Proposal for scientific drilling into coral reefs and carbonate platforms

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Abstract

Coral reefs are tropical to subtropical, coastal ecosystems comprising very diverse organisms. Reef deposits are fossil archives of environmental, tectonic, and eustatic variations that can be used to reconstruct the paleoclimatic and paleoceanographic history of the tropic surface oceans. We propose scientific drilling into coral reefs and carbonate platforms to delineate their whole lives (initiation, development, and demise). To achieve this purpose, the followings issues should be addressed. 1) the paradox of drowned reefs and carbonate platforms, 2) revivals of coral reefs at low sea stands, and 3) origin and genesis of dolomites. Accumulations rates of "healthy" coral reefs and carbonate platforms are much greater than subsidence of seamounts and 3rd-order sea level rises. However, there are numerous seamounts capped by drowned reefs and carbonate platforms. Although several hypotheses have been presented to resolve the discrepancy, none of them has been generally accepted as a unique answer. Recent studies revealed that two modes of reef formation were recognized: reef growth that kept pace with the subsidence of the island and rapid reef growth during periods of low sea stands and the following rapid transgressions. In the latter mode, reef formation re-started on a submerged island at low stands of the sea level. This hypothesis ("revivals of coral reefs at low sea stands") should be verified by examining many other atoll columns. Origin and genesis of dolomites is an unsolved scientific problem. Recent studies showed that Neogene dolomites from some carbonate islands are multigenerational, formed in seawater and that dolomitization primarily occurred during glacio-eustatic sea-level lowstands and cooler ocean temperatures. However, these findings should be verified by investigating dolomites in many other carbonate islands. Coral-reef/carbonate-platform drilling is expected to provide an important cue to resolve these enigmas.

Coral reefs are tropical to subtropical, coastal ecosystems comprising very diverse organisms. Their ancient counterparts, reef deposits, provide important, high-resolution records of geoscientific events in tropic to subtropical shallow waters, such as vertical and lateral tectonic movements, sea-level fluctuations, paleoclimatic changes and paleoceanographic variations. To obtain the records, it is inevitably needed to understand the initiation, growth, and demise of coral reefs, which have attracted the interest of many scientists ever since Darwin (1842). To resolve the problem, numerous boreholes were drilled on reefs and carbonate islands, such as Funafuti (Royal Society of London, 1904), Bermuda (Pirrson and Vaughan, 1913), the Bahamas (Field and Hess, 1933), and the Great Barrier Reef (Richards and Hill, 1942). Submerged reefs and carbonate platforms on seamounts were also drilled by the Ocean Drilling Program (e.g., Legs 143 and 144 [Sager et al., 1993; Premoli Silva et al., 1993]). In spite of the investigations conducted for more than a century, whole lives of coral reefs have not been clearly delineated yet because 1) limited drilling penetrated thick reef deposits and reached their basement rocks (e.g., Eniwetok Atoll; Ladd and Schlager, 1960), 2) core recovery is generally very low in drilling into shallow-water limestones, and 3) those drilling projects were mostly performed before recent progress in carbonate sedimentology and geochemistry.

There are some enigmas that are related to the whole lives of coral reefs.

The paradox of drowned reefs and carbonate platforms: Reefs/shallow-water carbonate platforms are drowned when tectonic subsidence or rising sea level outpaces carbonate accumulation, and carbonate production ceases (Schlager, 1981). Drowned platforms are common in the geologic record. However, the growth rates of Holocene reefs/shallow-water carbonates are at least one order of magnitude greater than subsidence rates of ancient carbonate platforms. If all factors involved had been correctly evaluated, there should be no drowning of platform at all. This is called “the paradox of drowned reefs and carbonate platforms”. This is one of the most enigmatic problems for geo-scientists. Some hypotheses have been presented to explain the paradox (Schlager, 1981; Grigg, 1982; Winterer and Sager, 1995; Hallock and Schlager, 1986; Wilson et al., 1998). Schlager (1981) suggested that the possible cause of platform drowning includes rapid pulse of relative sea-level, because platforms, at least modern ones, could grow much faster than they had to in order to keep pace with long-term subsidence and eustatic sea-level movements. Grigg (1982, 1997) proposed a term “the Darwin Point (at 29°N latitude)” and suggested that Hawaiian atolls and

coral islands transported northwest by tectonic movement of the Pacific Plate appears to have drowned near this Point because of decreasing growth rates of coral reefs. Winterer and Metzler (1984) showed that a karstic topography developed on many of the submerged reefs/carbonate platforms on the Mid-Pacific Mountains and suggested that the platform drowning was related to exposure and karstification and a subsequent rapid rise in relative sea level. Hallock and Schlager (1986) proposed that nutrient-rich environment, which might be caused by upwelling and riverine input, is very harmful for reef builders (e.g., scleractinian corals) and then resulted in the platform drowning. They suggested a carbonate-platform drowning occurred at the Cenomanian/Turonian boundary and correlated the platform drowning with OAE II (Oceanic Anoxic Event II), which is characterized by the organic carbon accumulation and the global positive carbon-isotope excursion. Wilson et al. (1998) showed that the carbonate platforms on guyots drowned sequentially across a wide range of time while they were being transported northwards by Pacific Plate motion through a narrow palaeolatitudinal zone (~0 to 10° S) and suggested that surface waters in a narrow equatorial zone were harmful to shallow-water sedimentation. However, none of theories has been generally accepted as a unique answer.

Revivals of coral reefs at low sea stands: Recent studies (Iryu et al., in press; Fig. 1) on 25-million-year history of Kita-daito-jima atoll revealed that two modes of reef formation were recognized: reef growth that kept pace with the subsidence of the island and rapid reef growth during periods of low sea stands and the following rapid transgressions. The former is

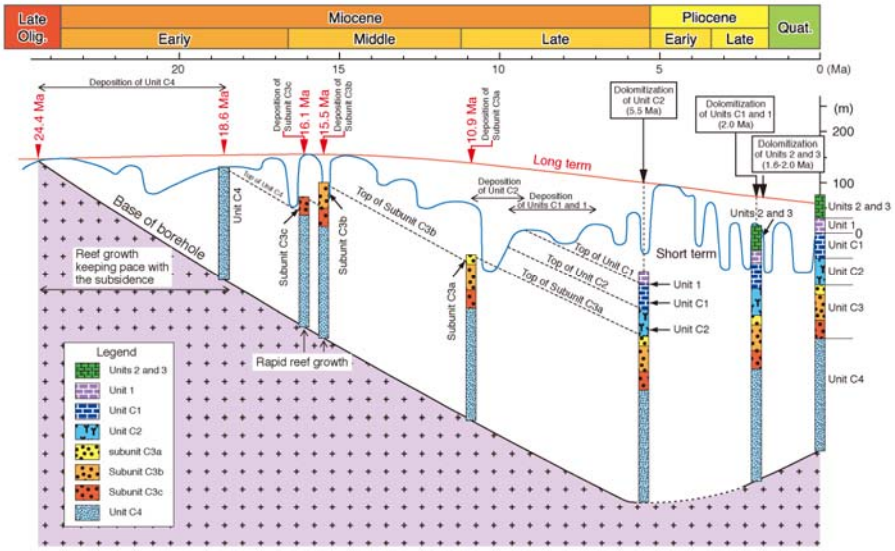

Fig. 2. Age-depth section showing the history of reef formation on Kita-daito-jima for the last 25 Ma. After Suzuki et al., 2006).

represented by the reef growth during the Late Oligocene to Early Miocene between 18.6 and 24.4 Ma, in response to a relative sea-level rise caused mainly by tectonic subsidence of this island. The latter mode of reef formation occurred at low sea stands and the subsequent transgressions at ~16.1 Ma and ~15.5 Ma. In this mode, reef formation was stimulated by the sea-level fall that resulted in the submerged island being brought into a shallow environment in which corals could recolonize. Therefore, sea-level falls are key events that cause submerged reefs to be rejuvenated, and reef formation may not be necessarily limited to warm periods that are characterized by high sea levels. It is noteworthy that the single atoll column consists of the two modes of reef deposition. This hypothesis ("revivals of coral reefs at low sea stands") should be verified by examining many other atoll columns.

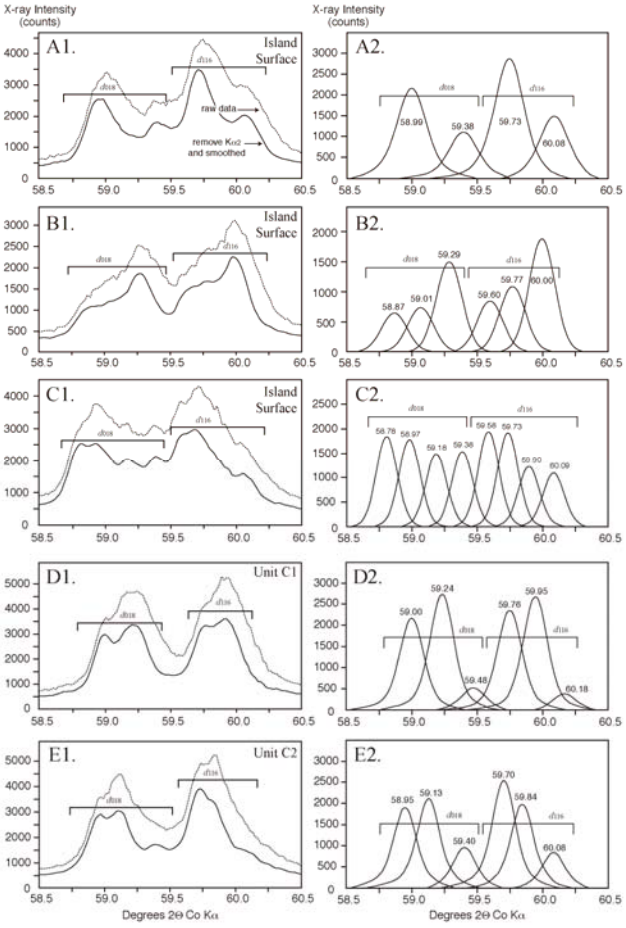

Fig. 2. (A1, B1, C1, D1, E1) Examples of dolomite d116 and d018 XRD reflection trace before deconvolution. Measured trace (dashed line) was stripped to remove the Ka2 and the smoothed (black line). (A2, B2, C2, D2, E2) Peaks determined from smoothed XRD data by peak-fitting technique (see Appendix 1 for further explanations). Only the d116 peaks were used to define separate dolomite phases. After Suzuki et al. (2006).

Origin and genesis of dolomites: Dolomites have attracted the interest of carbonate sedimentologists and geochemists for many decades. Several dolomitization models have been proposed: evaporative, seepage-reflux, mixing-zone, burial, and seawater models. The seawater dolomitization model is generally accepted as the most likely explanation for

dolomites within carbonate islands and platforms. Recent studies show that island dolomites at Kita-daito-jima (Suzuki et al., 2006) and Niue Island (Wheeler et al., 1999) comprise variable mixtures of plural dolomite crystal phases, each of which is distinguished by different major and trace element contents and carbon and oxygen isotope compositions. The fact that all phases of Kita-daito-jima dolomites were originated from seawater in association with cool global climates suggests a strong climatic control may exist for all Neogene island dolomites. However, these findings (marine dolomitization selectively occurring at low sea stands) have been confirmed only in Kita-daito-jima dolomites. Consequently more investigations are needed for dolomites from other carbonates islands.

Possible candidates for scientific drilling into reefs and carbonate platform to address these issues include Kita-daito-jima, northern Philippine Sea, Minami Seamounts in the Ogasawara Plateau, and Mimani-tori-shima (Marcus Island).

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