostrea virleti* Deshayes, 1832; O. frondosa (De Serres, 1829); Alectryonella plicatula Gmelin, 1791; *Chlamys gentoni* Fontannes, 1884; *Pecten* (*Oppenheimopecten*) *benedictus* Lamarck, 1819; *Pecten* (*P.*) *ziziniae* Blanckenhorn, 1901; *Echinolampas amplus* Fuchs, 1883; *Scutella ammonis* Fuchs, 1883; corals, other small bryozoans and algae (El-Sorogy et al., 2005). It lies stratigraphically below the Hommath Formation and overlies the clastic-carbonate sequence of Lower Miocene Gharra Formation (El-Sorogy et al., 2015; Tawfik et al., 2015).

3 RESULTS AND DISCUSSION

3.1 Growth Form and Morphology

Bryozoan nodules are defined as regular or irregular massive encrustations with vertical as well as lateral growth and are often not firmly attached to the substratum along the basal area. Free-rolling massive bryozoan colonies are also known as “ectoproctaliths”, “bryoliths” or “rolling stones” (Scholz and Hillmer, 1995; Dade and Cuffey, 1984).

Jackson (1979) defined sheets as two-dimensional encrustations more or less completely attached to the substratum. Scholz and Hillmer (1995) in their study on reef-bryozoans and bryozoans-microreefs, they assigned two types of sheets which produce nodules: First, S-(sheet) nodules which grow mainly by terminal budding, as nodule type illustrated by Stylopoma and Parasmittina from the Philippines. In S-nodules, only the uppermost parts are alive. Second, C-(celleporiform) nodules which grow by irregular frontal budding rather than laminar self-overgrowth through terminal budding. The whole colony is alive and reacts like a solitary organism to regional slow rate. control. Example of living colony is the large nodule, 56 mm diameter of Celleporaria fusca (Busk, 1854), collected at a depth of 180 m, Gulf of Aqaba (Scholz and Hillmer, 1995). The true bryozoans mounds of Jackson (1979) represented by Celleporaria are noted as C-nodules.

The morphology and size of the studied nodules are largely depending on the morphology, size and type of the

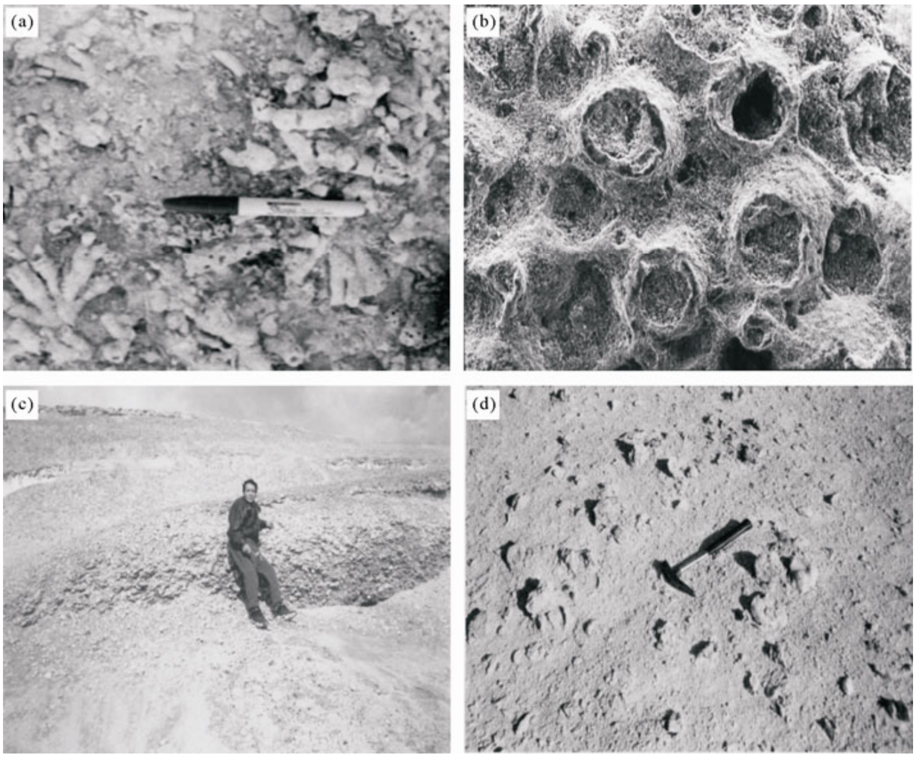

Figure 2. (a) Tree-like nodules act as frame-builder and sediment bafflers by trapping the sediment among branches, upper part of the Marmarica Formation, Matruh area; (b) enlargement part of a tree-like nodule. Marmarica Formation, Siwa Oasis. Scale bar=400 μm; (c) a general view of oyster bank of Genefe Formation, Gabal Homeira; (d) oysters pectinids and globular bryozoans embedded in limestone of the Genefe Formation, Gabal Gharra.

substrate on which they grew (Riedl, 1966). Two main morphologies are recorded.

3.1.1 Tree-like (ramose) nodules

This type consists of masses in the form of branches, tubes and horns (Fig. 3). They can be subdivided into hollow nodules (Figs. 3a–3c, 3g and Fig. 4a) and solid nodules (Figs. 3d–3f and 4b, 4c). Cuffey (1985) called branchstone for the framework formed of branched colonies. Such branchstone include some acanthocold-fenestrate bryozoan forms in the Permian of the Glass Mountains and also certain *Acropora* frameworks seen today on Eniwetok atoll and the Great Barrier Reef.

Tree-like nodules from Homiera and Gharra areas in Cairo-Suez District reach up to 10 cm in maximum height, and 2–2.5 cm in diameters with more or less circular and wide surface perforations (6 pores/cm^2, 0.75–3.50 mm in diameter each). Perforations appear like corallites of the scleractinian coral *Pocillopora* (Figs. 3a, 3b). These perforations extend mostly to the internal substrate (Fig. 3c). Nodules of Matruh and Siwa areas in North Western Desert (Figs. 3e, 3f) reach the same height and shape of those in Cairo-Suez District, but their perforations are frequent and smaller in size (14 pores/cm^2, 0.25–1.00 mm in diameter). Few ramose forms show mamelon like-structures on their external surfaces without perforations (Fig. 4b).

Concerning the role of tree-like nodules in mico-reef formation, they act as a major sediment former, where nodules contribute more volume of in-place calcareous skeletal materials, in addition to their role as sediment bafflers and sediment builders (Ernst and Königshof, 2008; Cuffey, 1985). Cuffey (1985) called branchstone to the bafflestone or sediment trapping or stabilizing branching colonies.

3.1.2 Globular (spheroidal) nodules

Ball-shaped, ovoid, spheroid and umbrella-like masses represent this type (Figs. 4d–4h). These globular nodules are built up of numerous, concentric successive layers around various substrates, such as algal and shell fragments. Bryozoans are partially or completely surround the substrate. They represent a typical substrate of some small encrusting epibionts forms that have very small attachment sites (Hageman et al., 1998). The framework formed of globular (massive or head-like) colonies is recognized as globstone (Cuffey, 1985).

Globular nodules are recorded from the Early Miocene sediments of Cairo-Suez District. Few ones, especially of ball and umbrella-like shape are recorded from the Middle Miocene sediments of North Western Desert. Globulars attain 9 cm in maximum diameter. The entire external surface shows mamelon like-structures, without perforations. About 4 mamelons/cm^2, each mamelon reaches 5 mm in maximum diameter and 1–3 mm in height.

These nodules act as sediment formers and sediment builders to microreef formation. As in treelike nodules, the globular ones contribute more volume of in-place calcareous skeletal materials and when attach up on one another they form a skeletal framework (framestone) or lattice infilled only by fine sediment, they called a globstone (Cuffey, 1985). Also nodules offer a hard and stable substrate to numerous epibiotic

organisms. The sessile epibionts (Fig. 2e) such foraminifera, serpulids and barnacles live attached to these calcareous nodules. Other bryozoans such as *Callopora lineate* Linnaeus, 1767, *Membranipora savartii* (Audouin, 1826) and *Calpensia nobilis* Esper, 1796 inhabit sheltered or protected spots on/or under nodules (Figs. 4h, 4i). Such bryozoans contribute significant amounts of skeletal material to the microreef.

3.2 Paleoecological Implications

Bryozoans dominate in subtropical-to-temperate shallow waters of normal salinity, high oxygen content, and very good trophic conditions (Zágoršek et al., 2012). Nodular growth can be interpreted as a flexible response of the colonies to control factors of the outside environment (Scholz and Hillmer, 1995). A number of ecological parameters must be simultaneously met, in order to appear and grow of present nodules.

3.2.1 Substrate

Substrate type and availability are amongst the most important environmental factors controlling the distribution of bryozoans (Zágoršek et al., 2012; Thomsen, 1977). A crucial aspect of nodular colony is a reduced surface/volume relationship in direct contact with the water column, and less exposed skeletal area relative to colony size (Jackson, 1979). The present nodules

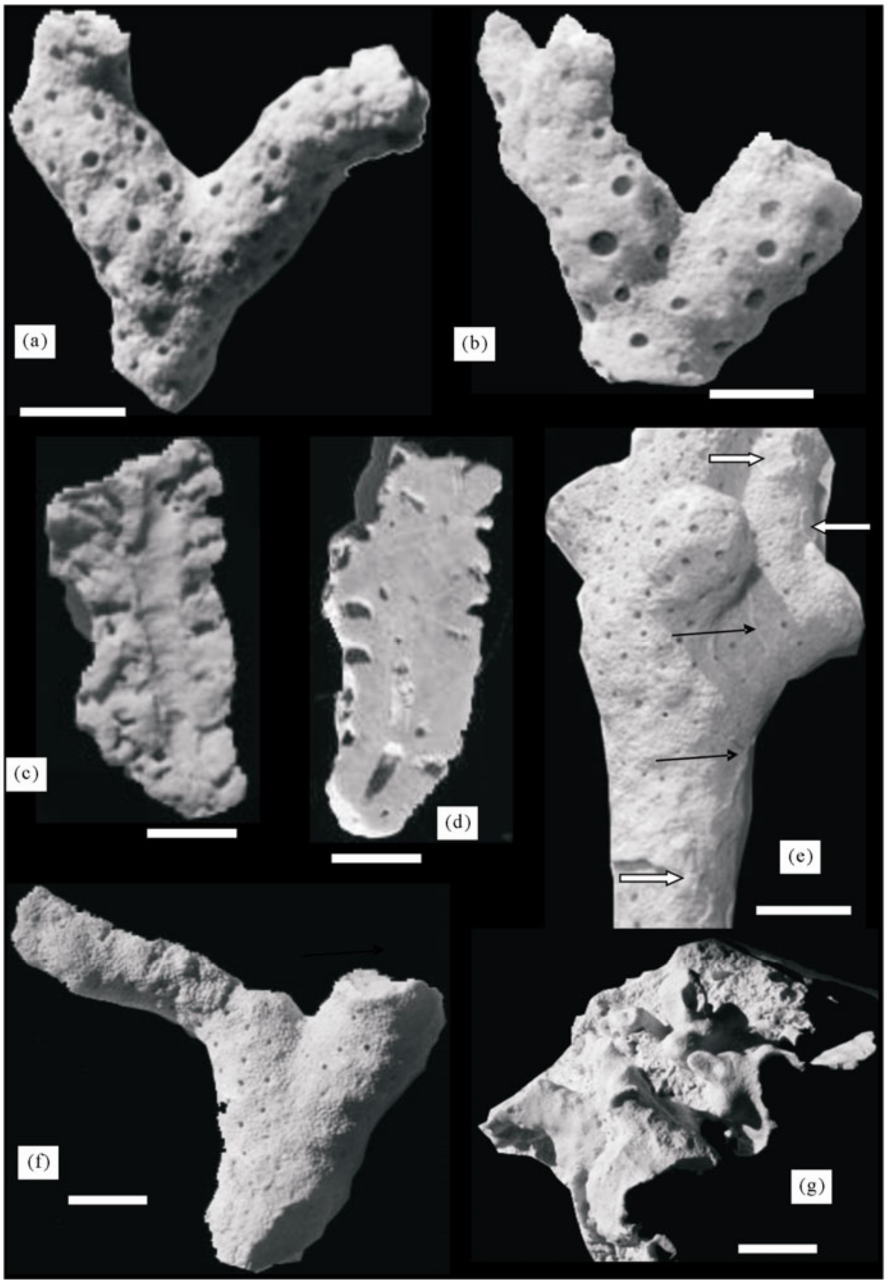

Figure 3. (a) and (b) Tree-like nodules with wide perforations, Genefe Formation, Homeira area; (c) and (d) naturally broken cross-section of wide perforated hollow nodules, perforations extend from the outer surface to the inner substrate, Genefe Formation, Homeira area; (e) and (f) narrow-perforated tree-like nodules with encrusting foraminifera (white arrows) and worm tubes (black arrows), Marmarica Formation, Matruh area; (g) a colony of *Tretocycloecia dichotoma* with hollow ends, Marmarica Formation, Siwa Oasis. Scale bar of figures from (c) to (i)=10 mm.

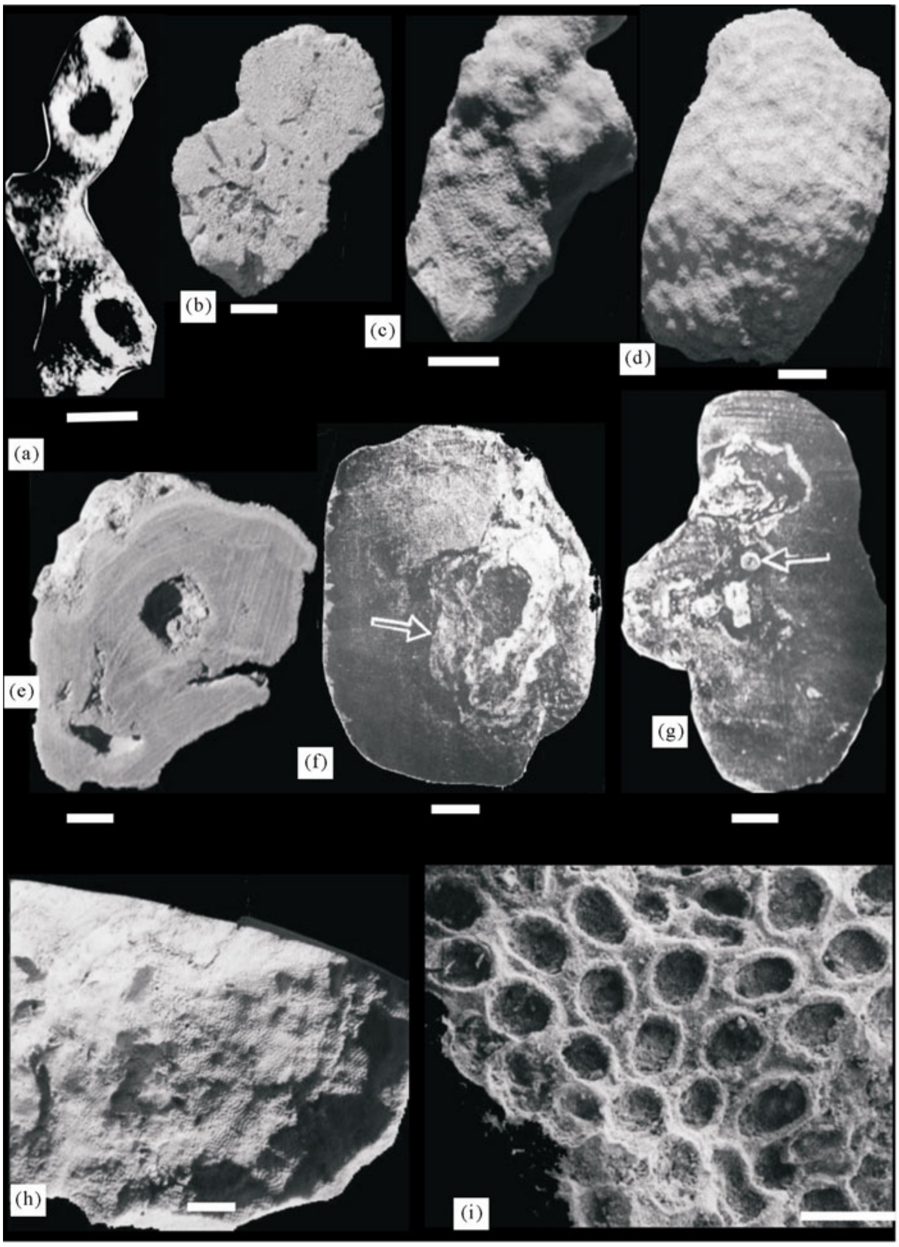

Figure 4. (a) Hollow tree-like nodule, Marmarica Formation, Matruh area; (b) polished surface of a solid narrow-perforated nodule, Marmarica Formation, Matruh area; (c) non-perforated nodule with mamelon like-structure on the outer surface, Gharra-Sadat Formation, Gharra area; (d) mamelon-like structures on the outer surface of oval nodule, Sadat Formation, Geneifa area; (e) polished surface of a spheroid-like nodule, with site of substratum in the center (arrows), Sadat Formation, Homeira area; (f) polished surface of a spheroid nodule, indicating encrustation on rhodoliths of coralline algae (arrow), Sadat Formation, Homeira area; (g) polished surface of an oval nodule, showing bryozoans encrustation on rhodoliths and masses of coralline algae (arrow), Sadat Formation, Geneifa area; (h) lower surface of an umbrella-like nodule shows encrusting bryozoa on the entire surface, the encrustation took place after separation of the mass from its substrate, Marmarica Formation, Siwa Oasis; (i) enlargement of (g), shows encrusting colony of *Callopora lineata* (Linnaeus), Marmarica Formation, Siwa Oasis, scale bar=400 µm. Scale bar of figures from (a) to (g)=10 mm.

resemble to high extent in shape and substrate with the bryozoan masses of the Miocene-Pliocene and Holocene of France, North Africa and the Mediterranean (Moissette and Pouyet, 1991), as well as Moravia (Zágoršek et al., 2007). *Bioflustra commensale* (Kirkpatrick and Metzelaar) concretions of Eweda (1999) from Middle Miocene Marrada Formation, Central Sirt Basin, Libya vary from the present nodules in that, the Marrada specimens grew primarily on a substrate of short-spired gastropods.

Scholz and Hillmer (1995) noted that, perforations on the outer surfaces of a recent colony of *Celleporaria fusca* (Busk, 1854) may act as communication pores among individuals of the colony, where a core drilled vertically to the growth direction showed that even layers at the base of the colony were alive. Perforations on the outer surfaces may also act as com-

munication pores among individuals of the colony. These pathways allow for nutrient regression during periods of environmental stress (Cummings, 1975).

Accordingly, perforations on the outer surfaces of the present tree-like nodules especially hollow ones (Figs. 3a–3c, 3g and 4a) may indicate that these colonies were alive (like samples of Gulf of Aqaba by Scholz and Hillmer, 1995) and such pores acted as communication pores and nutrients pass through to the interior bryozoans or may indicate encrustation around stems of a host plant substrate such as algae, phanerogames and sea fans, where pores may transmit light to plant stems during life. The non-perforated tree-like nodules (Fig. 2g), and globular ones (Figs. 4c–4g), may indicate encrustation on flexible or hard ephemeral plants/animals or other coral/biogenic rubbles. Mamelon like-structures on the surfaces of globular nodules (Fig. 4c) and partly on tree-like ones (Fig. 4b) may be formed as a result of the limited surface area of the substrate, in comparison to the number of bryozoan individuals settled on (Hageman et al., 1998). Nodules show increased size relative to the substrate occupied, they should be favored in areas where substrate monopolization is not advantageous (Scholz and Hillmer, 1995). Also McKinney and Jackson (1989) have suggested that multilayered growth developed by vertical budding from multilayered sheets is an expression of limited substrata.

3.2.2 Light and water depth

The symbiotic relationship between hermatypic corals and algae is only one example of widespread endosymbiosis between cnidarians and algae. Perforations on the outer surfaces of most tree-like nodules (Figs. 3a–3f) may suggest exosymbiosis interact between algae (or any other branched plant) and the studied bryozoans. For photosynthesis, plant takes carbon dioxide releasing from respiration of the encrusted bryozoans and light through the pores, where bryozoans take oxygen producing from photosynthesis of the living plant (substratum). The continuity of this process accelerates the secretion of calcium carbonate and consequently allowing faster skeletal growth.

The evidences of such suggestion are: (1) celleporid growth-form, in general is chiefly distributed in littoral and sublittoral zones. (2) Most abroad recorded bryozoans nodules are formed in photic zone depth range from 20 to 120 m (Scholz and Hillmer, 1995; Pillar and Vavra, 1991). Accordingly, nodules of Homiera and Gharra areas with wider surface pores (Figs. 3a–3d) may be grown in area of the continental shelf where the penetrating light was slight or in shallow and highly turbulent water than those of the narrower surface pores of the North Western Desert (Figs. 3e, 3f). *Celleporaria*, *Stylopoma*, *Parasmittina* and *Hippomenela* built similar bryozoan reefs and mounds recorded in Bahamas (Cuffey, 1977) and New Zealand (Bradstock and Gordon, 1983). Also Harmelin (1988) recorded a distinct occurrence of Mediterranean nodular bryozoans in cave environments.

Similar growth habits have been described for recent Mediterranean celleporarids on sponges, gorgonians, and serpulid worm tubes (Moissette and Pouyet, 1991). Also similar celleporarid limestones occurred at approximately 20 m water depth within the transition between slightly deeper (50 m), more oligotrophic carbonate deposition and very shallow (few meters deep) subtidal sea grasses to sand flats (Lukasik et al., 2000).

3.2.3 Water turbulence and rate of sedimentation

Water turbulence is beneficial to bryozoans for larval distribution, colony oxygenation and elimination of foreign particle and excrements (El-Sorogy, 2002). Turbid, muddy environment are generally avoided by bryozoans. Although many of the best preserved fossil bryozoans come from argillaceous deposits (marls), bryozoans tend not to inhabit environments with continuous influxes of fine-grained sediment which expose the colony to the dangers of burial and hamper suspension feeding-high silt loadings have been shown experimentally to decrease feeding activity, possibly through particle impacts causing physical damage of the lophophores (Tylor, 2005; Best and Thorpe, 1996). Requant and Zamarreno (1987) stated that globstone bryozoan colonies form under conditions of low to moderate current activity, where nuclei were never overturned.

The studied nodules may be grown in energy conditions, in general, range from low to moderate, with low rate of sedimentation, where multizoecial thickening serves to support larger erect forms and/or to make them more resistant to higher energy environments. This conclusion is supported by associated megafossils, consisting of coralline algae, oysters and corals. James et al. (2000) documented surprisingly high sedimentation rates during the Pleistocene in Great Australian Bight, with wave abrasion transporting sediment off the shelf, resulting in Quaternary sediment wedges hosting *Celleporaria* rich mounds. Their potential for rapid growth from a self-constructed foundation and specialized avicularia for shedding sediment suggest that *Celleporaria* can survive in environments of relatively continuous sedimentation (Scholz and Hillmer, 1995).

4 CONCLUSIONS

(1) Large tree-like and globular bryozoan nodules form a microreef buildup, about 1.2–4.5 m thick, with scleractinian corals, coralline algae and oysters in the Langhian-Serravalian sediments of North Western Desert and Cairo-Suez District, Egypt.

(2) The wide and narrow perforations on the outer surfaces of most studied tree-like forms may indicate an encrustation on living plant and symbiosis took place between bryozoan colonies and the plant substrate. Also such perforations might used as communication pathways among individuals of the whole nodule. Non-perforated nodules may indicate an encrustation on ephemeral plant stems or biogenic/detrital fragments.

(3) The wider pores on nodule's surfaces from Homiera and Gharra areas may indicate growth in slightly lighter or turbid areas of the continental shelf, in comparison with those of the narrower surface pores from North Western Desert.

(4) The studied nodules acted as sediment builders and sediment bafflers in micro-reef formation. Also nodules offer a hard and stable substrate to numerous foraminifera, serpulids, other bryozoans and barnacles.

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