Need for coral and coral reef drilling in the next phase of IODP

Tsuyoshi Watanabe (Hokkaido University),
Kazuhiko Fujita (University of the Ryukyus),
Atsushi Suzuki (Advanced Industrial Science and Technology), and
Yasufumi Iryu (Nagoya University)

Abstract

Coral reefs are excellent recorders of climate and environmental changes in the Earth history. Particularly, geochemical signals in coral skeletons can provide high-resolution (<biweekly) records of sea surface temperature (SST), salinity (SSS) and seawater chemistry. Coral skeletons are suitable for accurate age determinations by ^{14}C, U-series, and Sr-isotope dating methods. Resulting age data, combined with paleobathymetry determined by reef assemblages, enable to reconstruct fluctuations of past sea levels. Therefore, corals and coral reefs are important drilling targets for the next phase of the IODP.

The following scientific issues are expected to be resolved by coral and coral reef drilling: (1) Spatial variations in SST and SSS during the last deglaciation; (2) Role of subtropical and tropical seas as the “Heat Engine” in the climate system; (3) Past climate variability in low subtropical and tropical seas (e.g., El Nino-Southern Oscillation [ENSO], Pacific Decadal Oscillation [PDO], and Indian Ocean Dipole [IOD]); (4) Atmosphere-Ocean-Land linkages between the Indian and Pacific Oceans; (4) Human impacts, particularly impacts of ocean acidification, on coral reefs; and (5) Causes of initiation, development, and demise of coral reefs.

We present four proposals here; two of them are explained in more detail as individual white papers.

I. Drilling coral reef platform and margin marine sediments around the Mentawai Islands western off Sumatra: a new archive for reconstructing the histories of the Indian Ocean earthquakes and climate changes

The aim in this proposal is to: 1) understand nature of atmosphere and ocean dynamics in the Indian Ocean and its impact to earth’s climate system on glacial and interglacial time scales (Indian Ocean Dipole [IOD], El Nino- Southern Oscillation [ENSO], and Asian monsoon significantly influence on sea surface temperature and precipitation in proposed area [Fig. 2]. We propose to address the linkage between Indian and Pacific oceans using coral records from Mentawai Islands [Fig. 1]); 2) Unravel the mechanism of Indian Ocean earthquake and associated Tsunami; 3) Reconstruct the past histories of volcanic eruptions and their spatial and temporal distributions by examining coral and marine sediment cores around the Mentawai Islands. 4) Investigate the biological response of marine organisms in coral reefs ecosystem during and after rapid changes in ocean and terrestrial environments in past climatic (IOD and ENSO) and seismological (earthquakes and tsunamis) events and volcanic eruptions.

Our strategy comprises the followings. 1) Geochemical signals in coral skeletons could provide useful information of the past environments at weekly to monthly time resolution. We will use isotopic composition (e.g., $\delta^{18}O$ and $\delta^{13}C$) and trace element contents (e.g., Sr/Ca and Ba/Ca) to reconstruct past climate signals (e.g., sea surface temperature and precipitation), volcanic events, up welling, and earthquake and associated tsunami events. 2) Identification of tephra layers and paleontological analysis of microfossil fauna in marine sediments can provide precise chronological and geological data to delineate the past history of volcanic activities. Tsunami deposits in sediment cores will allow us to detect past tsunami events on geological time scales. 3) Calcification rate of coral skeletons from drilling cores would provide the information about biological impacts and calcification process during and after climate, seismological, and volcanic events.

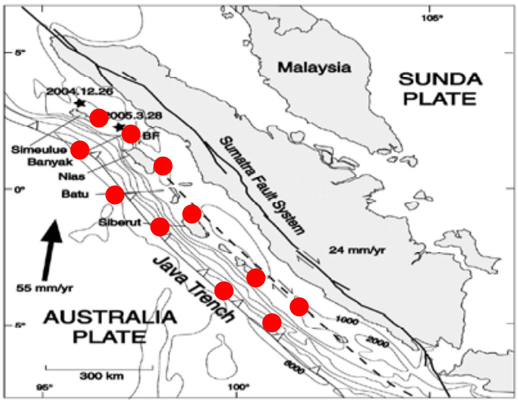

Fig. 1. Proposed sites (red)

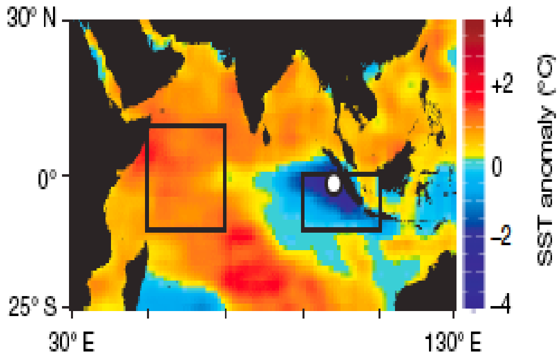

Fig. 2. Indian Ocean Dipole (IOD)

II. Revealing causes, timing and magnitudes of sea-level changes during Terminations

Terminations (glacial-interglacial transitions) are regarded as possible analogues for modern climate changes and associated rapid environmental changes. The precise reconstructions of sea levels during Terminations are crucial for understanding ice-sheet dynamics and suborbital climate variability. Previous studies showed that the last deglaciation (Termination I: TI) was characterized by rising sea levels associated with several rapid oceanographic events such as melt water pulses (MWPs). On the other hand, nature of older Terminations have not been so clear yet. Studies on the termination of the penultimate glacial period (Termination II: TII) are progressing, and a shallow-water sequence newly found from offshore Tahiti by the IODP Expedition 310 (Fujita et al., submitted; Iryu et al., submitted; Fig. 3) is the first complete and direct evidence to record sea levels and associated environmental changes during TII. The sea-level changes during TII reconstructed by these works were characterized by the two steps of rising sea-levels with an intervening sea-level drop, suggesting the presence of the sea-level reversal event during TII (Esat et al., 1999; Siddall et al., 2006). Such reversal event is similar to the Younger Dryas (YD) climate reversal event, though the YD event was not associated with a sea-level drop. However, there remains to be answered if this phenomenon was common during the periods of rising sea levels or limited to the TII period. Furthermore, causes of the sea-level reversal events during TII and older Terminations if exists are not yet known.

Thus, the purposes of this proposal are 1) to reconstruct sea levels and associated environmental changes during older Terminations, 2) to compare similarity and differences in sea-level changes among several Terminations, and 3) to reveal the existence and causes of sea-level reversal events during Terminations. Resulting sea-level data and associated environmental records will contribute to 1) the modeling of ice-sheet dynamics and 2) the understanding of biological responses such as coral reefs to rapid environmental changes. Proposed drilling sites are carbonate islands which are characterized by tectonically slow and constant subsidence rates (e.g., Tahiti, French Polynesia) and is located at considerable distance from the former major ice sheets (far-field). Several cores on transects from shallow shelf to shelf slope should be recovered and analyzed.

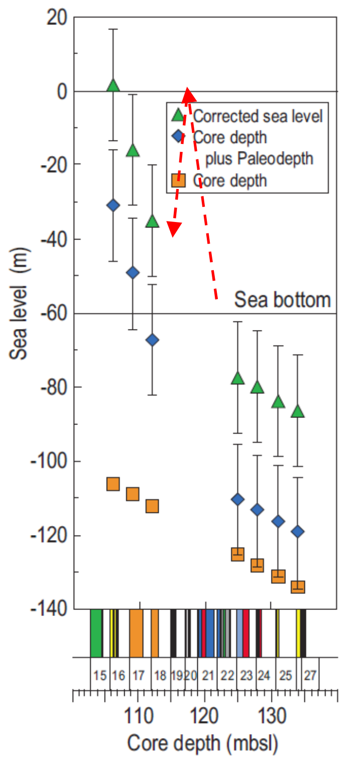

Fig. 3. Sea-level changes during Termination II (TII), reconstructed using a new shallow-water sequence found from offshore Tahiti by IODP Exp. 310 (Fujita et al., submitted; Iryu et al., submitted). Dotted red lines indicate a sea-level reversal event midway through TII.

III. Past ocean acidification events in Earth history

"Ocean acidification" is a recently-emerged environmental problem (IPCC, 2007). The term "ocean acidification" could not be found in the text of the Initial Science Plan (ISP, 2001), probably because scientific community had not yet realized the importance of this new threat to the global ocean at that time. Since then, several researches have been conducted the reconstruction of paleo-pH in seawater during the glacial time and the Paleocene-Eocene thermal maximum (PETM, 55 Ma ago). In particular, PETM event may be an analog for present-day environmental changes due to fossil fuel combustion and intensive studies have been conducted on the event. However, our knowledge on the magnitude of past pH changes in the ocean is still surprisingly limited (Kleypas et al., 2006; Fig. 4). In order to constrain the past pH changes in the ocean, systematic approach will be needed. The boron isotope ratio of biogenic carbonate is used as a proxy for ocean pH. However, there is concern about large uncertainties in the technique. Exploration of new pH proxies is important and, for example, the Zn/Ca ratio in benthic foraminifers is a potential proxy of the carbonate ion concentration of bottom waters. More calibration experiments are needed for improving reliability of these proxies. Relationship among seawater pH, carbonate production by marine calcifiers and community structure of marine organisms is an important topic. There seems to be evolutionary responses of calcifiers against the long-term changes in the carbonate chemistry in the ocean. Materials recovered by scientific drilling from marine deposits would be suitable for better examination on the hypotheses. Within 5-6 years, the next IPCC report will be due and the revision continues approximately 7 years. Scientific results relating past-pH changes in the ocean will be cited by the future versions of IPCC reports for showing the range of natural variations of the Earth systems.

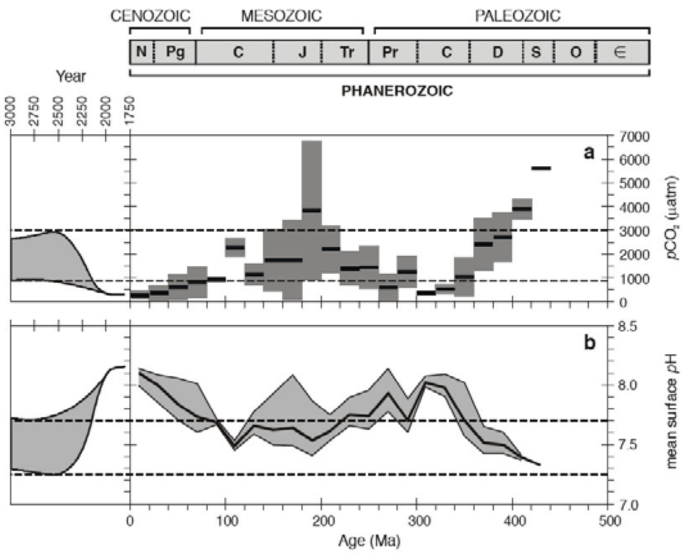

Fig. 4. Geologic history and projection of (a) atmospheric pCO_2 and (b) modeled changes in pH over the same time period. Horizontal dashed lines indicate the range of predicted pCO_2 peak atmospheric CO_2 concentration over the next century. Dark lines are average historical pCO_2 values, while gray shading indicates ± one standard deviation. After Ridgwell and Zeebe (2005).

IV. Initiation, development, and demise of reefs/carbonate platforms

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. In spite of the investigations conducted for more than a century, whole lives of coral reefs have not been clearly delineated yet.

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

Schlager's paradox: 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. Several hypotheses have been presented to resolve the discrepancy: nutrient-limited theory (Hallock and Schlager, 1986), exposure-attributable damage theory (Winterer and Metzler, 1984), and graveyard theory (Wilson et al., 1988). However, none of theories has been generally accepted as a unique answer.

Revivals of coral reefs at low sea stands: Recent studies 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 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. This hypothesis ("revivals of coral reefs at low sea stands") should be verified by examining many other atoll columns.

Marine dolomitization at low sea stands: Based on geochemistry and crystal chemistry of Kita-daito-jima dolomites, Suzuki et al. (2006) identified dolomite crystal phases and showed that all dolomite phases formed in seawater and that dolomitization primarily occurred during glacio-eustatic sea-level lowstands and cooler ocean temperatures. However, these findings (marine dolomitization selectively occurring at low sea stands) have not been confirmed in dolomites in other carbonate 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).

References

Esat, T.M., McCulloch, M.T., Chappell, J., Pillans, B., Omura, A., 1999. Science 283, 491 197-201.

Hallock P. and Schlager, 1986. Palaios, 1, 389–398.

IPCC, 2007. *Climate change 2007: the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change.* Cambridge_University Press, Cambridge.

Kleypas, J.A., Feely, R.A., Fabry, V.J., Langdon, C., Sabine, C.L. and Robbins, L.L., 2006. *Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research.* Report of a workshop held 18–20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey, 88 pp.

Ridgwell, A. and Zeebeb, R.E., 2005. Earth and Planetary Science Letters, 234, 299-315.

Siddall, M., Bard, E., Rohling, E.J., Hemleben, C., 2006. Geology 34, 817-820.

Suzuki, Y., Iryu, Y., Inagaki, S., Yamada, T., Aizawa, S. and Budd, D.A., 2006. Sedim. Geol., 183, 181–202.

Wilson, P. A., Jenkyns, H. C., Elderfield, H. and Larson, R. L., 1998, Nature, 392, 889–894.

Winterer, E. L. and Metzler, C. V., 1984. Jour. Geophys. Res., 89, 9969-9979.