N. Jb. Geol. Paläont. Mh. **2003** (11) 641 – 655 Stuttgart, November 2003

Scleractinian corals as pollution indicators, Red Sea Coast, Egypt

M. Abd El-Wahab, Hurghada and **A. S. El-Sorogy,** Zagazig

With 5 figures and 2 tables

Abd El-Wahab, M. & El-Sorogy, A. S. (2003): Scleractinian corals as pollution indicators, Red Sea Coast, Egypt. – N. Jb. Geol. Paläont. Mh., **2003**: 641–655; Stuttgart.

Abstract: The analysis of trace elements of thirty-four specimens of scleractinian corals from the Red Sea Coast indicates an enrichment in Cu, Pb, Ni, Zn and Co in Recent skeletons in comparison with their Pleistocene counterparts which were deposited in a pristine environment unaffected by human activities. Differences in the distribution patterns of trace elements among the Recent specimens are attributed in general to differences in microstructure and microarchitecture of the examined species. The highest concentrations are generally found in skeletons with loose crystal packing and high intergranular porosity (suborders Fungiina and occasionally Astrocoeniina), whereas the lowest concentrations are mostly recorded in skeletons with tight crystal packing as well as lower reactive surface area and intercrystalline porosity. The high concentrations of trace elements in Recent skeletons of scleractinian corals may be attributed to the increase of landfills, domestic sewage, phosphate mining and tourism activities in the Hurghada area.

Zusammenfassung: Rezente Korallen von der Küste des Roten Meeres zeigen gegenüber ihren pleistozänen Vertretern eine starke Anreicherung der Spurenelemente Cu, Pb, Ni, Zn und Co. Mikrostruktur und Mikroarchitektur beeinflussen Wechsel in der Verteilung und Konzentration der Spurenelemente. Die Anreicherung von Spurenelementen in Korallen der Gegend von Hurghada ist auf Landgewinnung, Hausabfälle und Abwasser, Phosphat-Abbau und Tourismus zurückzuführen.

0028-3630/03/2003-0641 $ 3.75

Introduction

During a long time, the Red Sea has been considered being relatively unpolluted. However recently, trials were done to monitor the pollution of some coastal areas of the Red Sea using sediments and sea shells (Hanna 1982a, b, Nawab 1983, Halim et al. 1987, Mansour et al. 2000, Ziko et al. 2001, Nour 2001).

Pollution by phosphates heavily affects Recent sea shells and sediments of the El-Hamrawein area are seriously affected by the phosphate pollution attributed to the intensive phosphate mining of phosphates along the Red Sea Coast (Ziko et al. 2001), particularly, by the washing and upgrading processes of the ore and its shipping from Safaga Port.

Corals absorb metals such as lead, mercury, tin, zinc, cadmium, copper, cobalt, iron, manganese, nickel, aluminum, vanadium and silver. However, high concentrations of these metals can kill corals and other reef organisms. Lower concentrations can inhibit coral growth and reproduction and may contribute to coral bleaching. Therefore, it is important to improve the quantitative and qualitative data on heavy metals in coral skeletons.

We selected the Hurghada area (Fig. 1) for our study, because field observations indicated pollution by oil and heavy metals resulting from the oil industry, nearby phosphate ore mining and shipping, sewage and other activities. We have studied heavy metal concentrations in Pleistocene corals which have grown in a pristine environment unaffected by anthropogenic activities and compared these values in their living counterparts. Higher concentrations of heavy metals in living corals are thought to be caused by pollution. The aim of the present study is to explore the potential of heavy metal concentrations in scleractinian corals as indicators of pollution.

Material and Methods

Thirty-four scleractinian specimens are collected from the coastal area of Hurghada City (Fig. 1); seventeen specimens from Pleistocene reefs and the other seventeen of the same species from the neighboring living reefs. Living samples are collected by scuba diving in water depths of 1 to 7 m below the mean low tide level. Species have been identified according to Sheppard & Sheppard (1991) and Veron (2000).

All samples are washed with distilled water and dried at room temperature, ten grams of each sample are ground in an electric agate mortar for 20 minutes and then passed through a 80-mesh sieve. Half a gram of each sample is digested in Teflon cups, using mixed reagents of HF, $HClO_4$ and HNO_3 acids with a ratio 1:2:3 respectively (Oregioni & Aston 1984). The elements of Zn, Cu, Ni, Co, Mn and Pb have been determined with an

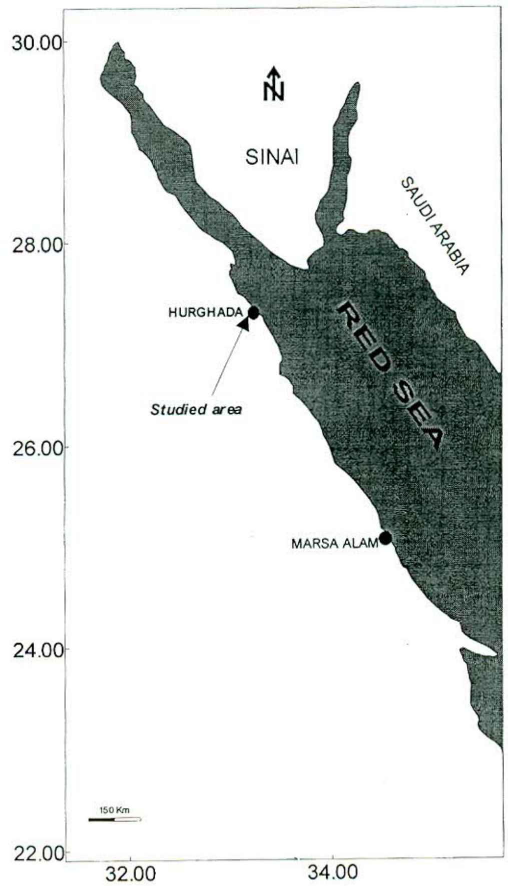

Fig. 1. Location map.

Atomic Absorption Spectrophotometer (GBC 932 AA type) in the laboratory of National Institute of Oceanography and Fisheries, Red Sea Branch, Hurghada.

Pleistocene reefs

The Pleistocene coral reefs along the Red Sea coastal plain of Egypt have been dealt with in numerous paleontological, stratigraphical and sedimento-

logical studies. Most of these studies indicate that the sequence of Pleistocene reefs is composed of three successive raised reef complexes separated by conglomerates. The studied specimens were collected from the intermediate reef, which is elevated 3.50-6.80 m above mean sea level. The scleractinian corals and the associated fauna are generally preserved in life position. Among the dominating scleractinian corals, representatives of the following species have been collected and analysed: *Stylophora pistillata* (Esper, 1797), *Pocillopora verrucosa* (Ellis & Solander, 1786), *Acropora pharaonis* (Edwards & Haime, 1860), *Porites mayeri* Vaughan, 1918, *Goniopora columna* Dana, 1846, *Cycloseris costulata* (Ortmann, 1889), *Fungia fungites* (Linnaeus, 1758), *Ctenactis echinata* (Pallas, 1766), *Galaxea fascicularis* (Linnaeus, 1767), *Mycedium elephantotus* (Pallas, 1766), *Lobophyllia corymbosa* (Förskal, 1775), *Favia pallida* (Dana 1846), *Favites complanata* (Ehrenberg, 1834), *Goniastrea edwardsi* Chevalier 1971, *Platygyra daedalea* (Ellis & Solander, 1786), *Leptoria phrygia* Ellis & Solander, 1786, and *Echinopora lamellosa* Esper, 1795 (Figs. 2, 3). In addition, the sampled reef contains also well preserved milleporids, pelecypods, gastropods, and echinoids. All components are cemented together by crustose red algae.

Living reefs

Specimens of the same Pleistocene species have been collected by scuba diving from 1-7 m depth below the mean low tide level, i.e. from the tidal flat to the upper part of the reef slope. Coral communities form dense small-sized colonies on the tidal flat and become larger towards the reef crest and upper reef slope.

Fig. 2. Scleractinian corals from the Hurghada area, Egypt
1. *Stylophora pistillata* (Esper, 1797), side view of a colony. 2. *Pocillopora verrucosa* (Ellis & Solander, 1786), side view of a colony. 3. *Acropora pharaonis* (Edwards & Haime, 1860), side view of a colony. 4. *Porites mayeri* Vaughan, 1918, top view of a colonial part. 5. *Goniopora columna* Dana, 1846, top view of a colonial part. 6. *Cycloseris costulata* (Ortmann, 1889), upper surface of a corallum. 7. *Ctenactis echinata* (Pallas, 1766), upper surface of a corallum. 8. *Fungia fungites* (Linnaeus, 1758), upper surface of a corallum. Scale bar = 10 mm.

Figure 2

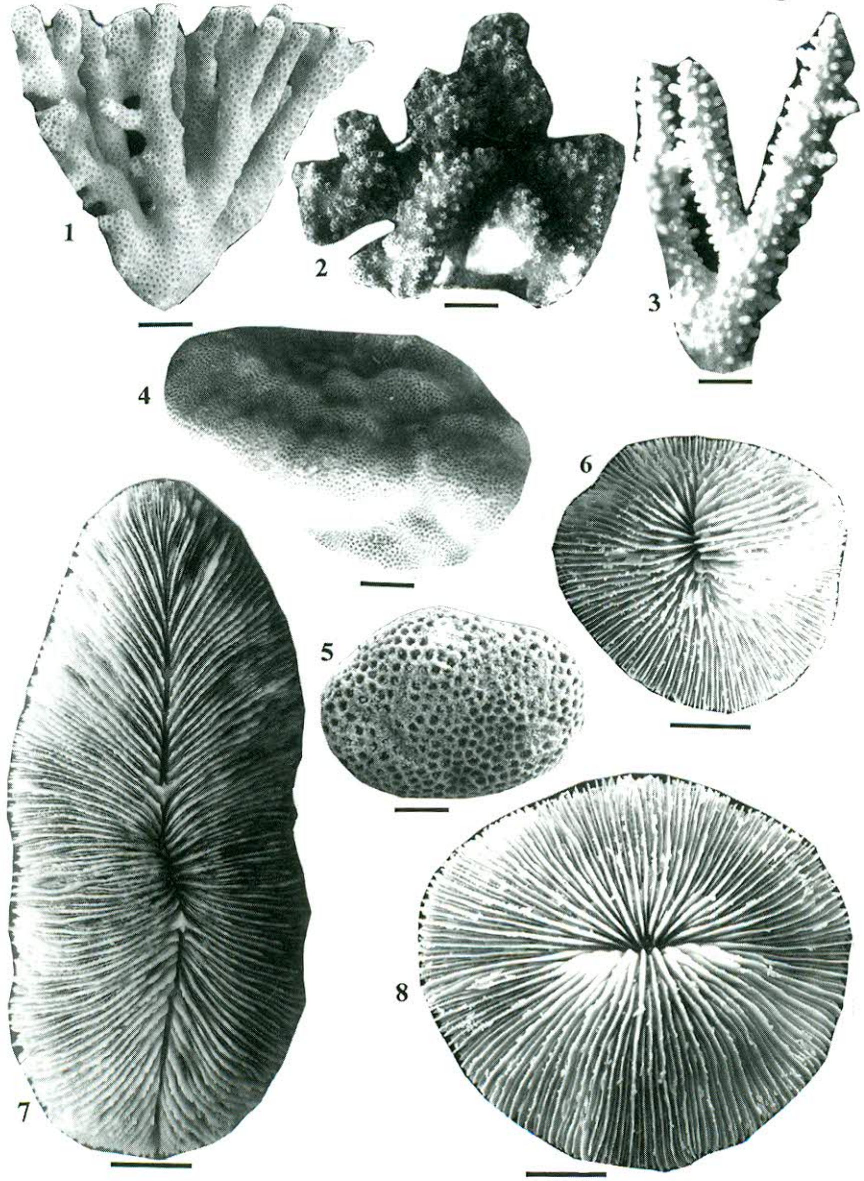

Fig. 2 (Legend see p. 644)

Concentrations of trace elements

Coral reefs are important indicators of and in part also active players in the composition of water masses and biogeochemical cycles. Therefore, coral heads and skeletons are a vast data bank from which we can retrieve information on the chemical and physical changes of the local environment. (Livingston & Thompson 1971, St. John 1974, El-Wakeel et al. 1984). Important factors influencing the portioning of a pollutant between ambient sea water and skeletons are the characteristics of the skeleton, such as the body area of interaction, porosity and permeability, but also the pH/Eh values, the concentration of the specific pollutant in the sea water, the time of exposure and selectivity of skeletons. In the following, we discuss the highest and lowest concentrations as well as the average values of trace elements found in the studied Pleistocene and Recent coral specimens from the Hurghada area.

1) Manganese

Mn, a member of the Fe-Co group of metals, is an essential metal in the terrestrial sediments, where it is mainly associated with iron. It is transported into the marine environment by landfills, marine paints, remains of construction and the corrosion of steel constructions and pipelines.

The Mn content in the Pleistocene samples varies from 2.53 ppm in *Favites complanata* to 70.45 ppm in *Ctenactis echinata*, averaging 19.91 ppm (Tab. 1), while in the living samples, it ranges between 0.33 ppm in *Galaxea fascicularis* and 7.78 ppm in *Ctenactis echinata*, with an average of 2.07 ppm (Tab. 2). The concentration of Mn in the Pleistocene skeletons is about 9 times higher than the Recent ones (Fig. 4).

Fig. 3. Scleractinian corals from the Hurghada area, Egypt
1. *Galaxea fascicularis* (Linnaeus, 1767), top view of a colonial part. 2. *Mycedium elephantotus* (Pallas, 1766), top view of a colonial part. 3. *Lobophyllia corymbosa* (Forskal, 1775), side view of a colonial part. 4. *Favia pallida* (Dana, 1846), top view of a colonial part. 5. *Favites complanata* (Ehrenberg, 1834), top view of a colonial part. 6. *Goniastrea edwardsi* Chevalier, 1971, top view of a colonial part. 7. *Platygyra daedalea* (Ellis & Solander, 1786), top view of a colonial part. 8. *Leptoria phrygia* Ellis & Solander 1786, top view of a colonial part. 9. *Echinopora lamellosa* Esper, 1795, top view of a colonial part. Scale bar = 10 mm.

Figure 3

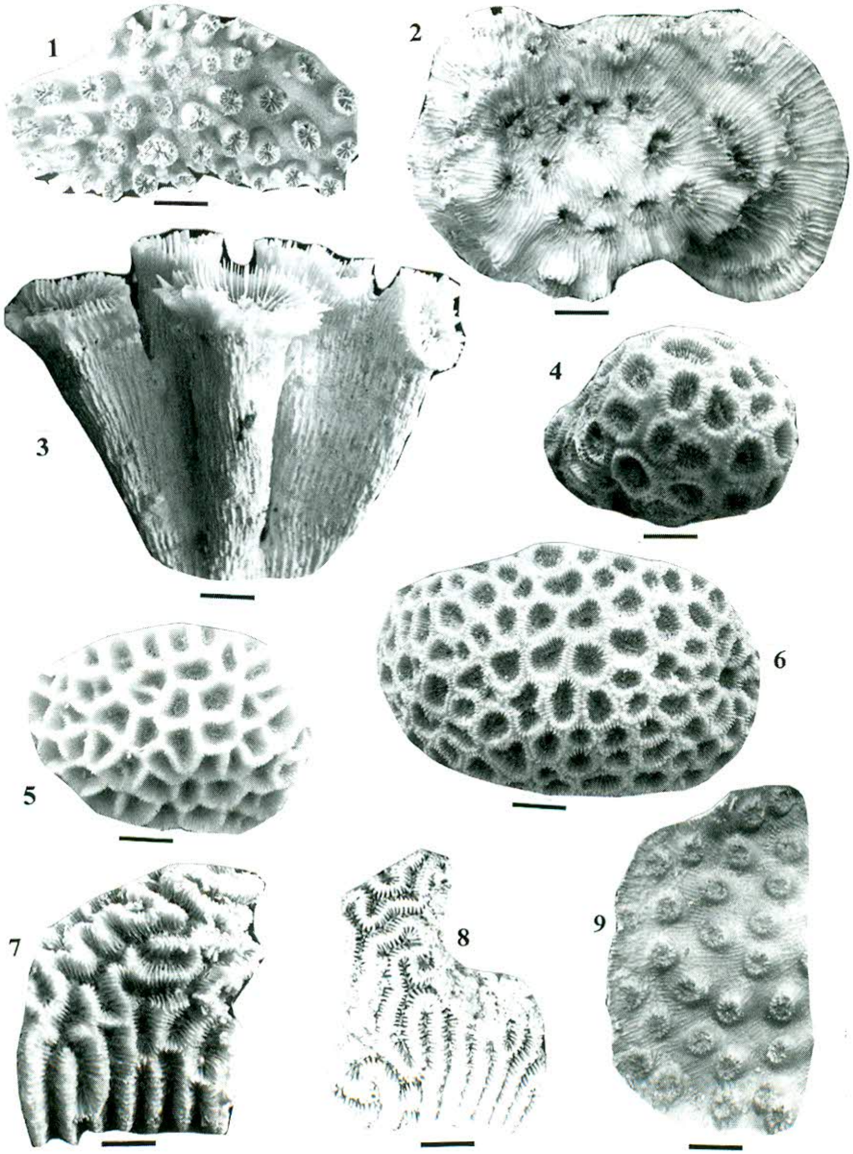

Fig. 3 (Legend see p. 646)

Table 1. Concentration of some trace elements in Pleistocene scleractinian corals from the Hurghada area, Egypt.

Suborders	Species	Cu	Ni	Pb	Zn	Mn	Co
Astrocoeniina	*Stylophora pistillata*	1.05	**0.63**	0.64	3.34	25.88	**1.13**
	Pocillopora verrucosa	**1.54**	0.21	0.57	2.00	9.75	0.14
	Acropora pharaonis	1.26	0.26	0.34	2.46	34.01	0.18
Fungiina	*Porites mayeri*	1.29	**0.01**	0.78	2.84	18.95	0.23
	Goniopora columna	0.82	0.03	1.07	**4.49**	16.34	0.19
	Cycloseris costulata	0.64	0.15	0.49	2.94	11.09	0.22
	Ctenactis echinata	1.11	0.46	**1.39**	4.25	**70.45**	0.04
	Fungia fungites	1.16	0.10	0.94	3.53	37.77	0.55
Faviina	*Galaxea fascicularis*	0.42	0.24	1.04	4.08	20.93	0.17
	Mycedium elephantotus	1.57	0.76	1.12	3.35	0.61	0.18
	Lobophyllia carymbosa	0.34	0.57	1.19	2.49	23.97	0.29
	Favia pallida	0.86	0.03	0.31	3.40	18.78	**0.01**
	Favites complanata	0.67	0.04	0.94	1.25	**2.53**	0.06
	Goniastrea edwardsi	0.79	0.34	0.78	2.07	14.99	0.16
	Platygyra daedalea	**0.23**	0.05	0.49	**1.15**	2.56	0.09
	Leptoria phrygia	0.26	0.06	0.85	2.15	14.18	0.08
	Echinopora lamellosa	0.40	0.39	**0.22**	4.10	12.8	0.11
Average		0.83	0.27	0.81	2.79	19.19	0.21

2) Copper

In aquatic environments Cu exists in particulate, colloidal and soluble form (Förstner & Wittmann 1983). In sea water, Cu is formed by direct precipitation from seawater as amorphous and crystalline salts; it coprecipitates with manganese oxides (Rifaat et al. 1992).

In the Recent samples Cu content varies from 0.80 ppm in *Lobophyllia corymbosa* to 3.23 ppm in *Favites complanata*, averaging 1.92 ppm (Tab. 2). In the Pleistocene species Cu ranges from 0.23 ppm in *Platygyra daedalea* to 1.54 ppm in *Pocillopora verrucosa* with an average of 0.83 ppm (Tab. 1). The concentration of Cu in Recent skeletons is about two times higher than the Pleistocene counterparts (Fig. 4).

3) Nickel

Ni is added to the marine environments by a wide range of anthropogenic causes: seepages of crude oil pollution by diesel fuel, drilling mud, marine paints and landfills.

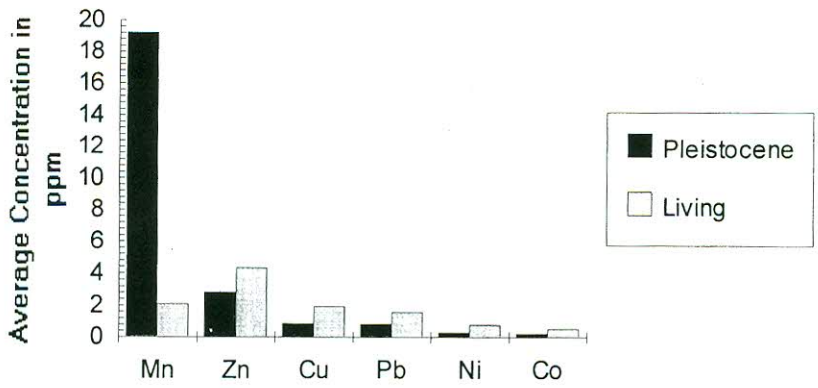

Fig. 4. Average concentrations of trace metals in Pleistocene and living coral species of the Hurghada area, Egypt.

Ni-content in the Pleistocene samples ranges from 0.01 ppm in *Porites mayeri* to 0.63 ppm in *Stylophora pistillata*, with an average of 0.27 ppm (Tab. 1), while in the living samples it varies between 0.12 ppm in *Goniopora columna* and 1.95 ppm in *Stylophora pistillata*, averaging 0.76 ppm (Tab. 2). This means that the average concentration of Ni in the Recent samples is about three times higher than in the Pleistocene ones (Fig. 4).

4) Lead

Pb is used in the marine paints as lead chlorides, as weights for the diving equipment and is also added to the marine environment with the oil and water from boats. It is mainly associated with carbonates and can become dissolved in aragonite crystals (Beltagy 1984).

Pb content in the living specimens ranges from 0.75 ppm in *Pocillopora verrucosa* to 4.22 ppm in *Galaxea fascicularis* (average value 0.54 ppm; Tab. 2), while in the Pleistocene ones it varies between 0.22 ppm in *Echinopora lamellosa* and 1.39 ppm in *Ctenactis echinata* (average 0.81 ppm; Tab. 1). The average concentration of Pb in the Recent skeletons is about two times higher than in those of the Pleistocene (Fig. 4).

Table 2. Concentration of some trace elements in living scleractinian corals from the Hurghada area, Egypt.

Suborders	Species	Cu	Ni	Pb	Zn	Mn	Co
Astrocoeniina	*Stylophora pistillata*	1.48	**1.95**	1.28	4.68	3.15	**1.80**
	Pocillopora verrucosa	2.61	0.48	**0.75**	3.74	2.08	0.31
	Acropora pharaonis	2.31	0.85	1.49	**1.49**	2.34	0.33
Fungiina	*Porites mayeri*	2.40	0.38	1.25	3.05	1.34	0.56
	Goniopora columna	1.49	**0.12**	1.36	**9.14**	2.22	0.45
	Cycloseris costulata	2.24	0.30	1.32	3.35	1.91	0.62
	Fungia fungites	2.11	0.39	1.67	3.95	1.94	0.99
	Ctenactis echinata	1.63	0.98	1.44	3.26	**7.78**	0.36
Faviina	*Galaxea fascicularis*	1.74	0.52	**4.22**	4.79	**0.33**	0.20
	Mycedium elephantotus	1.76	0.95	1.37	3.67	1.08	0.32
	Lobophyllia corymbosa	**0.80**	0.96	2.07	4.57	0.35	0.54
	Favia pallida	1.69	0.68	1.25	4.06	3.23	**0.03**
	Favites complanata	**3.23**	0.35	1.28	3.59	1.79	0.33
	Goniastrea edwardsi	2.24	1.03	1.30	3.23	1.19	0.52
	Platygyra daedalea	2.21	0.82	1.10	3.65	0.88	0.58
	Leptoria phrygia	1.86	0.29	1.45	2.95	2.85	0.55
	Echinopora lamellosa	1.19	1.26	1.60	4.37	0.92	0.31
Average		1.92	0.76	1.54	4.31	2.07	0.49

5) Zinc

Zn-Sulphate is the main source of anthropogenic zinc in the marine environment. It is widely uses in construction and as paint.

Pleistocene samples have Zn values from 1.15 ppm in *Platygyra daedalea*, to 4.49 ppm in *Goniopora columna* with an average of 2.79 ppm

Fig. 5. Microstructure of sclearctinian corals from the Hurghada area, Egypt.
1. Wide aragonitic needles comprising the trabecular structure of *Favites complanata* (Suborder Faviina). Scale bar = 10 μ. 2. Enlargment of fig. 1. Scale bar = 7 μ. 3. Aragonite needles comprising the isolated trabecular structure of *Fungia fungites* (Suborder Fungiina). Scale bar = 20 μ. 4. Enlargment of fig. 3. Scale bar = 10 μ. 5. Aragonite needles comprising the trabecular structure of *Acropora pharaonis* (Suborder Astrocoeniina). Scale bar = 30 μ. 6. Enlargment of fig. 5. Scale bar = 20 μ.

Figure 5

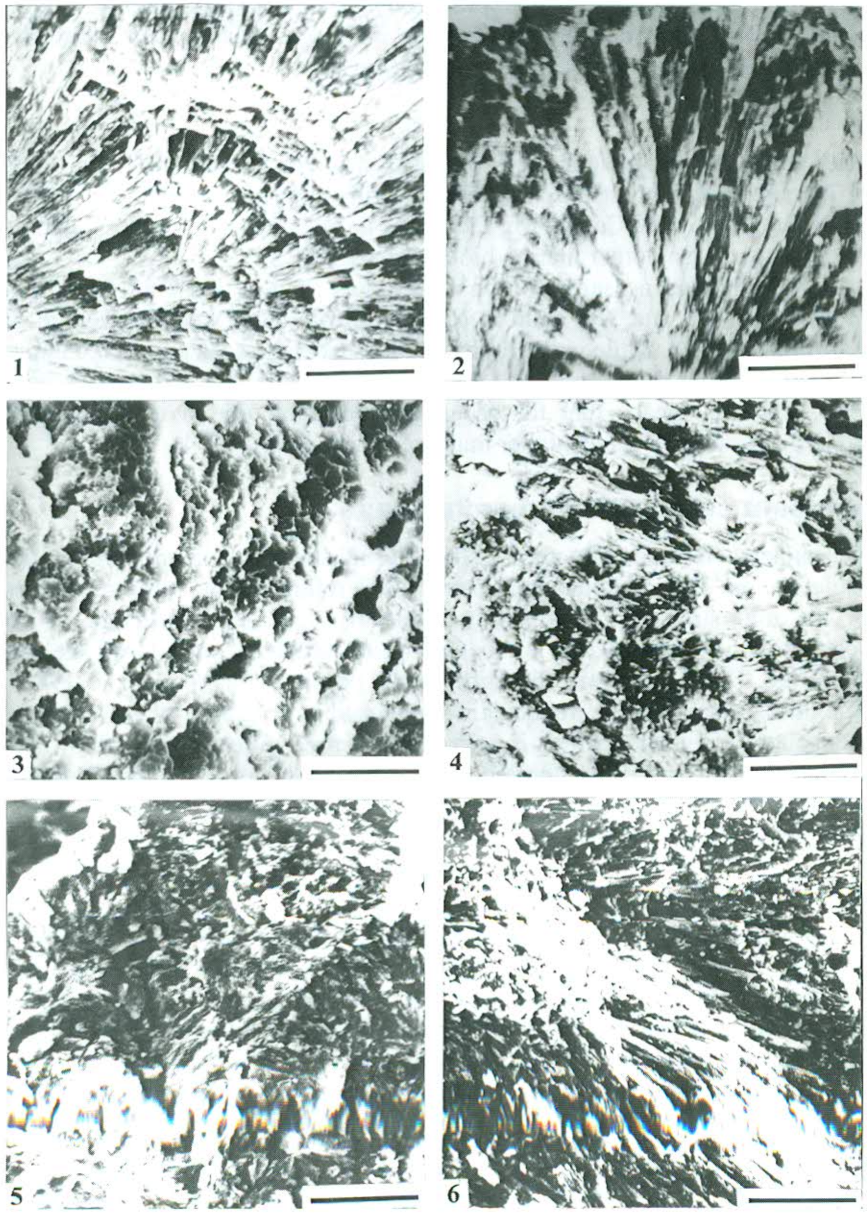

Fig. 5 (Legend see p. 650)

(Tab. 1). Zn values of living specimens range between 1.49 ppm in *Acropora pharaonis* and 9.14 ppm in *Goniopora columna* with an average of 4.31 ppm (Tab. 2). The mean concentration of Zn in Recent skeletons is about two times higher than in the Pleistocene ones (Fig. 4).

6) Cobalt

The main anthropogenic sources of cobalt are: contamination by fuel oils, refineries, marine paints (Co-oxides), landfills and shipyards. The chemical similarity of Co with Ca and Mg facilitates its accumulation in the skeletons of corals and many other marine biota (SMITH 1992).

In the Pleistocene samples, Co has values ranging between 0.01 ppm in *Favia pallida* and 1.13 ppm in *Stylophora pistillata* with an average of 0.21 ppm (Tab. 1), while in the living samples Co values vary from 0.03 ppm in *Favia pallida* to 1.8 ppm in *Stylophora pistillata*, averaging 1.49 ppm (Tab. 2). This means that the mean concentration of Co in the Recent skeletons is about 7 times higher than the Pleistocene (Fig. 4).

Microstructure and microarchitecture

The skeletal "microarchitecture" is the internal structural organization of the skeleton and the skeleton "microstructure" refers to the building stones of the microarchitecture (CONSTANTZ 1986). The basic structure of all scleractinian corals are the trabecula, which are bars or rods of skeletal aragonite. These bars form the light-weight porous skeleton (DULLO 1987). The ultrastructure of the trabecula is composed of aragonite fibers arranged in a spherulitic cluster, which is called the sclerodermite (WELLS 1956). The degree of intercrystalline porosity within the sclerodermites and therefore the tightness of the packing and arrangement of the fibers vary within the different suborders of the stony corals.

Suborder Faviina

In the studied samples, the suborder Faviina is represented by species with massive growth form (*Favia pallida, Favites complanata, Goniastrea edwardsi, Platygyra daedalea, Leptoria phrygia, Echinopora lamellosa, Galaxea fascicularis),* foliaceous growth form (*Echinopora lamellosa* and *Lobophyllia corymbosa*), and encrusting growth form (*Mycedium elephantotus*). Septa are essentially laminar, consisting of massive and linear arrangement of trabecular centers. They exhibit tight crystal packing of broad aragonite fibers, which – in contrast to the Fungiinae and Astrocoeniinae – restricts the reactive surface area and intercrystalline porosity to a minimum (EL-SOROGY 1997a, b). In SEM micrographs (Fig. 5/1,2), the size of the aragonite needles of the trabecular structure of some faviinian species ranges from 0.35-0.50 μm.

Suborder Fungiina

The solitary species *Fungia fungites, Cycloseris costulata*, and *Ctenactis echinata* and the massive species *Goniopora columna*, and *Porites mayeri* represent this suborder. The septa are composed of small, loosely arranged sticks with an isolated trabecular center, loose crystal packing and high amounts of intergranular porosity (Constantz 1986). Therefore, these skeletons have a high total surface area (El Sorogy 1997a). In SEM micrographs (Fig. 5/3,4), the size of the aragonite needles composing the trabecular structure ranges from 0.15-0.20 μm.

Suborder Astrocoeniina

The suborder Astrocoeniina occupies an intermediate position between the Fungiina and the Faviina. Owing to the small size of the crystallites comprising the polycrystalline fibers, the reaction surface area is large, but the tight packing of the fibers reduces intercrystalline porosity. *Stylophora pistillata, Pocillopora verrucosa* and *Acropora pharaonis* have a branched growth form. In SEM micrographs (Fig. 5/5,6), the size of the aragonite needles of the trabecular structure of some astrocoeniinian species ranges from 0.20-0.30 μm.

Discussion and conclusions

In Recent corals of the Hurghada area, average concentrations of the trace elements Zn, Cu, Ni, Co and Pb are significantly higher than in their Pleistocene representatives which lived in a pristine environment. This increase is caused by polluting human activities.

The normalization of the trace elements to the Pleistocene values shows enrichment of Ni (3 times), Cu and Pb (2 times), while Co is strongly enriched (7 times). In contrast, the Mn concentration in Pleistocene skeletons is 9 times higher than in Recent ones. The extremly high values of Mn in the Pleistocene skeletons respectively is most probably due to post-depositional processes. Mn and Co are mobile elements and more sensitive to redox changes in the depositional environment. Dodd & Stanton (1990) stated that the Mn/Ca ratio usually increases in fossils. This ratio has been used to appreciate the alteration in an open system, which has affected a fossil. The increase in Mn values observed in the Pleistocene scleractinian corals may be parallel to the change from the aragonitic structure of the living forms to the calcitic of the fossil ones.

In general, the degree of differences in the concentration patterns of trace metals between Recent and Pleistocene representatives of scleractinian species may be attributed to differences in the microstructure and micro-

architecture of their skeletons. Skeletons with tight crystal packing, low reactive surface area and reduced intercrystalline porosity of the suborder Faviina (*Lobophyllia corymbosa, Favia pallida, Galaxea fascicularis*) have the lowest concentrations of trace metals, in particular of Cu, Co and Mn.

Skeletons with loose crystal packing and high intergranular porosity of the suborder Fungiina (*Goniopora columna, Ctenactis echinata*) have the highest concentrations of Zn and Mn. The highest concentrations of Ni and Co are observed in *Stylophora pistillata* (suborder Astrocoeniina), which is characterized by an isolated and patchy arrangement of the trabecular centers.

Even in the studied Pleistocene skeletons, the highest concentrations of trace elements such as Ni, Zn, Co and Mn are present in species characterized by highly porous skeletons (*Pocillopora verrucosa, Stylophora pistillata, Goniopora columna*, and *Ctenactis echinata*).

Acknowledgments

We would like to thank Prof. Dr. A. El-Kammar (Cairo University) and Prof. Dr. A. Ziko (Zagazig University) for their comments and reviewing the manuscript.

References

Beltagy, A. I. (1984): Elemental geochemistry of some Recent marine sediments from north Red Sea. – Bull. Inst. Oceangr. Fisheries, A. R. Egypt: 1-11.

Constantz, B. R. (1986): The primary surface area of corals and variations in their susceptibility to diagenesis. – In: Schroeder, H. J. & Purser, B. H. (Eds.): Reef diagenesis: 53-76; Springer; Heidelberg.

Dodd, J. R. & Stanton, R. J. (1990): Paleoecology: Concepts and applications, 502 p.; Wiley-Interscience Publ., New York.

Dullo, W.-Ch. (1987): The role of microarchitecture and microstructure in the preservation of taxonomic closely related scleractinians. – Facies, **16**: 11-22.

El-Sorogy, A. S. (1997a): Progressive diagenetic sequence from Pleistocene coral reefs in the area between Quseir and Mersa Alam, Red Sea coast, Egypt. – J. Geol., **41**/1: 519-540.

– (1997b): Pleistocene coral reefs of southern Sinai, Egypt: fossil record, facies analysis and diagenetic alterations. – M. E. R. C., Ain Shams Univ., Earth Sci. Series., **11**: 17-36.

El-Wakeel, S. K., El-Sayed, M. K. & Hassain, S. A. (1984): Relative abundance of carbonate minerals in common reef-building corals. – Proc. Symp. Coral Reef, Environ. Red Sea, Jeddah: 276-292.

Förstner, U. & Wittmann, A. (1983): Metal pollution in the aquatic environment (2nd Ed.); Springer; Berlin.

Halim, U., Awad, H., El-Sayed, M. Kh., El-Zorka, S., Hanna, R. G., Ormond, R. & Stiern, I. J. (1987): Review of the state of the Marine Environment, Red Sea and Gulf of Aden. – Gesamp Work Group 26, UNEP.

HANNA, R. G. (1982a): Abnormal fluoride concentrations in the Northwest Red Sea coast. – Intern. Conf. Marine Sci., Red Sea, El-Ghardaga, Red Sea, 48 p.

– (1982b): Phosphate eutrophication in the littoral Egyptian Red Sea waters. – 2nd Egyptian Phosphate Conf.; Cairo.

LIVINGSTON, H. D. & THOMPSON, G. (1971): Trace element concentrations in some modern corals. – Limnology and Oceanography, **16**: 786-795.

MANSOUR, A. M., NAWAR, A. H. & MOHAMED, A. W. (2000): Geochemistry of coastal marine sediments and their contaminant metals, Red Sea, Egypt: A legacy for the future and a tracer to modern sediment dynamics. – Sediment. Egypt., **8**: 231-242.

NAWAB, Z. A. (1983): Red Sea mining is a new era. – In: Proc. Mabahiss John Murray Internat. Symp. on Marine Sci., Northwest Indian Ocean and adjacent waters: 16-17; Alexandria, Egypt.

NOUR, H. (2001): Quaternary sea shells and their environmental significance in the area between Gebel Zeit and El-Hamrawein, Red Sea coast, Egypt. – M. Sc. Thesis, Fac. Sci. Zagazig Univ., 178 pp.

OREGIONI, B. & ASTON, S. (1984): The determination of selected trace metals in marine sediments by flameless/flame atomic absorption spectrophotometery. – IAEA, Monaco Laboratory (Internal report). (cited from Reference methods on Pollution Studies N. 38, UNEP. 1986).

RIFAAT, A. E., EL-SAYED, M. KH., BELTAGY, A., MORSY, M. A. & NAWAR, A. (1992): Geochemical predictive models of manganese, zinc, nickel, copper and cadmium in Nile shelf sediments. – Marine Geol., **108**: 59-71.

SHEPPARD, C. R. & SHEPPARD, A. L. S. (1991): Corals and coral communities of Arabia. – Fauna of Saudia Arabia, **125**: 170 pp.

SMITH, S. L. (1992): A primer of Environmental Toxicology, Health Sciences Bookstall. – WA 670, S658, USA.

St. JOHN, B. E. (1974): Heavy metals in the skeletal carbonate of scleractinian corals. – Proc. 2nd Int. Reef Committee, Brisbane.

VERON, I. (2000): Corals of the world, 1400 p. (3 vols); Australian Institute of Marine Science.

WELLS, J. W. (1956): Scleractinia. – In: R. C. MOORE (Ed.): Treatise on Invertebrate Paleontology. Part F, Coelenterata, F328-444; Geol. Soc. Amer. and Univ. Kansas Press: 328-444.

ZIKO, A., EL-SOROGY, A. S., ALY, M. M. & NOUR, H. (2001): Sea shells as pollution indicators, Red Sea Coast, Egypt. – Egypt. J. Paleont., **1**: 97-113.

Received: October 20, 2002.
Accepted by the Tübingen editors: January 14, 2003.

Addresses of the authors:

Dr. M. ABD EL-WAHAB, National Institute of Oceanography and Fischeries, Red Sea Branch, Hurghada, Egypt.
Dr. A. S. EL-SOROGY, Geology Department, Faculty of Science, Zagazig University, Zagazig, Egypt.

N. Jb. Geol. Paläont. Mh. **2003** (11) 656–666 Stuttgart, November 2003

The mixosaurid ichthyosaur *Phalarodon* from the Middle Triassic of China

Da-Yong Jiang, Wei-Cheng Hao, Yuan-Lin Sun, Beijing
and **Michael W. Maisch, Andreas T. Matzke,** Tübingen

With 1 figure and 1 table

JIANG, D.-Y., HAO, W.-C., SUN, Y.-L., MAISCH, M. W. & MATZKE, A. T. (2003): The mixosaurid ichthyosaur *Phalarodon* from the Middle Triassic of China. – N. Jb. Geol. Paläont. Mh., **2003**: 656–666; Stuttgart.

Abstract: A skeleton of a mixosaurid ichthyosaur from the Anisian Guanling Formation of Guizhou Province (southwestern China) is the first record of the genus *Phalarodon* from the People's Republic of China. Autapomorphies of *Phalarodon* clearly shown in the material are mesiodistally elongated, laterally compressed teeth of the posterior dentary region and very wide and blunt teeth of the maxilla which are longer than high, as well as a high sagittal crest. The specimen is the first record of the genus from the eastern Tethys and underlines the cosmopolitan distribution of this mixosaurid genus. *Phalarodon* is currently the most long-lived and widely distributed Triassic ichthyosaur genus. Reason for this might be its strongly heterodont dentition which allowed it to cope with a wider variety of food items than other ichthyosaurs, making *Phalarodon* a generalist feeder.

Zusammenfassung: Das Skelett eines mixosauriden Ichthyosauriers aus der ansisischen Guanling Formation der Provinz Guizhou, Südchina, ist der erste Nachweis der Gattung *Phalarodon* aus der Volksrepublik China. Autapomorphien von *Phalarodon,* die das neue Material zeigt, sind unter anderem die mesiodistal verlängerten und lateral zusammengedrückten posterioren Zähne des Dentale und Maxillare sowie die hohe Sagittalcrista. Das Exemplar ist der erste Nachweis der Gattung aus der östlichen Tethys und unterstreicht die kosmopolitische Verbreitung dieses Mixosauriden. *Phalarodon* ist gegenwärtig die am weitesten verbreitete und langlebigste triassische Ichthyosauriergattung überhaupt. Der Grund hierfür mag in der stark heterodonten Bezahnung liegen, die es *Phalarodon* erlaubte, mehr Nahrungsquellen zu nutzen als andere Ichthyosaurier und ihn so zu einem Ernährungs-Generalisten machte.

0028-3630/03/2003-0656 $ 2.75