Cover Page

Title: Ocean circulation during a turnover from the greenhouse Earth to the icehouse Earth

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Abstract:

Recent extensive efforts indicate that at least ephemeral continental ice sheet had been developed in both hemispheres in the middle Eocene. Although these Cenozoic initial glaciation events have been widely discussed in these few years, oceanographic condition, such as ocean circulation, during the transitional phase between the greenhouse Earth and the icehouse Earth have been poorly documented. Because the Earth's surface environment, such as continental arrangement and atmospheric carbon dioxide concentration, was dramatically modified during this transitional interval, paleoceanographic dynamics for the long-term transition can't be discussed only with analyses of a certain event. However, while some long-term proxy records of ocean temperature and circulation are available in the early Paleogene, the Cretaceous records are unfortunately insufficient. Especially in the Pacific, proxy records for ocean temperature and circulation are surprisingly poor. On the other hand, because the Pacific was the largest Ocean in this interval, it must play an important role in global ocean circulation. Therefore, to understand ocean and atmospheric circulation in the greenhouse mode Earth and disclose how it turns into the icehouse mode Earth, we must appreciate global array of proxy data including the Pacific. I propose that IODP need to gather long continuous sediment cores from various sites and depth in the Pacific in order to investigate three dimensional ocean circulations during this huge transitional phase of the Earth's surface environment. This result allows scientist to examine responses of atmospheric and ocean circulation systems against a temperature change.

Understanding the mechanisms of extreme climate development has been proposed as one of the major scientific targets of the initial phase of the IODP. One typical example of this extreme climate is represented by a period of intense global warming during the mid-Cretaceous and early Eocene. The mid-Cretaceous supergreenhouse condition, which is accompanied by high sea-surface temperatures, elevated atmospheric carbon dioxide contents (pCO_2), and raised sea-level, has especially been analyzed by many authors in this decade (*1-16*). The most curious climate transitional event in this greenhouse Earth must be massive accumulation of organic, carbon-rich sediments and water column anoxia. Especially in the Oceanic Anoxic Event across the Cenomanian/Turonian boundary, rapid and extreme warming and sudden negative feedback cooling have been clearly described by an organic seawater temperature proxy of TEX_{86} (*13*). An internal forcing for this climate transition is ascribed to massive volcanic activities and associated carbon dioxide input into the atmosphere (*17, 18*). With many other pieces of evidence, our knowledge for cause and effect of the Cretaceous anoxia has been gradually increasing.

On the other hand, another long running debate in climatic transition concerns a timing of initial polar ice-sheet development after the greenhouse condition. Sedimentological analyses, such as ice-rafted debris and clay mineral composition, and physicochemical proxies such as oxygen isotopes and Mg/Ca in foraminiferal tests indicate that a massive ice-sheet was first developed around the Eocene/Oligocene boundary (*19-23*). However, some studies questioned this view, arguing for earlier and/or larger polar ice sheets, and even bipolar glaciation and sea ice development in the Eocene (*24-27*). The Cretaceous greenhouse has now been not an exception of this heated dispute. Although some authors indicate little possibility for a polar ice-sheet (*14*), multi-proxy analyses for temperature and oxygen isotopic composition of the mid-Cretaceous ocean imply that at least a short-lived ice-sheet had been developed in the greenhouse Earth (*11, 15*).

While these extreme climate “events” have been intensively discussed, a paleoceanographic dynamics in the transitional phase from the maximum greenhouse to the initial ice development have been poorly documented. Because internal forcing, such as continental arrangement on the Earth and pCO_2, had been dramatically altered during the late Cretaceous and early Paleogene, paleoceanographic dynamics for the long-term transition can’t be discussed only with analyses of a certain event. Although some continuous long-term climatic profiles have been published in the Atlantic and south Indian Oceans (*28, 3, 29*), the Pacific Ocean have been left from consideration of ling-term climatic transition. During the late Cretaceous and early Paleogene, the Atlantic Ocean had not been fully open like a modern state, the Pacific Ocean represent the only and largest Ocean on the Earth in this interval. Therefore, we must understand paleoceanography of the Pacific Ocean for discussion of ocean circulation in this transitional phase.

Besides proxy records, numerical climate modeling predicts that southern high latitude is assumed to be a deep water formation site in the mid-Cretaceous supergreenhouse period (*30, 31, 5*). However, in those model experiments, deep water begins to be produced in the northern Pacific high latitude with decreasing $p\mathrm{CO}_2$. Therefore, $p\mathrm{CO}_2$ decrease, hence cooling, in the late Cretaceous could involve considerably huge revolution of ocean circulation. This putative paleoceanographic revolution might be supported by neodymium isotope records in the early Paleogene. Although author stated deep water would be produced in the northern Pacific during a warmer interval instead of a cooler interval, neodymium isotopes show distinctive shift from a cooler to warmer interval (*32*).

The Pacific Ocean, thus, might played an important role in global ocean circulation during the transitional phase from the supergreenhouse to the icehouse. As in recent glacial-inter glacial cycles, it can be easily imagine that a rate of deep water formation and/or a shift of a deep water formation site influence whole ocean condition, and also affect biodiversity and biogeographic distribution for marine organisms especially having planktic larval ecology. Nevertheless, lack of long-term and geographically wide spread proxy data sets in the Pacific Ocean prevents us from understanding paleoceanographic dynamics in this dramatic environmental turnover interval. Therefore, IODP need to gather long continuous sediment cores from various sites and depth in the Pacific Ocean in order to convert a single site result to a three dimensional picture of oceanic circulation. This result allows scientist to examine sensitivity and a threshold of ocean circulation systems against a temperature change.

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