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Ecologically controlled distribution of recent Textulariid foraminifera in subtropical, carbonate-rich Safaga Bay (Red Sea, Egypt)

by

Thomas G. Haunold[1]

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Inhalt

Abstract

Out of a total foraminiferal fauna of 238 taxa, and a textulariid fauna of 24, extracted from 73 samples collected all over northern Safaga Bay (Red Sea, Egypt), the most frequent 14 agglutinated species are examined for ecological preferences. Environmental parameters considered are grain size, density of seagrass growth, water depth, and the influence of open marine conditions, as reflected by the number of planktonic foraminifera in the sediment.

Agglutinated foraminifera, as such, abound where deeper (water depth ≥40 m) habitats are exposed to open marine influences and silt and clay amount to about 20% of total sediment weight. Textulariid frequencies decline in coarse substrates, in extremely muddy sediments, and in seagrass areas.

Typical of seagrass areas are (?)*Verneuilina* sp.1, *Sahulia* cf. *S. barkeri*, *Textularia rugulosa*, and *Clavulina angularis*, with *T. rugulosa* definitely favouring deeper seagrass stands. *Sahulia kerimbaensis, Textularia cushmani, T. foliacea occidentalis, T.* sp.C, and *Pseudogaudryina* sp.A prefer environments exposed to open marine conditions, as indicated by their significantly positive correlation with planktonic foraminifera. A preference for the same kind of habitats is also suggested for *Sahulia* cf. *S. conica*, a taxon for which otherwise no definite ecological preferences could be ascertained. *Eggerella* sp.A, *Textularia foliacea foliacea*, and, to a lesser extent, *Reophax* sp.1 are characteristic of soft bottom substrates, avoiding gravel and sand. *Textularia agglutinans*, the most frequent agglutinated species in northern Safaga Bay, is very common throughout the study area, thus hinting at a great adaptability of this taxon to various environmental settings.

No textulariid species were found to be significantly positively correlated with gravel and sand. The taxon least negatively influenced by coarse sediment is *Textularia foliacea occidentalis. Eggerella* sp.A *and Textularia foliacea foliacea*, the most characteristic 'mud dwellers', are negatively correlated with seagrass.

Zusammenfassung

Aus einer Foraminiferenfauna von 238 Taxa, gewonnen an 73 Probenpunkten in der nördlichen Bucht von Safaga (Rotes Meer, Ägypten), wurden die häufigsten 14 von insgesamt 24 textulariiden Taxa hinsichtlich ihrer ökologischen Ansprüche untersucht. Die hierbei berücksichtigten Umweltparameter sind Korngröße, Dichte des Seegrasbestandes, Wassertiefe, sowie der allgemeine Einfluß des offenen Meeres, widergespiegelt durch die Menge der an den einzelnen Probenpunkten abgelagerten planktonischen Foraminiferen.

Agglutinierte Foraminiferen finden sich allgemein am häufigsten in tieferen (Wassertiefe ≥40m) Lebensräumen, die deutlich den Einfluß des offenen Meeres erkennen lassen und Sedimente mit einem Gewichtsanteil von etwa 20% Silt und Ton aufweisen. Die Häufigkeit textulariider Formen nimmt sowohl in grobem, als auch in sehr schlammigem Substrat ab, sowie in Gebieten mit dichtem Seegrasbestand.

Deutliche Vorliebe für Seegraswiesen zeigen (?)*Verneuilina* sp.1, *Sahulia* cf. *S. barkeri*, *Textularia rugu-*

[1] Institute of Paleontology, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria.
fax: ++43-1-31336 784, e-mail: Thomas-Georg.Haunold@univie.ac.at

losa und *Clavulina angularis*, wobei *T. rugulosa* eindeutig tiefere Seegrasbestände bevorzugt. *Sahulia kerimbaensis, Textularia cushmani, T. foliacea occidentalis, T.* sp. C und *Pseudogaudryina* sp.A bevorzugen offen-marin beeinflußte Lebensräume, was in der signifikant positiven Korrelation dieser Arten mit der abgelagerten Menge planktonischer Foraminiferen zum Ausdruck kommt. Ein Vorkommen unter vergleichbaren ökologischen Bedingungen wird auch für *Sahulia* cf. *S. conica* angenommen, eine Form, für die darüberhinaus keine genaueren ökologischen Vorlieben herausgearbeitet werden konnten. Charakteristische Bewohner weicher, schlammiger Böden sind *Eggerella* sp. A und *Textularia foliacea foliacea*, sowie, in etwas eingeschränkterem Maß, *Reophax* sp.1; Substrate mit erhöhten kiesigen oder sandigen Korngrößenanteilen werden von diesen Taxa gemieden. *Textularia agglutinans*, die weitaus häufigste agglutinierte Form in der nördlichen Bucht von Safaga, tritt nahezu im gesamten Untersuchungsgebiet sehr häufig auf, ein Umstand, der auf sehr große Anpassungsfähigkeit dieser Art an verschiedenste Lebensumstände schließen läßt.
Keine der untersuchten textulariiden Arten ist signifikant positiv mit sandigem oder kiesigem Sediment korreliert. Die am wenigsten negativ von gröberem Substrat beeinflußte Form ist *Textularia foliacea occidentalis*. Die typischen Schlammbewohner *Eggerella* sp.A und *Textularia foliacea foliacea* zeigen negative Korrelation mit Seegras.

Introduction

General remarks

Safaga Bay is situated on the Egyptian coast of the Red Sea, about 120 km south of the entrance to the Gulf of Suez (longitude 33°56' to 34° E; latitude 26°37' to 26°52' N; see Fig. 1). The northern part of Safaga Bay, separated from its southern reaches by Gazirat Safaga (Safaga Island), has been chosen for an integrated actuopaleontological approach by members of the Institute of Paleontology at the University of Vienna, Austria (topography and bottom facies: Piller & Pervesler, 1989; sedimentology: Piller & Mansour, 1990 and 1994; microfacies: Piller, 1994; echinoids: Nebelsick, 1992; corals and boring bivalves: Kleemann, 1992; coralline algae: Piller & Rasser, 1993; molluscs: Zuschin & Piller, 1997a, b, c; Zuschin & Hohenegger, 1998).
One of the most interesting groups of organisms, both ecologically and paleoecologically, are foraminifera, which not only are present in all types of facies, but contribute prominently to the build-up of the sediment itself. Therefore, a systematic-taxonomical inventory, as well as investigations of the distribution and the ecological needs of these microorganisms rank among the most central aspects of this actuopaleontological project. A detailed systematic-taxonomic documentation of the benthic foraminifera of northern Safaga Bay, including their total and relative frequencies at sample sites, was presented by Haunold & Piller (1998) and Haunold et al. (1998). A comprehensive survey of the distribution of foraminiferal associations was furnished by Haunold et al. (1997), who discerned 13 major foraminiferal associations assigned to four categories, reflecting hardground, sand (with or without seagrass and/or corals), firmground, and soft bottom ('mud'). However, since overall faunal presentations necessarily tend to concentrate on the most frequent taxa only, the need remains for more detailed information on some of the minor constituents of the total foraminiferal population. The present study thus aims at a better understanding of the stimuli instigating agglutinated foraminifera in selecting their favorite habitats. It is apparent, however, that although this presentation takes into account a number of ecological parameters, numerous additional influences, biotic and abiotic, prevail in any marine body of water which may alter or complement the findings of this investigation. That significant changes in the (micro)environmental setting may take place within surprisingly short distances even became evident during the assessment of total foraminiferal associations by Haunold et al. (1997), when neighbouring samples often turned out to be dominated by characteristically different faunas.
The results of the present analysis not only may be applied to the investigation of recent foraminiferal faunas, but, on the precondition of taxonomical uniformity, may aid in the recognition and interpretation of ancient subtropical, carbonate-rich environments. The improved knowledge of agglutinated foraminiferal habits also might contribute to the identification of (paleo)ecological parameters not readily documented in the fossil record (e.g. seagrass growth). Right from the onset of activities, the gathering of such actuopaleontological information ranked central among research interests in northern Safaga Bay.

Northern Safaga Bay

Northern Safaga Bay encloses a shallow body of water, approximately 10km long (N to S), and about 7km wide (E to W), characterized by subtropical, carbonate-rich environmental conditions. Inside the bay, water depth varies from 0 to ≈55m, outside the bay, to the east, depth increases rapidly towards the open ocean, with well over 200m being reached at only a few hundred meters distance from the outer fringes of the bay (Piller & Pervesler, 1989, p. 105).
The northern bay area can be subdivided into four main regions (Piller & Pervesler, 1989, p. 107–110):

1) The 'East area', facing the ocean, exhibits the greatest water depths of down to ≈55m, and is most strongly influenced by open marine conditions.

2) The 'West area', separated and sheltered from the ocean by the islands and shoals of Tubya Al-Hamra and Tubya Al-Bayda, largely consists of a secluded basin, down to 38m deep.
3) The 'North area' is the shallowest part of the study area, with a maximum depth of approximately 12m. This is the region least exposed to open marine influences.
4) The SW-channel, connecting the northern and southern parts of Safaga Bay, gradually extends out of the western basin, with water depths steadily decreasing from about 30m to less than 5m.

The general current pattern within the study area shows an influx of Red Sea surface water south of Ras Abu Soma, with the main branch passing south of Tubya Al-Bayda, and via the SW-channel on into the southern part of the bay. This main current sends a much less intensive branch around the northern tip of Tubya Al-Hamra, into the northern, shallow reaches of the bay, and via the western basin on to join the main current into the SW-channel. This general current scheme can be temporarily altered by tidal activity. Tidal range during spring tide is less than 1m, the average range being distinctly smaller (PILLER & PERVESLER, 1989, p. 111).
During field work, in 1987, salinity varied from 41.7‰ in February, to 44.5‰ in July, while water temperatures lay between 22.8°C in February, and 28.4°C in July. Measurements were recognized as to be valid for the most of the bay, except for very shallow waters, where considerably higher values may be recorded, especially during the summertime (PILLER & PERVESLER, 1989, p. 110–111).
Coral reefs line the seaward sides of Ras Abu Soma, of Tubya Al-Hamra and Tubya Al-Bayda, and of a number of smaller rocky rises and slopes along the seaward fringes of the bay. Most of the shallow 'North area' is covered by seagrass (mostly *Halophila stipulacea*; to a much lesser extent *Halodule uninervis* and *Cymodocea rotundata*), with densities varying from true meadows to isolated stalks. Seagrass also lines the better part of Safaga Bay's western coast, the northern tip of Gazirat Safaga, and both banks of the SW-channel. Mud and muddy sands dominate in the central part of the western basin and extend southward into the SW-channel. Fine-grained sediments also cover the deeper parts of the 'East area', while most of the rest of the bay is covered by coral carpet or sand, both with and without coral patches. A survey of bottom types in northern Safaga Bay was presented by PILLER & PERVESLER (1989).

Material and Methods

Out of approximately 150 sample sites distributed all over northern Safaga Bay 73 were chosen for foraminiferal analysis (Fig. 1). Samples originate from water depths of 0 to 62m, cover all types of sedimentary facies, and were selected based on the results of sedimentary (PILLER & MANSOUR, 1990; 1994) and microfacies analysis (PILLER, 1994). Sample sizes were standardized by extracting identically gauged tube-cores (core length 5cm; core diameter 5cm; ≈98cm³). Parallel with each foraminiferal sample a sedimentological box-core was taken (PILLER & MANSOUR, 1990; PILLER, 1994).
Immediately upon core extraction, foraminiferal samples were immersed in alcohol/Rose-Bengal mixture, left for several days, and subsequently washed over a 63mm sieve and air-dried. Laboratory work consisted of another washing of samples over a set of sieves (mesh sizes 500, 250, 125, 63mm), oven-drying, and microsplitting to reduce sample sizes and thus the number of foraminifera. From the last split all foraminiferal tests were picked, identified and counted. Poorly preserved specimens were classified with one of the three major foraminiferal groups (agglutinated, porcelaneous, hyaline), and counted as unidentified representatives of the respective group. Stained and unstained tests were not treated separately, due to the small number of properly stained tests and in keeping

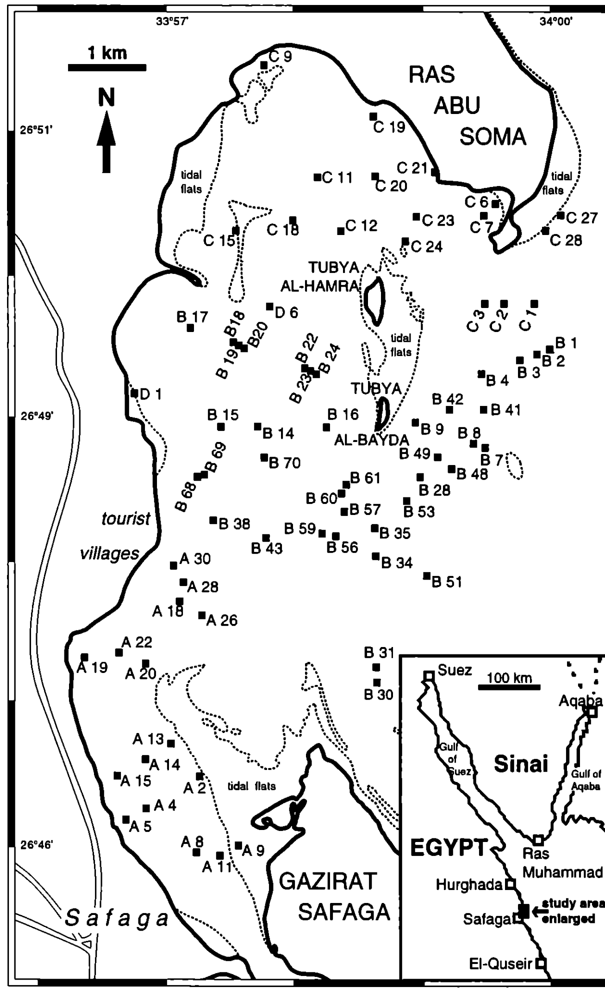

Figure 1: Geographic setting of study area and locations of sample sites (after PILLER, 1994).

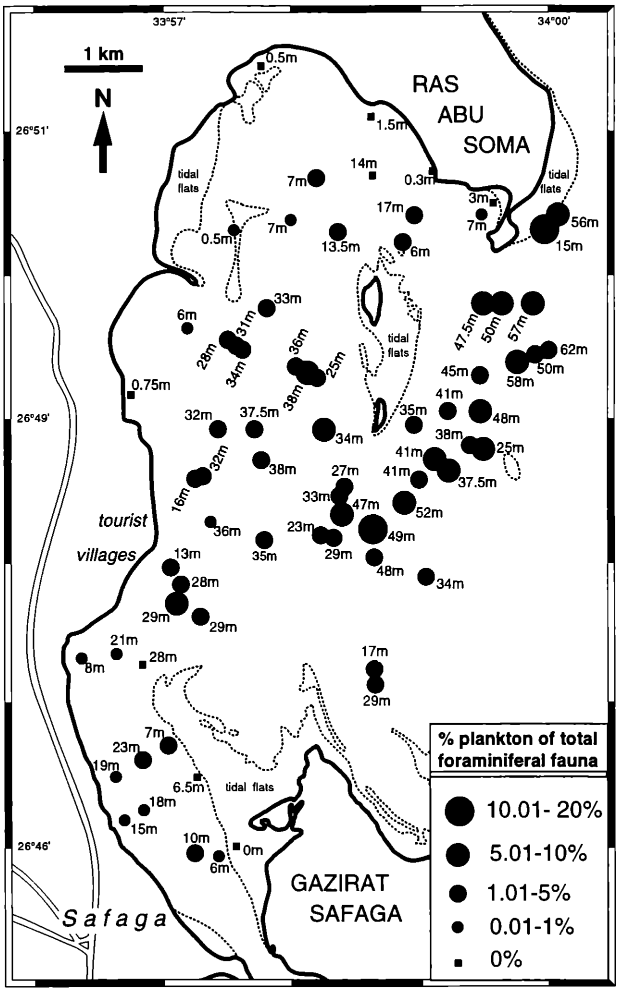

Figure 2: Water depth (after PILLER & MANSOUR, 1990) and frequencies of planktonic foraminifera at sample sites.

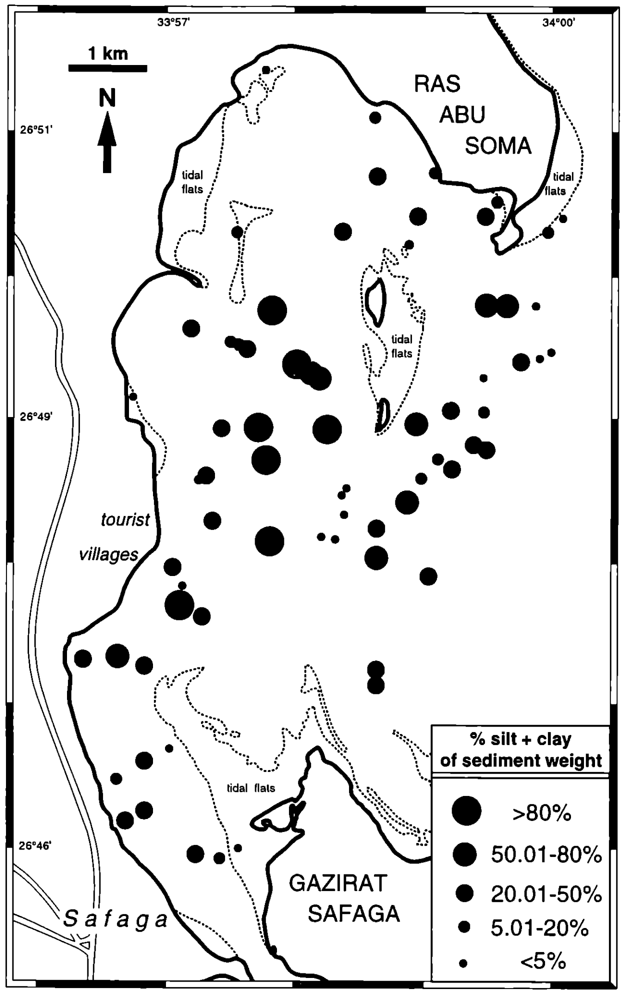

Figure 3: Amount of silt and clay at sample sites (after PILLER & MANSOUR, 1990).

with the basic actuopaleontological orientation of the study, i.e., representation of foraminiferal tests in the sediment and direct application to the fossil record. Also, because of the well sheltered setting of the study area, with minor current activity and small tidal range, total foraminiferal assemblages are considered to be more or less (par)autochthonous and to therefore reflect the distribution of the living organisms sufficiently well enough to warrant the evaluation of substrate preferences of selected taxa without disrciminating between living and dead tests (compare HAUNOLD et al., 1997). This assumption is backed by the results of BAHAFZALLAH (1979), who, in similarly well protected Jiddah Bay (Red Sea, Saudi Arabia), found dead foraminiferal assemblages to 'very faithfully' record the general distribution of the living species (BAHAFZALLAH, 1979, p. 397).

The 73 samples yielded a total of 24814 foraminiferal specimens which were assigned to 238 taxa (including planktonics as one taxon) and to 3 categories of unidentifiable tests. Agglutinated forms are the least numerous among the three major foraminiferal groups, amounting to a mere 24 taxa, versus 83 porcelaneous, and 132 hyaline taxa. For this study of textulariid foraminiferal environmental preferences only those of the 24 agglutinated taxa were taken into account which either occurred in at least 10% of all samples (= 7 samples), or which accounted for 1% or more of the total foraminiferal fauna in one sample at least; in this way, 14 species were selected for analysis (see Appendix 1). Environmental parameters examined in this study are grain-size, the intensity of seagrass growth, and the general influence of open marine conditions, reflected by the quantity of deposited planktonic foraminiferal tests. Water depth at sample sites is also recorded. Environmental data were provided by PILLER & MANSOUR (1990). Grain-size data are given in percentages of sediment weight, planktonic foraminifera are recorded in percentages of the total foraminiferal fauna. The seagrass stock is documented semiquantitatively, applying a point system to accomodate the individually observed density of growth, ranging from '0' (= no seagrass) to '3' (= dense seagrass meadow). Water depth is given in meters. Environmental data are compiled in Appendix 1; for spatial distribution of environmental parameters see Figs. 2-4.

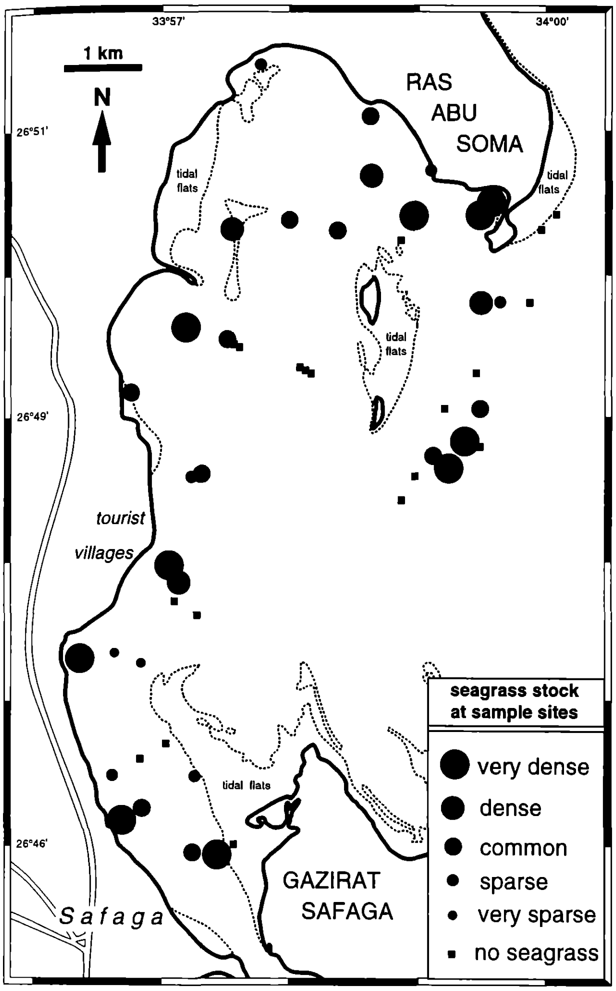

Figure 4: Seagrass stock at sample sites (after PILLER & MANSOUR, 1990).

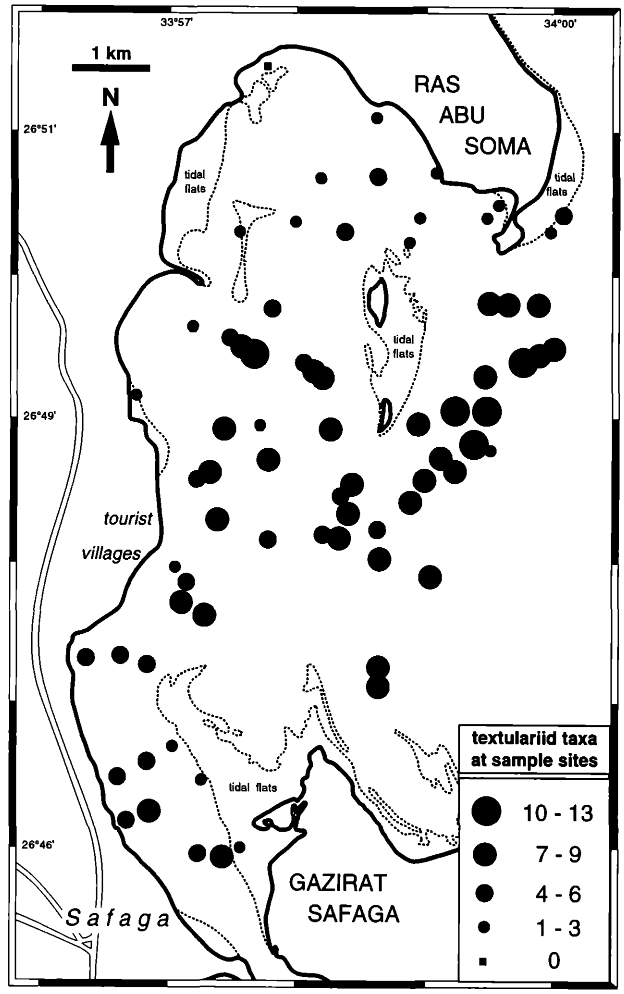

Figure 5: Textulariid taxa at sample sites.

Table 1. Correlation matrix incorporating environmental parameters, general textulariid distribution data, and factor scores; coefficients ≥95% significant given in bold print [95%-significance threshold: ±0.231].

	gravel (%)	sand (%)	silt (%)	clay (%)	seagrass (dens.-rank)	plankton (%)	depth (m)
gravel (%)	1						
sand (%)	**.312**	1					
silt (%)	**-.455**	**-.985**	1				
clay (%)	**-.360**	**-.893**	**.858**	1			
seagrass (density-rank)	-.123	**.230**	-.181	**-.261**	1		
plankton (%)	.046	-.193	.158	**.245**	**-.375**	1	
depth (m)	.016	**-.294**	**.252**	**.363**	**-.442**	**.578**	1
number of textul. taxa	.062	-.226	.182	**.294**	**-.290**	**.291**	**.733**
textul. specimens/98ccm	-.093	-.078	.091	.062	.164	.093	**.345**
textul% of total fauna	.153	-.080	.034	.142	-.224	.226	**.633**
factor 1	-.081	-.134	.146	.080	**.314**	-.114	.044
factor 2	-.029	.159	-.156	-.068	-.163	**.369**	**.486**
factor 3	**-.250**	**-.624**	**.626**	**.544**	**-.285**	-.0004	.140

Table 2. Correlation matrix incorporating most frequent textulariid taxa and environmental parameters; coefficients ≥95% significant given in bold print [95%-significance threshold: ±0.231].

	gravel (%)	sand (%)	silt (%)	clay (%)	seagrass (dens.-rank)	plankton (%)	water depth (m)
Reophax sp.1	-.170	**-.261**	**.280**	.193	.002	-.127	-.040
(?)*Verneuilina* sp.1	-.089	-.033	.051	.011	**.399**	-.008	.084
Eggerella sp.A	-.211	**-.646**	**.637**	**.582**	**-.309**	.100	.181
Sahulia cf. *S. barkeri*	-.027	.073	-.072	-.018	**.267**	.089	.199
Sahulia cf. *S. conica*	-.104	.003	.010	.034	.030	.178	**.327**
Sahulia kerimbaensis	-.118	-.091	.097	.132	-.205	**.313**	**.482**
Textularia agglutinans	-.068	-.073	.088	.020	.092	-.020	**.233**
Textularia cushmani	-.105	.053	-.037	-.007	-.058	**.259**	**.378**
Textularia foliacea foliacea	**-.244**	**-.498**	**.498**	**.495**	**-.309**	.211	**.350**
Textularia fol. occidentalis	.027	.087	-.092	-.042	-.196	**.235**	**.382**
Textularia rugulosa	-.055	.085	-.068	-.081	**.251**	.059	**.258**
Textularia sp.C	-.070	-.022	.026	.056	.142	**.254**	**.318**
Pseudogaudryina sp.A	-.071	.056	-.051	.016	-.106	**.284**	**.460**
Clavulina angularis	.071	-.001	-.005	-.039	**.349**	-.077	.046

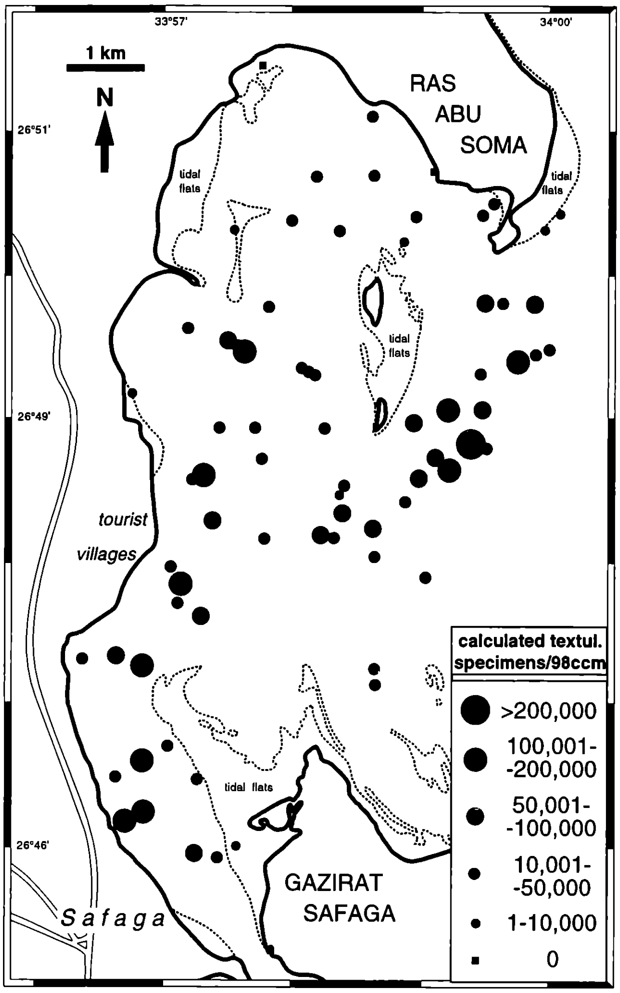

Figure 6: Calculated total numbers of textulariid specimens per ≈98cm³ of sediment at sample sites.

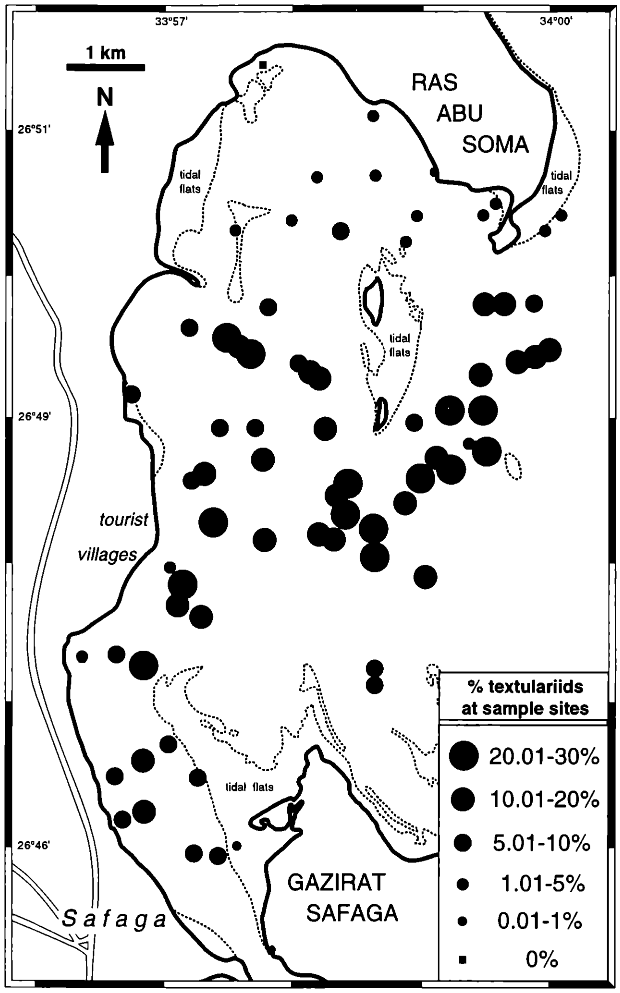

Figure 7: Percentages of textulariids of the total foraminiferal fauna at sample sites.

Foraminiferal and environmental data furnished by the 73 samples provided the basis for a correlation analysis to detect coincidences in the distributions of textulariid taxa and of ecological parameters. Principal component factor analysis aided in discerning probable environmental settings.

Samples and foraminiferal specimens are stored in the micropaleontological collection at the Institute of Paleontology, University of Vienna, Austria.

Results

General findings

Agglutinated tests were encountered in all but one of the 73 samples; the only sample which yielded no such foraminifera is sample C9 (Fig. 1), located in the northernmost, almost land-locked corner of the shallow northern reaches of Safaga Bay (water depth 0.5m). With 13 agglutinated taxa, sample B3 exhibits the highest textulariid species diversity, closely followed by sample B8, with a total of 11 species. These two samples also hold the largest concentrations of agglutinated specimens calculated per ≈98cm³ of sediment: 280576 and 182272 individuals for samples B8 and B3, including unidentified tests. Both samples stem from the outer, seaward side of the study area, where water depths are comparatively great (58m and 38m, respectively). The maximum proportion of agglutinated foraminifera was encountered in sample B28, with 28.1% of the total foraminiferal population, including unidentified tests. This sample, too, originates from the rather deep waters (41m) of the eastern part of the bay. Textulariid data are compiled in Appendix 1, for spatial distribution of textulariids see Figs. 5–7.

Correlation analysis of environmental parameters and of general textulariid distribution data (Table 1) shows that textulariid species diversity is significantly positively correlated with rising numbers of deposited planktonic foraminiferal tests and with water depth; it is commonly high in silty and clayey sediments, while it declines in sand and in the presence of seagrass. Total numbers of agglutinated specimens are significantly positively correlated with water depth, as are percentages of textulariids of the total foraminiferal fauna, the latter also being rather positively correlated with planktonic foraminifera and rather negatively with seagrass.

Selected species

Species – grain size correlation

None of the investigated agglutinated taxa is significantly positively correlated with coarse-grained sediments (Table 2). Gravel and sand are definitely avoided by several species, especially by *Textularia foliacea foliacea, Eggerella* sp. A, and *Reophax* sp. 1 (Table 2). Sand, in particular, appears to be a most unfavourable substrate for some foraminifera to live on/in, as high negative correlation coefficients evaluated for *Eggerella* sp.A and *Textularia foliacea foliacea* indicate. Fine-grained sediments, on the other hand, yielded no significantly negative correlations with any of the investigated agglutinated forms, some taxa even exhibit a pronounced preference for these types of substrates. *Eggerella* sp. A, *Textularia foliacea foliacea*, and, to a somewhat lesser extent, *Reophax* sp.1 are highly positively correlated with muddy sediments (Fig. 8; Table 2). Noteworthy are different substrate preferences of two variants of *Textularia foliacea*: The more compressed *T. f. foliacea* is typical of silty and clayey sediments and is significantly negatively correlated with gravel and sand. The oval rounded *T. f. occidentalis*, though not correlated significantly with either gravel or sand, nevertheless, appears to prefer these more coarse-grained sediment constituents to the finer silt and clay grain-size fractions (Table 2).

Species – seagrass correlation

Significantly positively correlated with seagrass are (?)*Verneuilina* sp. 1, *Clavulina angularis, Sahulia* cf. *S. barkeri*, and *Textularia rugulosa* (Fig. 9a–d; Table 2). Distinctly negatively correlated with seagrass are *Eggerella* sp. A and *Textularia foliacea foliacea* (Fig. 9e, f; Table 2). Seagrass is highly positively correlated with sand only, but significantly negatively with clay, water depth, and planktonic foraminiferal deposits (Table 1).

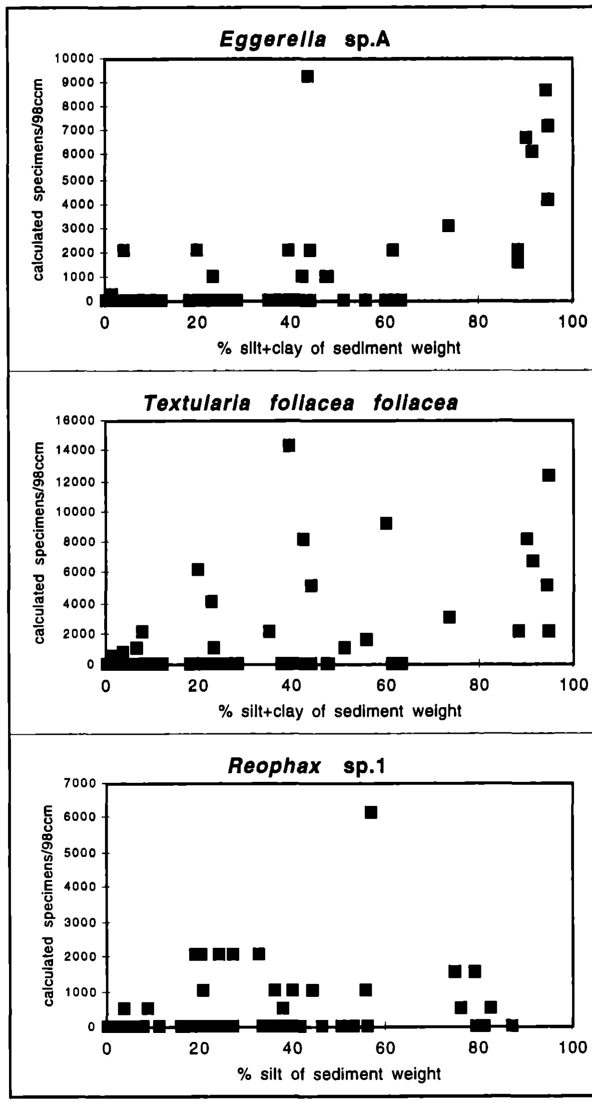

Figure 8: Calculated numbers of specimens per sample (≈98cm³) vs. proportions of silt and clay of total sediment weight, for *Eggerella* sp.A, *Textularia foliacea foliacea*, and *Reophax* sp.1.

Table 3. Oblique Solution Primary Pattern Matrix of a Principal Component Factor Analysis (Orthotran/Varimax Transformation) of frequencies of most common textulariid taxa at sample sites. Most significant positive factor loading(s) for each taxon given in bold print.

	factor 1	factor 2	factor 3
Reophax sp.1	**.526**	-.388	**.478**
(?)*Verneuilina* sp.1	**.833**	-.016	-.077
Eggerella sp.A	.059	-.186	**.830**
Sahulia cf. *S. barkeri*	**.795**	.119	.006
Sahulia cf. *S. conica*	**.509**	**.503**	-.102
Sahulia kerimbaensis	.026	**.723**	.149
Textularia agglutinans	**.716**	.203	.352
Textularia cushmani	.006	**.847**	-.0002
Textularia foliacea foliacea	-.076	.260	**.745**
Textularia fol. occidentalis	-.0007	**.747**	-.115
Textularia rugulosa	**.748**	.439	-.002
Textularia sp.C	-.015	**.550**	-.413
Pseudogaudryina sp.A	.224	**.747**	-.040
Clavulina angularis	**.817**	-.075	-.067

Species – plankton correlation

Sahulia kerimbaensis, Pseudogaudryina sp.A, *Textularia cushmani, T.* sp.C, and *T. foliacea occidentalis* are significantly positively correlated with planktonic foraminiferal remains (Table 2). Planktonic foraminifera are significantly positively correlated with water depth and clay, and significantly negatively with seagrass (Table 1).

Species – depth correlation

A significant positive correlation with water depth was ascertained for *Sahulia kerimbaensis, Textularia cushmani, T. foliacea occidentalis, T.* sp.C, and *Pseudogaudryina* sp.A.; all these species are also positively

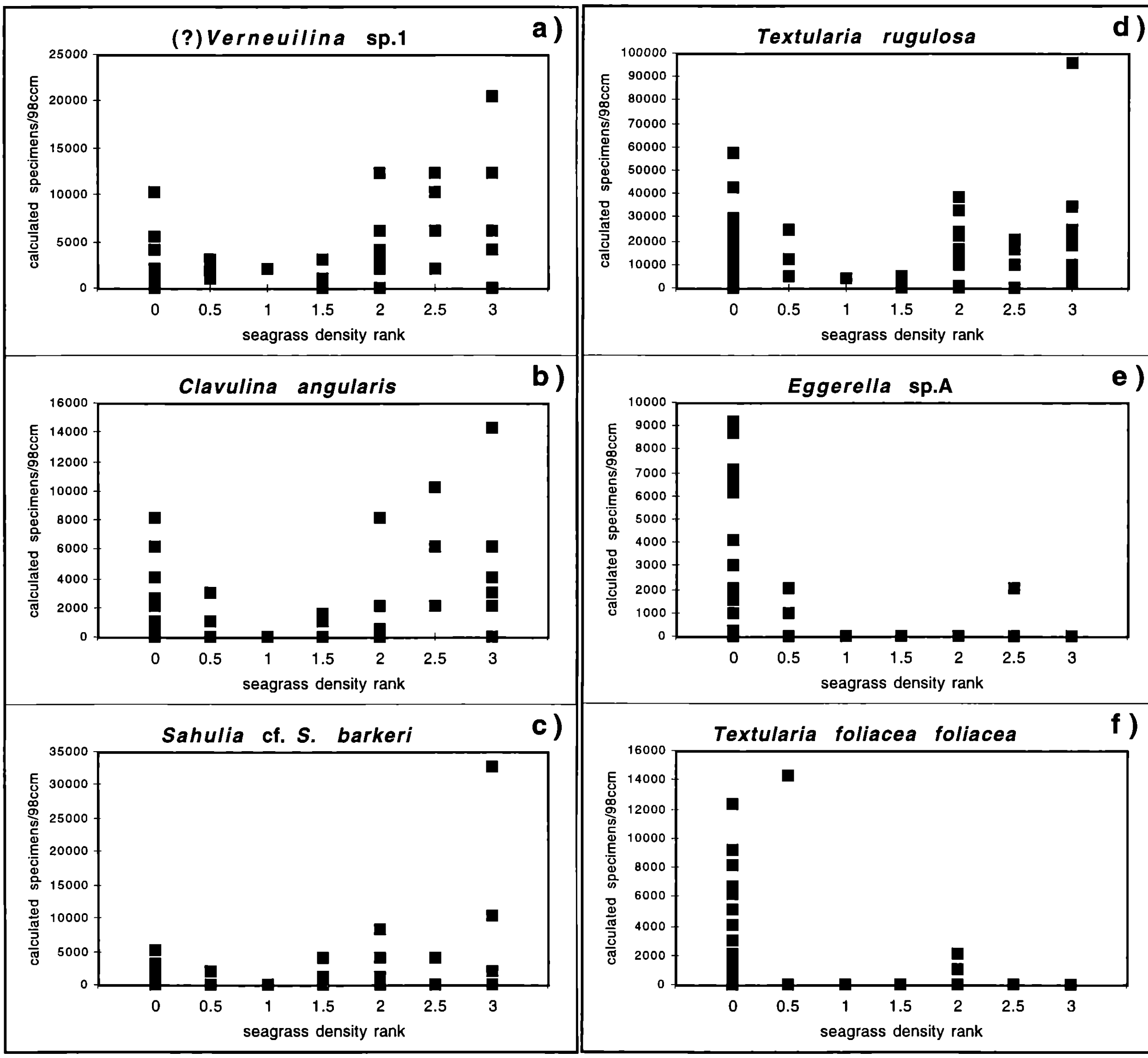

Figure 9: Calculated numbers of specimens per sample (≈98cm³) vs. densities of seagrass stock at sample sites, for (?)*Verneuilina* sp.1 (a), *Clavulina angularis* (b), *Sahulia* cf. *S. barkeri* (c), *Textularia rugulosa* (d), *Eggerella* sp.A (e), and *Textularia foliacea foliacea* (f).

correlated with planktonic foraminifera. Positive correlation with water depth further exhibit *Textularia foliacea foliacea*, a taxon also significantly positively correlated with silt and clay, and *T. rugulosa*, which is positively correlated with seagrass as well. A significantly positive correlation with water depth was the sole significant correlation ascertained for *Sahulia* cf. *S. conica* and *Textularia agglutinans.*

Factor analysis

The 14 most frequent textulariid taxa were selected for principal component factor analysis. Three factors are discerned (Table 3; Appendix 1). Factor 1 exhibits highest positive loadings of *Reophax* sp.1, (?)*Verneuilina* sp.1, *Sahulia* cf. *S. barkeri*, *S.* cf. *S. conica, Textularia agglutinans, T. rugulosa*, and *Clavulina angularis*. Most positively loaded with factor 2 are *Sahulia kerimbaensis, Textularia cushmani, T. foliacea occidentalis, T.* sp. C, and *Pseudogaudryina* sp.A. Highest positive loadings with factor 3 show *Eggerella* sp.A and *Textularia fol. foliacea. Reophax* sp.1 is significantly negatively loaded with factor 1, while *Textularia* sp.C is significantly negatively loaded with factor 3.

Correlation analysis of factor scores and environmental parameters (Table 1) disclosed that factor 1 is significantly positively correlated with seagrass, factor 2 with planktonic foraminifera and water depth; factor 3 is highly positively correlated with silt and clay, and significantly negatively with gravel, sand, and seagrass.

Discussion

Correlation and factor analyses reveal distinct interrelations between environmental parameters and the agglutinated foraminiferal population of northern Safaga

Bay. Generally, textulariid foraminifera abound where environmental conditions are marked by open marine influences and substrates contain about 20% of silt and clay (e.g. sample B3: 20%; sample B8: 23%). In northern Safaga Bay, such conditions dominate in deeper parts of the 'East area' along the seaward fringes of the bay, and, to a minor extent, are encountered along the margins of the 'West area'-basin, as well as in parts of the SW-channel. Textulariid species diversity and specimen numbers usually decline in seagrass areas and in extremely muddy, 'soupy' sediments, such as those covering the center of the western basin (compare Figs. 3–7; Table 1).

Several ecologically controlled textulariid species-groups are recognized. A first group comprises (?)*Verneuilina* sp.1, *Sahulia* cf. *S. barkeri, Textularia rugulosa*, and *Clavulina angularis*. These taxa all are significantly positively correlated with seagrass (Table 2) and characteristic elements of factor 1 (Table 3), the factor distinctly positively correlated with seagrass (Table 1). As far as *T. rugulosa* is concerned, a significant positive correlation with water depth (Table 2) and a high positive loading with factor 2, the factor positively correlated with both planktonic foraminifera and water depth, suggest that this taxon prefers deeper seagrass stands. It cannot be definitely answered, however, whether species typical of seagrass areas actually live clinging to the leaves, or whether they rather inhabit the sheltered, sandy environment between the stalks. Since specimens were extracted from sediment cores, and were not picked from the seagrass leaves directly, it remains unknown, whether the respective taxa are living at the bottom of the seagrass meadows primarily, either epi- or infaunally, or whether they have dropped from their natural habitat on the stalks to become embedded in the surrounding substrate. According to the morphogroup model of JONES & CHARNOCK (1985), the most probable mode of life of these forms is infaunal, judging from the proportions of their rather elongate tests. LANGER (1993), on the other hand, reported an epiphytic habit of *Textularia* and other smaller agglutinated taxa. In his opinion, these textulariids are not highly specialized epiphytes, however, but live as motile grazers on all kinds of phytal substrates (LANGER, 1993, p. 257, 258; Tab. 2). Nevertheless, the results of this study suggest that the presence of seagrass, in some way, is essential for the thriving of (?)*Verneuilina* sp.1, *Sahulia* cf. *S. barkeri, Textularia rugulosa*, and *Clavulina angularis*, as their correlation with other environmental parameters disclosed no comparably significant preferences.

A second group of species includes *Sahulia kerimbaensis, Textularia cushmani, T. foliacea occidentalis, T.* sp. C, and *Pseudogaudryina* sp.A. These taxa are significantly positively correlated with planktonic foraminiferal deposits and water depth (Table 2) and are most positively loaded with factor 2 (Table 3), the factor distinctly positively correlated with planktonic foraminifera and water depth (Table 1). Planktonic foraminiferal remains and water depth, which, in this study, is not considered as to be a truly limiting environmental parameter in its own right, can be taken as indicators for a suite of environmental factors which may actually control the distribution of these species. Operationally summarized as 'open marine influence', and most probably triggered by the influx of open Red Sea water, conceiveable parameters to come under this heading may include such ecological factors as the transport of nutrients, or the supply of more oxygenated and/or less saline water. However, since no specific data on any of these parameters are at hand, their actual significance cannot be evaluated here.

A third ecological species-group comprises *Eggerella* sp.A and *Textularia foliacea foliacea.* Both taxa are significantly positively correlated with silt and clay and are distinctly negatively correlated with gravel, sand, and seagrass (Table 2). They exhibit highest positive loadings with factor 3 (Table 3), the factor significantly positively correlated with silt and clay, and distinctly negatively with gravel, sand, and seagrass (Table 1). *Eggerella* sp. A and *Textularia foliacea foliacea* are the most specialized 'mud dwellers' among the agglutinated foraminiferal population of northern Safaga Bay, which concurs with the findings of HAUNOLD et al. (1997), who listed both taxa as characteristic elements of soft bottom associations. *Eggerella* sp. A is almost exclusively confined to the extremely muddy, even 'soupy', sediments of the western and eastern basins of the study area, whereas *Textularia foliacea foliacea* is also typical of muddy sands partly covered by microbial mats. This adaptability to a wider habitat range is also reflected by a significantly positive correlation of *T. fol. foliacea* with water depth (Table 2), as well as by a positive loading with factor 2, the 'open-marine'-factor (Table 3). According to JONES & CHARNOCK (1985), these characteristic soft bottom-species most probably have a predominantly infaunal habit, living as detrital and/or bacterial scavengers.

Among the 14 investigated most frequent agglutinated taxa from northern Safaga Bay three taxa remain for which no definite environmental preferences could be ascertained: *Reophax* sp.1, *Sahulia* cf. *S. conica*, and *Textularia agglutinans*.

Reophax sp.1 is most positively loaded with factor 1 (Table 3), the seagrass-factor, but it is not significantly positively correlated with seagrass directly (Table 2). Instead, *Reophax* sp.1 is highly positively correlated with silt and clay (Table 2) and exhibits a second very significant positive loading with factor 3 (Table 3), the soft bottom-factor. The species is significantly negatively correlated with sand and quite negatively with gravel, and it is the taxon most negatively correlated with planktonic foraminifera and water depth (Table 2), a fact also reflected by a significant negative load-

ing of this species with factor 2, the 'open-marine'-factor (Table 3). Combined, these results indicate that *Reophax* sp.1 prefers soft bottom-environments, but, apparently, favorite habitats have to be somewhat shielded from direct marine influences, hence negative correlation with water depth and planktonic foraminifera, and eventually support some seagrass growth. *Sahulia* cf. *S. conica* exhibits almost identically high positive loadings with factors 1 and 2, the seagrass- and 'open-marine'-factors, respectively, however, save for water depth, there exist no significant direct correlations of this taxon with any of the investigated environmental parameters. Definite statements of the actual ecological preferences of this species thus cannot be offered. The present results suggest, that *Sahulia* cf. *S. conica* favours deeper habitats which are probably exposed to open marine influences and which eventually support some seagrass stock.
The third species for which no definite environmental preferences could be established is *Textularia agglutinans*, the most common agglutinated taxon in northern Safaga Bay, by far, both by specimen numbers and by occurrence at sample sites (Appendix 1). The widespread distribution of *T. agglutinans* throughout the study area is reflected by a lack of significant direct correlations with any of the respected environmental parameters, except water depth (Table 2), as well as by high to very high positive loadings with each of the three established factors (Table 3). It thus appears, that either is habitat selection by *T. agglutinans* triggered by some other environmental criteria than the ones considered in the present investigation, or, which is the assumption favoured with this study, that *T. agglutinans* is a highly adaptable species abounding over an extremely wide range of ecological settings.
Aside from Haunold et al. (1997), earlier investigations of recent Red Sea foraminifera offer only a very limited basis of comparison with the findings of this study. Data on the environmental preferences of agglutinated species are particularly rare, especially if compared to the amount of information available on the habits of larger foraminifera. A study by Anan (1984) of littoral recent foraminifera from a stretch of Egyptian coast about 100km south of Safaga Bay mentions *Eggerella advena, Textularia agglutinans, T. foliacea*, and *Clavulina angularis*, however, the only information offered on these taxa is their frequency at sample sites. No details are given regarding substrates or other environmental parameters. Azazi (1992), in a study of benthic foraminifera from the Gulf of Suez, reports *Textularia agglutinans, T. foliacea, and Clavulina pacifica* from water depths of 0 to ≈100m (≈100m being the maximum depth recorded in that study area). From Jiddah Bay (Red Sea, Saudi Arabia), Bahafzallah (1979) offers some information on the distribution of agglutinated foraminifera in general, but does not specify environmental preferences of individual taxa, although a comparison of northern Safaga Bay with this equally land-locked, hypersaline area would be very instructive. Abou Ouf (1992) reports *Clavulina* as to be the only textulariid taxon encountered in the coastal sabkha of Al-Kharrar lagoon on the Saudi Arabian coast of the Red Sea.

Conclusions

This investigation of ecological preferences of common agglutinated taxa from subtropical, carbonate-rich northern Safaga Bay yielded the following results:

1) Textulariid species diversity, specimen numbers, and percentages of textulariids of the total foraminiferal fauna are highest in deeper habitats (water depth ≥40m) exposed to open marine conditions with silt and clay amounting to about 20% of total sediment weight. Frequencies decline in coarse substrates, in extremely muddy, 'soupy' sediments, and in seagrass areas.
2) Seagrass associated taxa are (?)*Verneuilina* sp.1, *Sahulia* cf. *S. barkeri, Textularia rugulosa, and Clavulina angularis*, with *T. rugulosa* prefering deeper seagrass stands. Due to core-sampling it remains unknown whether these forms live truly epiphytically, or whether they rather inhabit the sheltered environment at the bottom of the seagrass meadows, living either as epi- or as infaunal elements.
3) *Sahulia kerimbaensis, Textularia cushmani, T. foliacea occidentalis, T.* sp. C, and *Pseudogaudryina* sp. A are characteristic of environments exposed to open marine influences. Most probably, the actual distribution of these species is controlled by a variety of ecological parameters (e.g. transport of nutrients; supply of more oxygenated and/or less saline water), however, since no data on these factors are at hand, more detailed information cannot be offered. Deeper areas exposed to open marine conditions and eventually supporting some seagrass stock also seem to provide the most likely habitat for *Sahulia* cf. *S. conica*, one of the few investigated species for which no definite environmental preferences could be ascertained.
4) *Eggerella* sp.A, *Textularia foliacea foliacea*, and, to a somewhat lesser extent, *Reophax* sp.1 are typical of muddy, even 'soupy' sediments. These taxa most probably have an infaunal habit living as detrital and/or bacterial scavengers.
5) No definite environmental preferences were established for *Textularia agglutinans*, by far the most frequent agglutinated taxon in northern Safaga Bay. Throughout the study area this species is very common at almost all sample sites which is interpreted as to reflect an extreme adaptability of *T. agglutinans* to a wide range of ecological settings.

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APPENDIX 1

Samplewise compilation of foraminiferal data, environmental parameters, and factor scores. Infrequent taxa not considered in statistic analysis marked (*).

sample number / contents	picked fraction of 98ccm sample	picked total foram. specimens	picked textulariid specimens	calculated textul. specimens/98ccm	% textulariids of total fauna	number of textulariid taxa	indetermined textulariid specimens	*Reophax* sp.1	(*)*Reophax* sp.2	(*)*Haplophragmoides bradyi*	(*)*Labrospira jeffreysii*	(*)*Ammobaculites* cf. *A. crassaformis*	(*)(?)*Haddonia* sp.	(*)*Spiroplectammina earlandi*	(?)*Verneuilina* sp.1	*Eggerella* sp.A	*Sahulia* cf. *S. barkeri*	*Sahulia* cf. *S. conica*	*Sahulia kerimbaensis*	*Textularia agglutinans*	*Textularia cushmani*	*Textularia foliacea foliacea*	*Textularia foliacea occidentalis*	*Textularia rugulosa*	*Textularia* sp.C	*Pseudogaudryina* sp.A	(*)*Pseudogaudryina* sp.B	(*)*Plotnikovina* cf. *P. aequa*	(*)*Siphoniferoides* cf. *S. balearicus*	*Clavulina angularis*	(*)*Valvulina oviedoiana*
A 2	1/2048	293	17	34816	5.8	3	5	0	0	0	0	0	0	0	1	0	0	0	0	9	0	0	0	2	0	0	0	0	0	0	0
A 4	1/2048	444	57	116736	12.8	8	11	1	0	0	0	0	0	0	2	0	0	0	3	18	0	1	0	16	0	0	0	0	0	4	1
A 5	1/2048	513	50	102400	9.8	5	11	0	0	0	0	0	0	0	3	0	1	0	0	20	0	0	0	12	0	0	0	0	0	3	0
A 8	1/2048	282	28	57344	10.0	6	1	0	0	0	0	0	0	0	1	0	0	0	1	15	1	0	0	8	0	0	0	0	0	1	0
A 9	1/1024	461	2	2048	0.4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
A 11	1/1024	542	48	49152	8.9	7	9	0	0	0	0	0	0	0	4	0	2	1	3	7	0	0	0	19	0	0	0	0	0	3	0
A 13	1/1024	179	15	15360	8.4	3	4	0	0	0	0	0	0	0	0	0	1	0	0	7	0	0	0	3	0	0	0	0	0	0	0
A 14	1/2048	370	57	116736	15.4	6	8	0	0	0	0	0	0	0	1	1	0	2	7	25	0	0	0	13	0	0	0	0	0	0	0
A 15	1/512	506	35	17920	6.9	6	0	1	0	0	0	0	0	0	1	0	1	0	0	20	0	0	0	9	0	0	0	0	0	3	0
A 18	1/1024	234	28	28672	12.0	8	3	0	0	0	0	0	0	1	0	2	0	1	3	14	0	2	0	0	0	0	0	0	0	1	1
A 19	1/1024	412	17	17408	4.1	4	1	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	3	0	0	0	0	0	2	0
A 20	1/1024	483	116	118784	24.0	5	25	1	0	0	0	0	0	0	2	0	0	0	2	61	0	0	0	24	0	0	0	0	0	1	0
A 22	1/2048	326	30	61440	9.2	5	0	3	0	0	0	0	0	0	1	1	0	0	0	19	0	0	0	6	0	0	0	0	0	0	0
A 26	1/1024	613	71	72704	11.6	7	7	0	0	0	0	0	0	0	4	9	0	0	1	43	0	0	1	4	0	0	0	0	0	2	0
A 28	1/2048	283	57	116736	20.2	6	11	0	0	0	0	0	0	0	3	1	2	0	0	27	0	0	0	8	0	0	0	0	0	5	0
A 30	1/2048	477	20	40960	4.2	3	3	1	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	5	0	0	0	0	0	0	0
B 01	1/256	249	42	10752	16.9	9	2	0	0	0	0	0	0	0	0	0	0	5	1	11	4	3	3	11	0	1	0	0	0	1	0
B 02	1/512	268	30	15360	11.2	8	2	0	0	0	0	0	0	0	0	0	0	0	2	9	3	0	2	9	1	1	1	0	0	0	0
B 03	1/2048	456	89	182272	19.5	13	7	0	0	0	0	0	0	0	1	1	0	2	8	24	6	3	3	28	1	1	3	0	0	1	0
B 04	1/1024	212	26	26624	12.3	7	1	0	0	0	0	0	0	0	1	0	3	3	1	11	0	0	2	4	0	0	0	0	0	0	0
B 07	1/1024	314	12	12288	3.8	3	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	5	0	0	0	0	0	1	0
B 08	1/2048	607	137	280576	22.6	11	10	1	0	0	0	0	0	0	10	0	16	4	2	37	1	0	1	47	0	1	0	0	0	7	0
B 09	1/2048	514	43	88064	8.4	7	5	0	1	0	0	0	0	0	5	0	0	0	1	18	0	0	0	8	0	0	1	0	0	4	0
B 14	1/1024	423	22	22528	5.2	3	1	0	0	0	0	0	0	0	0	7	0	0	0	0	2	12	0	0	0	0	0	0	0	0	0
B 15	1/512	418	41	20992	9.8	9	4	0	0	0	0	0	0	1	2	2	2	1	0	17	0	2	0	8	0	0	0	0	0	2	0
B 16	1/512	454	64	32768	14.1	8	6	3	1	0	0	2	0	0	0	13	0	0	0	19	0	16	0	3	0	0	1	0	0	0	0
B 17	1/1024	348	24	24576	6.9	3	8	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	6	0	0	0	0	0	3	0
B 18	1/1024	262	59	60416	22.5	6	11	0	0	0	0	0	0	0	0	0	0	1	5	18	1	0	0	22	1	0	0	0	0	0	0
B 19	1/512	353	42	21504	11.9	8	9	0	0	0	0	0	0	0	1	0	0	1	3	3	0	0	1	18	1	0	0	0	0	5	0
B 20	1/1024	547	147	150528	26.9	10	39	1	0	0	0	0	0	0	2	1	5	2	11	48	0	8	1	29	0	0	0	0	0	0	0
B 22	1/512	455	33	16896	7.3	5	8	1	0	0	0	0	0	0	0	8	0	0	1	11	0	4	0	0	0	0	0	0	0	0	0
B 23	1/1024	198	29	29696	14.6	7	4	1	0	0	0	0	0	0	0	3	0	0	2	8	0	3	0	6	0	0	0	0	0	2	0
B 24	1/1024	292	32	32768	11.0	8	5	1	0	0	0	0	0	0	0	0	2	0	7	4	0	1	2	4	0	0	0	0	0	6	0
B 28	1/512	427	120	61440	28.1	9	19	0	0	0	0	0	0	0	2	0	3	1	8	40	1	0	3	42	0	0	0	0	0	1	0
B 30	1/1024	374	29	29696	7.8	9	2	1	0	0	0	0	0	0	1	1	0	1	2	12	0	0	0	5	0	0	0	0	0	3	1
B 31	1/1024	276	23	23552	8.3	8	6	2	0	0	0	0	1	0	2	0	0	1	0	0	0	0	1	5	1	0	0	0	0	4	0
B 34	1/512	426	95	48640	22.3	8	17	0	0	0	0	0	0	0	0	0	1	0	16	29	0	3	3	20	3	3	0	0	0	0	0
B 35	1/1024	357	75	76800	21.0	5	16	0	0	0	0	0	0	0	0	0	0	0	14	29	0	5	0	10	0	1	0	0	0	0	0
B 38	1/1024	406	84	86016	20.7	9	12	0	0	0	0	0	0	0	3	2	2	0	13	22	3	14	0	12	0	0	0	0	0	1	0

APPENDIX 1

sample number / contents	% gravel of sediment weight	% sand of sediment weight	% silt of sediment weight	% clay of sediment weight	seagrass - density (range: 0-3)	% planktonic foraminifera	water depth (m)	factor 1 ('open marine-factor')	factor 2 ('seagrass-factor')	factor 3 ('soft bottom-factor')
A 2	0.85	98.53	0.62	0	1	0	6.5	-0.33	-0.50	-0.59
A 4	1.98	62.98	32.93	2.12	2	0.45	18.5	-0.72	1.72	0.85
A 5	5.66	72.24	20.98	1.12	3	0.58	15	-0.62	1.05	-0.36
A 8	4.5	68.8	25.35	1.35	2	1.07	10	0.14	-0.24	-0.55
A 9	3.87	94.6	1.53	0	0	0	0	-0.39	-0.50	-0.59
A 11	2.88	78.56	17.62	0.93	3	0.37	6	-0.26	0.35	-0.43
A 13	6.47	91.91	1.62	0	0	1.12	7	-0.30	-0.62	-0.60
A 14	0.91	54.84	41.57	2.69	0	1.08	23	0.56	-0.33	0.11
A 15	0.39	89.56	9.05	1.01	1.5	0.59	19	-0.50	-0.22	-0.36
A 18	0.01	11.29	79.77	8.93	0	5.55	29	-0.30	-0.45	0.36
A 19	1.43	70.04	27.07	1.46	3	0.97	8	-0.37	-0.45	-0.59
A 20	1.61	75.78	21.01	1.6	0.5	0	28	-0.41	0.24	-0.10
A 22	1.05	37.06	56.89	5	0.5	0.92	21	-2.14	2.05	2.61
A 26	0.61	55.64	37.89	5.85	0	2.28	29	-0.88	0.65	2.07
A 28	15.71	80.17	4.11	0	2.5	1.41	28	-1.04	1.77	0.34
A 30	2.33	70.98	24.28	2.42	3	1.68	13	-0.80	0.15	0.25
B 01	1.45	94.94	3.62	0	0	2.41	62	0.27	-0.81	-0.60
B 02	1.98	95.77	1.72	0.53	0	3.36	50	0.80	-1.00	-0.96
B 03	1.68	78.32	17.58	2.42	0	8.76	58	6.50	-1.31	-0.42
B 04	3.1	95.68	1.22	0	0	3.78	45	0.35	-0.63	-0.75
B 07	3.64	54.74	39.09	2.53	0	6.37	25	-0.31	-0.55	-0.60
B 08	1.22	75.76	20.23	2.79	3	3.62	38	0.35	6.87	1.25
B 09	0.13	38.23	56.05	5.6	0	3.89	35	-0.70	1.33	-0.32
B 14	0.03	4.91	87.06	8	0	4.73	37.5	-0.50	0.12	3.55
B 15	6.84	69.72	21.32	2.12	0	3.35	32	-0.44	-0.27	-0.09
B 16	0.1	9.78	79.17	10.95	0	5.07	34	-1.24	0.67	3.38
B 17	0.85	75.03	22.66	1.47	3	0.29	6	-0.39	-0.28	-0.57
B 18	1.82	85.73	11.44	1.01	2	1.53	28	0.67	-0.75	-0.94
B 19	12.56	80.45	5.72	1.27	0	1.13	31	0.05	-0.43	-0.79
B 20	2.1	55.5	35.98	6.42	0	4.02	34	0.47	0.52	1.64
B 22	0.13	4.78	82.63	12.47	0	3.74	36	-0.75	-0.13	1.15
B 23	2.27	24.03	55.82	17.88	0	5.04	33	-0.74	0.28	1.28
B 24	0.96	47.89	44.43	6.73	0	1.71	25	0.26	0.19	-0.06
B 28	2.47	87.51	8.18	1.84	0	4.68	41	0.58	-0.48	-0.69
B 30	2.6	49.8	39.97	7.64	0.5	3.48	29	-0.66	0.21	0.19
B 31	2.24	77.08	19.21	1.46	0	1.81	17	-0.41	0.48	-0.13
B 34	2.11	41.99	50.79	5.11	0	3.52	48	2.04	-1.18	-1.12
B 35	0.72	55.35	38.2	5.73	0	10.09	49	1.25	-0.85	0.25
B 38	0.89	59.78	35.34	3.99	0.5	0.99	36	0.92	0.03	2.57

APPENDIX 1

sample number / contents	picked fraction of 98ccm sample	picked total foram. specimens	picked textulariid specimens	calculated textul. specimens/98ccm	% textulariids of total fauna	number of textulariid taxa	indetermined textulariid specimens	*Reophax* sp.1	(*)*Reophax* sp.2	(*)*Haplophragmoides bradyi*	(*)*Labrospira jeffreysii*	(*)*Ammobaculites* cf. *A. crassaformis*	(*)(?)*Haddonia* sp.	(*)*Spiroplectammina earlandi*	(?)*Verneuilina* sp.1	*Eggerella* sp.A	*Sahulia* cf. *S. barkeri*	*Sahulia* cf. *S. conica*	*Sahulia kerimbaensis*	*Textularia agglutinans*	*Textularia cushmani*	*Textularia foliacea foliacea*	*Textularia foliacea occidentalis*	*Textularia rugulosa*	*Textularia* sp.C	*Pseudogaudryina* sp.A	(*)*Pseudogaudryina* sp.B	(*)*Plotnikovina* cf. *P. aequa*	(*)*Siphoniferoides* cf. *S. balearicus*	*Clavulina angularis*	(*)*Valvulina oviedoiana*
B 41	1/1024	334	75	76800	22.5	10	8	0	0	0	0	0	0	0	0	0	8	0	5	22	2	1	0	23	2	1	0	1	0	2	0
B 42	1/2048	262	65	133120	24.8	10	6	0	0	0	0	0	0	0	2	0	1	2	4	22	3	2	0	21	0	1	0	0	0	1	0
B 43	1/512	526	63	32256	12.0	6	8	0	0	2	0	1	0	0	0	17	0	0	0	24	1	10	0	0	0	0	0	0	0	0	0
B 48	1/2048	219	51	104448	23.3	7	13	0	0	0	0	0	0	0	6	0	5	0	0	5	2	0	0	17	1	0	0	0	0	2	0
B 49	1/1024	285	51	52224	17.9	7	3	0	0	0	0	0	0	0	3	0	1	0	7	20	0	2	0	13	0	0	0	0	0	2	0
B 51	1/512	473	79	40448	16.7	9	14	1	0	0	0	0	0	0	11	2	2	0	0	15	1	0	0	27	0	0	0	0	0	5	1
B 53	1/1024	270	45	46080	16.7	8	4	0	0	0	0	0	0	0	0	0	1	1	9	13	0	9	0	6	0	1	0	1	0	0	0
B 56	1/256	333	50	12800	15.0	8	10	0	0	0	0	0	0	0	2	0	1	0	6	14	0	0	1	13	1	2	0	0	0	0	0
B 57	1/512	462	105	53760	22.7	7	21	1	0	0	0	0	0	0	0	0	4	0	5	32	1	0	0	40	0	0	0	0	0	0	1
B 59	1/1024	282	52	53248	18.5	6	15	0	0	0	0	0	0	0	0	0	1	0	4	15	0	0	1	12	0	0	0	0	0	4	0
B 60	1/512	91	18	9216	19.9	4	2	0	0	0	0	0	0	0	0	0	0	1	0	9	0	0	1	5	0	0	0	0	0	0	0
B 61	1/256	289	58	14848	20.1	9	8	0	0	0	1	0	0	0	0	1	1	0	1	20	1	2	2	21	0	0	0	0	0	0	0
B 68	1/1024	185	17	17408	9.2	6	1	0	0	0	1	0	0	0	1	0	1	0	3	5	0	0	0	5	0	0	0	0	0	0	0
B 69	1/2048	468	58	118784	12.4	7	17	0	0	0	1	0	0	0	3	0	2	0	3	12	0	0	0	19	0	0	0	0	0	1	0
B 70	1/512	505	54	27648	10.7	8	5	3	0	0	2	1	0	0	0	12	0	0	1	15	0	13	0	2	0	0	0	0	0	0	0
C 01	1/1024	823	53	54272	6.4	9	9	0	0	1	0	0	0	0	0	0	2	0	8	15	1	0	0	11	0	1	0	1	0	4	0
C 02	1/1024	417	47	48128	11.3	8	9	0	0	0	0	0	0	0	3	0	4	0	7	16	2	0	2	3	0	0	0	0	0	1	0
C 03	1/2048	321	43	88064	13.4	7	11	0	0	0	0	0	0	0	6	0	0	3	2	6	0	0	0	10	2	0	0	0	0	3	0
C 06	1/2048	310	5	10240	1.6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0
C 07	1/2048	237	5	10240	2.1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	1	0
C 09	-1/128	247	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C 11	1/2048	319	6	12288	1.9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5	0	0	0	0	0	0	0
C 12	1/2048	329	21	43008	6.4	4	4	0	0	0	0	0	0	0	6	0	0	0	1	5	0	0	0	5	0	0	0	0	0	0	0
C 15	1/2048	264	3	6144	1.1	2	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C 18	1/1024	288	11	11264	3.8	3	2	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	1	1	0	0	0	0	0	0	0
C 19	1/2048	402	15	30720	3.7	3	0	0	0	0	0	0	0	0	1	0	0	0	0	9	0	0	0	5	0	0	0	0	0	0	0
C 20	1/2048	454	18	36864	4.0	5	3	1	0	0	0	0	0	0	5	0	0	0	0	1	0	0	0	5	0	0	0	0	0	3	0
C 21	1/1024	254	2	2048	0.8	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
C 23	1/2048	464	17	34816	3.7	2	5	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	9	0	0	0	0	0	0	0
C 24	1/512	417	7	3584	1.7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
C 27	1/512	286	12	6144	4.2	5	0	0	0	0	0	0	0	0	0	0	0	4	4	0	1	0	2	1	0	0	0	0	0	0	0
C 28	1/1024	161	3	3072	1.9	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	0
D 01	1/256	96	5	1280	5.2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	0
D 06	1/512	403	36	18432	8.9	6	4	1	0	0	0	0	0	0	0	3	1	0	0	18	0	4	0	5	0	0	0	0	0	0	0

APPENDIX 1

sample number / contents	% gravel of sediment weight	% sand of sediment weight	% silt of sediment weight	% clay of sediment weight	seagrass - density (range: 0-3)	% planktonic foraminifera	water depth (m)	factor 1 ('open marine-factor')	factor 2 ('seagrass-factor')	factor 3 ('soft bottom-factor')
B 41	1	92.06	5.82	1.13	2	5.69	48	1.50	-0.09	-1.00
B 42	1.91	75.31	18.65	4.13	0	3.05	41	2.37	0.14	0.08
B 43	0	5.3	81.39	13.31	0	3.99	35	-0.93	0.18	2.80
B 48	2.53	74.52	19.02	3.93	3	6.85	37.5	0.61	1.57	-0.88
B 49	6.12	86.01	6.12	1.75	2	5.26	41	0.07	-0.08	-0.13
B 51	7.33	44.85	37.71	10.11	0	2.75	34	-0.64	0.59	0.05
B 53	0.95	38.78	46.33	13.93	0	5.56	52	0.89	-0.61	0.94
B 56	23.08	75.55	1.37	0	0	4.8	29	0.22	-0.75	-0.76
B 57	9.93	86.43	3.64	0	0	5.19	47	-0.10	-0.20	-0.33
B 59	18.25	80.25	1.51	0	0	3.55	23	0.17	-0.21	-0.61
B 60	7.87	90.05	2.09	0	0	1.1	33	-0.13	-0.77	-0.68
B 61	7.01	91.49	1.5	0	0	4.51	27	-0.07	-0.69	-0.51
B 68	8.3	88.89	2.82	0	1.5	1.08	16	-0.11	-0.58	-0.57
B 69	2.06	59.04	33.59	5.32	2	1.49	32	0.01	0.76	-0.33
B 70	0	8.37	75.06	16.57	0	3.76	38	-1.17	0.56	2.97
C 01	3.88	94.24	1.56	0.32	0	6.56	57	0.80	-0.21	-0.55
C 02	0.64	35.79	52.02	11.54	1.5	5.52	50	0.99	-0.52	-0.68
C 03	1.19	36.25	53.11	9.45	2.5	6.54	47.5	0.80	0.66	-1.75
C 06	0.21	81.56	16.02	2.22	3	0	3	-0.29	-0.71	-0.62
C 07	0.42	61.89	33.9	3.8	3	0.42	7	-0.36	-0.44	-0.59
C 09	0.03	98.72	1.06	0.2	1.5	0	0.5	-0.30	-0.74	-0.63
C 11	6.19	91.72	2.09	0	0	1.25	7	-0.24	-0.60	-0.61
C 12	1.53	73.19	24.39	0.89	2	2.74	13.5	-0.44	0.44	-0.43
C 15	1.84	91.87	5.47	0.83	2.5	0.38	0.5	-0.44	-0.31	-0.57
C 18	12.75	85.68	1.37	0.2	2	0.7	7	0.02	-0.85	-0.73
C 19	1.88	90.49	6.77	0.86	2	0	1.5	-0.30	-0.42	-0.58
C 20	0.43	71.4	27.32	0.86	2.5	0	14	-1.34	1.79	0.49
C 21	0.82	92.96	5.9	0.32	1.5	0	0.3	-0.29	-0.73	-0.63
C 23	1.58	56.38	40.13	1.9	3	1.08	17	-0.20	-0.48	-0.60
C 24	1.5	96.46	2.05	0	0	1.92	6	-0.28	-0.70	-0.62
C 27	9.71	88.31	1.98	0	0	9.79	56	0.24	-0.93	-0.73
C 28	3.27	91.2	5.22	0.31	0	17.98	15	-0.16	-0.79	-0.62
D 01	0.12	99.59	0.29	0	2	0	0.75	-0.32	-0.68	-0.62
D 06	0.1	11.21	76.2	12.5	0	4.71	33.5	-0.55	-0.29	0.41

PLATE 1

SEM photomicrographs of recent textulariid taxa most common in northern Safaga Bay (Red Sea, Egypt). Scale bar equals 200µm.

1 *Reophax* sp.1; sample B16.

2 (?)*Verneuilina* sp.1; sample B9.

3 *Eggerella* sp.A; sample B16.

4 *Sahulia* cf. *S. barkeri* (HOFKER, 1978); sample B8.

5 *Sahulia* cf. *S. conica* (d'ORBIGNY, 1839); sample B20.

6 *ahulia kerimbaensis* (SAID, 1949); sample B34.

7 *Textularia agglutinans* d'ORBIGNY, 1839; sample B16.

8 *Textularia cushmani* SAID, 1949; sample B8.

9 *Textularia foliacea foliacea* HERON-ALLEN and EARLAND, 1915; sample B16.

10 *Textularia foliacea occidentalis* CUSHMAN, 1922; sample B1.

11 *Textularia rugulosa* (CUSHMAN, 1932); sample B18.

12 *Textularia* sp.C; sample B34.

13 *Pseudogaudryina* sp.A; sample B34.

14 *Clavulina angularis* d'ORBIGNY, 1826; sample B9.

PLATE 1