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Corals as speaking stones

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Abstract

Corals are animals living in shallow seas (where they may form coral reefs) or in the deep sea. Because they fossilize well, these 'stones' inform us in detail about the geological past; not only about the history of the Earth as a whole (rotation, tectonics, sea-level changes), but also about past local environmental conditions in the sea. Joint research of marine biology and marine geology can therefore solve many questions about our changing world, and can be used to discover what factors cause deterioration of living coral reefs.

Introduction

Throughout human history, the word 'coral' was used for a wide variety of organisms. The Greek word 'χειραλλιον' (cheirallion, meaning 'what becomes hard in the hand') was used for the precious red coral (*Corallium rubrum*), because it was believed that corals only became hard when they were taken out of the water. The word 'coral', when used in its wide sense, still indicates those organisms (plants or animals) that build a hard calcium carbonate skeleton within their fleshy tissue by extracting calcium ions from sea water.

Primitive Paleozoic organisms that could extract calcium from sea water and deposit it in a skeleton structure, such as stromatopores, tabulates and rugosans (from the early Ordovicium to the late Permian), formed thick layers of limestone. Most of these organisms became extinct at the end of the Permian, but left their fossil remains as proof of their early life on Earth. During the Mesozoic, it was mainly the scleractinian corals (coral in a strict sense) that produced reef limestone. Many of these coral genera became extinct at the end of the Cretaceous, but others continued to flourish in the Tertiary. During the Oligocene, most scleractinian coral genera building the recent reefs were already present.

Corals can fossilize very well and the skeleton remains of rugosan corals from the Silurian (430 Ma) or of scleractinian corals from the Triassic (220 Ma) or from the Oligocene (30 Ma) can be studied in detail. These 'speaking stones' can tell us about the circumstances in which they grew in those days (Wells 1963). Nowadays, scleractinian corals (together with the cementing coralline algae) build huge reef structures in tropical shallow seas. They form the framework of the richest and most complicated marine ecosystem on Earth. Constructive and destructive elements make the balance for reef growth (Fagerstrom 1987).

Numerous catastrophes destroying reefs occurred throughout geological times, but nowadays also a slow destruction by Man is visible in many rich coral reef areas, impoverishing their ecosystems in an unsustainable way. These living framework builders should be protected before too much damage will have been done in too short a time (Best et al. 1992).

Stones speaking of Earth history

Paleontologists studied fossil corals in detail long before biologists started to look carefully at their living descendants. Well preserved coral skeletons reveal numerous details about physical circumstances in the distant past. Wells (1963) was the first to interpret the ridges on the coral epitheca as annual or even daily deposits of calcium carbonate by the polyp tissue. He succeeded in counting approximately 400 ridges in one year in a rugosan coral, *Heliophyllum halli*, of the Middle Devonian (about 370 Ma). He called this new dating method 'geochronometry'. As it is accepted by astronomers that the length of the year has remained unaltered, Wells' result indicate that the length of the day during the Middle Devonian was 22 h; the rotation of the Earth must have been slowing down ever since. Runcorn (1967) discussed the phenomenon of the lengthening days. He argued that the rotation may be slowing down because the tides decelerate the spinning Earth. Such geochronometrical studies were continued in the following years, but the results were often so uncertain that the findings could not be used as a base for conclusions about the past.

The studies by Goreau (1959) explain the daily ridges on the theca of the coral. He proved that coral polyps secrete more calcium carbonate during the day than during the night. This is the result of the stimulating effect on the calcium metabolism of CO_2 removal by symbiotic algae (that live in the coral tissue) for their photosynthesis. Isotope studies on the carbon contained in fossil coral skeletons have taught us much about the climate in the Quaternary (as detailed below).

Stones speaking of environmental conditions

Biologists used the annual bands as indicators of environmental conditions. During nuclear tests by the Americans at Enewetak atoll between 1948 and 1958, corals recorded these explosions as radioactive bands (containing Sr-90) in their thecal construction. Knutson et al. (1972) described such annual bands from several coral colonies. The heaviest atomic explosion was shown by a stronger radioactive band. The 1948 and 1951 tests were relatively low-yield tests and gave no detectable amount of radioactivity, whereas the 1952–1954 and 1956 bands were very clearly detectable; these explosions also had the highest announced total yield.

Biology students of Goreau and Runcorn continued the study of the ridges on the epitheca of several coral species from Jamaica. They used more refined methods with the scanning electron microscope and stained coral colonies with alizarin blue in order to follow the deposition of calcium carbonate. The evidence indicated that zooxanthellate corals produce epitheca in which the growth ridges are linked to a daily cycle of expansion and contraction (Barnes 1972). Not only the epitheca of the coral skeleton was studied, but also other skeletal elements, such as the size of the calices, the number and thickness of the septa, the number of calices per unit area and skeletal attachment to the substrate. The formation of the skeleton as a whole proved to depend on the environmental conditions under which the coral animal or colony had grown up.

Coral colonies can thus be used as microenvironmental indicators (Hubbard 1974). A certain relationship exists between hydrodynamics and external growth form. This phenomenon was critically reviewed by Stearn (1982). Paleontological studies provide in this way indications for environmental circumstances in the past by measuring the skeleton characteristics of the fossil corals (Foster 1979), and biologists can interpret or explain the intraspecific variability in skeleton characteristics by measuring present-day environmental conditions. These habitat-induced modifications of reef corals have consequences for taxonomy (Best 1974). The latter study showed that coral growth is mainly influenced by the light/depth factor. This supported the findings by Goreau that calcium carbonate is mainly deposited under daylight conditions.

A new study field could thus develop in the marine sciences: sclerochronology. The study of tree rings (dendrochronology) had greatly enhanced the knowledge of climatological changes during the past 7000 years. The new sclerochronology promised to provide useful methods of detecting environmental changes of millions of years ago. To test the possibility of reconstructing the ecological history in a specific area, a study was undertaken in SE Florida, where reefs had suffered severe damage in 1969–1970 (with 80–90% mortality) as a result of heavy rainfall. Cores were taken from dead and living coral colonies and examined by X-ray radiographic methods. Bands from the last 35 years (1940–1975) were examined and correlated with the local weather phenomena and air-temperature data were obtained from the U.S. Weather Bureau field station in Florida (Hudson et al. 1976). The cores showed distinctive 'stress bands' in the growth layers of the colony over these 35 years. Thanks to these positive test results, sclerochronology promised to become a tool for the reconstruction of paleoecologic patterns in coral-bearing deposits. Similar investigations were also carried out for a master study at the Free Universities of Brussels and Amsterdam by A. Melles (1991). He investigated *Porites* colonies from the deteriorating coral reefs off the Kenyan coast. High- and low-density bands were visible in X-ray ra-

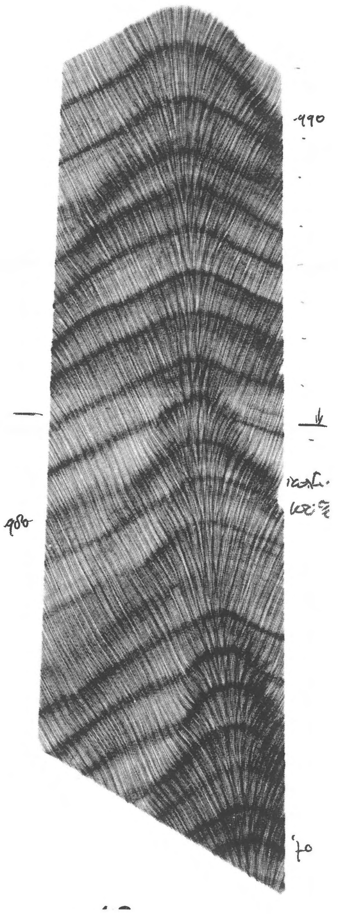

Figure 1. X-ray radiograph of *Montastrea annularis* showing yearly density bands from 1970 till 1991. From Bosscher (1992).

diographs, providing data on annual growth and stress caused by river outlet and pollution.

The PhD study by Bosscher (1992) showed the growth rings in the coral *Montastrea annularis* (Ellis & Solander 1786). The X-ray radiograph (Figure 1) shows twenty years of coral growth. The high- and low-density bands correspond to annual variations: the high-density bands were formed during low coral growth (high water temperature, reproductive period), whereas periods of stress (cold water, bleaching, sedimentation) are visible as low-density bands.

Kerr (1998) discussed a study (using the carbon isotope method) indicating that specimens of the deep-sea coral *Flabellum* that lived 15,000 years ago at a depth of 1800 m, can be used by paleoceanographers as indicators of water movement in the past. These azooxanthellate corals indicate that deep-ocean circulation is much more rapid than previously thought.

The above mentioned studies were mainly aimed at refining the method and to solve geological and biological questions. Nowadays, the method is also used to solve conservation problems. However, X-ray radiography requires well equipped laboratories that are lacking in many of the coral-reef areas where the reef deterioration is strongest. These conservation problems in developing countries become more acute each year, because of the over-exploitation of reefs to cope with food and building demands by a growing population. Water pollution is often uncontrolled and reefs are breaking down. The causes are not always clear, but they are certainly related to the introduction of modern industries; they result in lower protein production and the loss of natural protection of the coast lines. Deterioration of coral reefs also occurs in developed countries like the U.S.A. (Florida) and Australia (Great Barrier Reef) but is in these countries not catastrophic for the local population as far as food is concerned.

Threatened coral reefs must be studied by interdisciplinary research teams that combine field work with high-technology methods. In my opinion, sclerochronology does not yet receive enough attention as a means of identifying the main causes of reef deterioration, although it proved to be a fairly easy method for tracing environmental influences over the last 25 years. The corals themselves record what caused their high density and stress bands. Local conservationists and local politicians should start to take action, in order to avoid further damage.

Joint coral-reef research

Biologists and paleontologists working together in coral-reef areas can provide useful information on the development of the reefs throughout the geological past. Because the Indonesian–Philippine region, with its long geological past, is the richest coral-reef area in the world as far as biodiversity is concerned, joint research in this area is a tremendous challenge. During the Snellius II expedition (1984) in the eastern Indonesian Archipelago, coral scientists were able to study on the spot Tertiary and Quaternary corals in remote places.

Eastern Indonesia originated some 25 Ma ago. The collision of three large plates (the western Pacific, the Australian and the southeastern Asian) resulted in island arcs and small plate fragments that form the archipelago. The coral reefs that developed around

Figure 2. Prof. G.J. Boekschoten during fieldwork in South Bali (May, 1998). Reconstruction of the geological past of Bali based on fossil coral reefs.

these islands are probably the most unstable of our planet. Tectonic and volcanic activities as well as sea-level changes influenced coral-reef formation during the late Tertiary and Quaternary. The effect of the rapid and frequent sea-level fluctuations and the tectonic uplifts were studied in Ambon and Sumba (Pleistocene) and Salayer (Pliocene). The studies showed that sea-level changes of more than 120 m during the Quaternary have deeply influenced Indonesian coral biodiversity and geography (Boekschoten et al. 1989). The coastlines in these tectonically unstable islands endured severe ecological stress: reefs drowned or were uplifted, reef communities died. New populations by recolonisation consisted of strong generalist coral species, whereas fragile coral species had no time to settle. Biodiversity was therefore low.

In contrast, the study of recent and fossil reefs in the more western Sunda islands, such as Sumbawa and Komodo, showed reefs of a high biodiversity (Best & Boekschoten 1988). These islands were less influenced by tectonic instability; they were uplifted about 15 Ma ago and remained stable ever since.

Joint research on the island of Bali carried out in the summer of 1998 (Figure 2) revealed a great influence of Pleistocene sea-level fluctuations on recent and fossil reefs. The coral formation of the north coast is young, as Bali was connected with Java and Kalimantan (Sunda shelf) 15,000 years ago, when the sea-level was 120 m lower. The south coast has coral reefs that are much affected by active vulcanism. Two areas around Bali were studied: Nusa Menjangan to the NW and Nusa Lembongan to the SE. They were examined for coral species composition and coral density. The first results show a lower diversity (50–75 species) and density in the north, and a normal diversity (75–100 species) in the south, in comparison with other eastern Indonesian islands. The percentage of rare species is low (about 10%) in both areas, probably as a result of tectonic instability, sea-level fluctuations and vulcanic activity. In general the Menjangan 'reefs' are no more than young coral communities with a low coral cover, whereas the Lembongan reefs can be called reef communities with a high coral diversity and a high cover. The terms to indicate what sort of 'reefs' we are dealing with and the indication of rare species were explained by Best & Boekschoten (1988, 200–202). Further study of the biological part of the reef surveys around Bali, also in comparison with the geological data, will reveal more about the Pliocene and Pleistocene history of coral-reef growth. The island of Bali is interesting but rather unknown in this respect and the reconstruction of its coral reefs will be presented on the 9th International Coral Reef symposium in Bali (Boekschoten & Best in prep.).

Conclusions

'Corals' build up their skeletons step by step with calcium ions from the surrounding sea water, thus building simultaneously a record of ambient sea-water conditions. Corals fossilize easily and therefore are excellent indicators of environmental changes, such as those resulting from sea-level changes and tectonic movements for coastal areas, but also of water circulation in the deep sea.

The present contribution summarizes research done by scientists who translated the information corals hold in their 'stony skeletons' about the history of the Earth. It advocates further use of the method of sclerochronology in order to identify the causes of the increasing stress on coral reefs over the last 25 years, a worldwide problem facing mankind. Corals are stones that can speak to us, but one has to learn their language.

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