WG.1.4 Extreme events and punctuated evolution

Cretaceous environmental changes

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Abstract

The Cretaceous is a typical greenhouse period due to high concentration of CO_2 in the atmosphere derived from elevated global igneous activity, and characterized by high surface temperatures (>14°C) in high latitudes, a lack of permanent ice sheets and higher sea level. During the climax of Cretaceous warming, anoxic condition expanded through the global oceans, and organic rich sediments were widely deposited within the marine carbonate sediments. The formations of black shales in the marine environments are called as Oceanic Anoxic Events (OAEs) that were found at least 10 times during the Cretaceous period. The OAEs probably induced accumulations of organic carbons resources and extinction of marine benthic faunas.

The formations of black shales are related with large volcanism that formed large igneous provinces (LIPs) such as the Ontong Java Plateau and Shatsky Rise. Many studied cores were recovered in the Atlantic and Tethyan regions during the Cretaceous, whereas the drilling cores were rare in the Pacific Ocean. In future drilling, we need to recover the Cretaceous sequence in the Pacific Ocean.

Introduction

The Earth climate has alternated between greenhouse and icehouse modes throughout the Phanerozoic. Although the earth is at present in the midst of an icehouse climate mode, recent dramatic increase in atmospheric CO_2 from the burning of fossil fuels has led to significant global warming. To understanding the ocean–climate system during past greenhouse climate modes is essential for more accurate prediction of future climate and environmental changes and ecological impacts in the warming Earth. The Cretaceous is known as a latest typical greenhouse period caused largely by increased CO_2 from elevated global igneous activity, as it is characterized by globally averaged surface temperatures that were >14°C higher than those of today (Tarduno et al., 1998), a lack of permanent ice sheets (Frakes et al. 1992) and over 100-200 m higher sea level than that of today (Haq et al., 1987; Miller et al., 2005; Müller et al., 2008).

Oceanic Anoxic Events

During the climax of Cretaceous warming, anoxic condition in the oceans globally expanded, resulted in accumulations of organic rich sediments (so-called black shales). These events are called Oceanic Anoxic Events (OAEs), and occurred at least 10 times during the Cretaceous period (Figure 1). The study of OAEs is important from three different perspectives: (i) the OAEs acted as the thermostat during the greenhouse climate because they eliminated carbon from atmosphere (CO_2) to sediments (black shales); (ii) the expansions of anoxic condition in the oceans caused mass extinctions of marine biota; (iii) most of source rocks were formed during Cretaceous under anoxic oceanic environments. The OAEs are much better studied in areas of the Atlantic Ocean and Tethys Sea than in the Pacific Oceans because most of Cretaceous Pacific ocean-floor has already subducted under continents. Since the Pacific was much larger than today and was the largest ocean during the Cretaceous, spacio-temporal distributions of black shales in the Pacific Ocean are important to clarify the global environmental and biotic impacts during the OAEs.

Rapid warming at the OAEs

Recent geochemical methods such as oxygen isotopes and TEX_{86} provided change in sea surface temperatures and vertical thermal gradients during the OAEs. These studies revealed that rapid warming of sea surface (OAE 1b and OAE 2) and/or deep sea (OAE 1d and 2) coincided with the onset of black shale depositions (Huber et al., 1999; Wilson and Norris, 2001; Erbacher et al., 2001; Forster et al., 2007, Wagner et al., 2008). However, Cretaceous DSDP and ODP cores with continuous recovery and abundant well-preserved fossils suitable for isotopic study are very limited. Especially, paleo-temperature reconstructions during the OAEs are reported only in the equatorial Atlantic regions (Demerara, Blake Nose and Mazagan). A denser global array of deep-sea cores is needed to provide more detailed reconstructions of global climate changes and oceanographic conditions during the OAEs.

Relationship between LIPs formations and OAEs

Although the ultimate trigger for the OAEs are still unresolved, recent models attribute OAEs and sudden warming to the impact of substantial submarine volcanisms and/or hydrothermal activities (e.g., Orth et al., 1993; Sinton and Duncan, 1997; Kerr, 1998; Leckie et al., 1998, 2002; Erba, 2004; Snow et al., 2005). These hypotheses suggest that extensive submarine volcanism caused an expansion of the oxygen minimum zone associated with elevated primary productivity, due to injection of biolimiting metals and/or nutrient-rich deep water into the surface ocean. On the other hand, some workers consider sub-aerial volcanism to be a major trigger of some OAEs (Kuroda et al., 2007). These hypotheses suggest sub-aerial volcanism caused elevation of SSTs which prevented or slowed the formation of deep water, resulting in oceanic stratification. At present, we need to determine whether the timing and duration of LIPs is correlative with OAE events. Sites near the LIPs that record both volcanic history and OAE events.

Biocalcification crises

Recent simulation studies predict that rapid atmospheric release of CO_2 will cause acidification of sea surface water that could affect marine ecosystems significantly. In the Cretaceous ocean, the global drowning of shallow-water carbonate platforms occurred several times (Figure 1). Weissert and Erba (2004) pointed out that the coincidence between the drowning events of shallow-water carbonate platforms and the crisis of heavily calcified plankton groups recorded in the pelagic facies. They termed these events “Biocalcification crises”. The Biocalcification crises occurred 5 times during Cretaceous. The three of them coincided with OAEs (Weissert, OAE1b, 2), but rest two are not accompanied by the major environmental event. Although recent hypotheses blame elevated pCO_2-induced lowered surface ocean pH, the mechanism responsible for these event remains poorly constrained.

Cretaceous rapid cooling episodes

Since the Cretaceous period is generally assumed to have been ice-free interval, it has long been debated about the mechanism for the large and rapid changes observed in Cretaceous sea level (e.g., Skelton et al., 2003). Miller et al (1999, 2005) demonstrated that several rapid sea level falls recorded in New Jersey could be explained only by glacio-eustacy. According to integration between occurrences of ice-rafted and/or glacial deposits around the polar regions, positive oxygen isotope values of foraminifera and intervals of rapid sea level fall, it is quite possible that the glacial events did occur during greenhouse climate (e.g., Bornemann et al., 2008). Although several geologically short-term glacial events during Cretaceous have been proposed (e.g., middle Turonian, middle Campanian, and earliest and late Maastrichtian; Figure 1), the causes of cooling and ice-volume at those times are still unclear.

Conclusion

The Cretaceous study is a still important target in deep sea drilling projects. The high-quality data in geochemical analysis in both carbonates and organic matters depend on good recovery of drilling materials. Particularly, there are few data concerning the Cretaceous studies in the Pacific Oceans. We need new drilling proposals to penetrate the Cretaceous sequence on the Sea-Mounts and LIPs such as Ontong Java Plateau and Shatsuky Rise.

References

Erba, E. 2004. Calcareous nannofossils and Mesozoic oceanic anoxic events. *Marine Micropaleontology* 52: 85-106.

Erbacher, J., B. T. Huber, R. D. Norris and M. Markey. 2001. Increased thermohaline stratification as a possible cause for an oceanic anoxic event in the Cretaceous period. *Nature* 409: 325-327.

Frakes, L. A., Francis, J. E., Syktus, J. I., 1992. Climate modes of the Phanerozoic. Cambridge University Press, Cambridge, 274 p.

Forster, A., Schouten, S., Moriya, K., Wilson, P. A., Sinninghe Damsté, J. S., 2007. Tropical warming and intermittent cooling during the Cenomanian/Turonian oceanic anoxic event 2: Sea surface temperature records from the equatorial Atlantic. Paleoceanography 22, PA1219, doi:10.1029/2006PA001349.

Haq, B. U., Hardenbol, J., Vail, P. R., 1987. Chronology of fluctuating sea levels since the Triassic. Science 235, 1156–1167.

Huber, B.T., Leckie, R.M., Norris, R.D., Bralower, T.J., and E. CoBabe, 1999, Foraminiferal assemblage and stable isotopic change across the Cenomanian-Turonian boundary in the subtropical North Atlantic, Jour. Foram. Res., 29, 392-417.

Kerr, A. C., 1998. Oceanic plateau formation: a cause of mass extinction and black shale deposition around the Cenomanian–Turonian boundary. Journal of Geological Society, London 155, 619–626.

Kuroda, J., Ogawa, O. N., Tanimizu, M., Coffin, M. F., Tokuyama, H., Kitazato, H., Ohkouchi, N., 2007. Contemporaneous massive subaerial volcanism and late Cretaceous Oceanic Anoxic Event 2. Earth and Planetary Science Letters 256, 211–223.

Leckie, R. M., Yuretich, R. F., West, O. L. O., Finkelstein, D., Schmidt, M., 1998. Paleoceanography of the southwestern Western Interior Sea during the time of the Cenomanian-Turonian boundary (Late Cretaceous). In: Dean, W. E., Arthur, M. A. (Eds.), Stratigraphy and Paleoenvironments of the Cretaceous Western Interior Seaway, USA, Concepts in Sedimentology and Paleontology. Vol. 6, Soc. Sediment. Geol., Tulsa, Okla, pp. 101–126.

Leckie, R. M., Bralower, T. J., Cashman, R., 2002. Oceanic anoxia events and plankton evolution; biotic response to tectonic forcing during the mid-Cretaceous. Paleoceanography 17 (10.1029/2001PA000623).

Miller, K. G., E. Barrera, R. K. Olsson, P. J. Sugarman and S. M. Savin. 1999. Does ice drive early Maastrichtian eustasy? *Geology* 27: 783-786.

Miller, K. G., Kominz, M. A., Browning, J. V., Wright, J. D., Mountain, G. S., Katz, M. E., Sugarman, P. J., Cramer, B. S., Christie-Blick, N., Pekar, S. F., 2005. The Phanerozoic record of global sea-level change. Science 310, 1293–1298.

Müller, R. D., SSdrolias, M., Gaina, C., Steinberger, B., Heine, C., 2008. Long-term sea-level fluctuations driven by ocean basin dynamics. Science, 319, 1357-1362.

Orth, C. J., Attrep, M., Quintana, L. R., Elder, W. P., Kauffman, E. G., Diner, R., Villamil, T., 1993. Elemental abundance anomalies in the late Cenomanian extinction interval: A search for the source(s). Earth and Planetary Science Letters 117, 189–204.

Sinton, C. W., Duncan, R. A., 1997. Potential links between ocean plateau volcanism and global ocean anoxia at the Cenomanian–Turonian boundary. Economic Geology 92, 836–842.

Snow, L. J., Duncan, R. A., Bralower, T. J., 2005. Trace element abundances in the Rock Canyon Anticline, Pueblo, Colorado, marine sedimentary section and their relationship to Caribbean plateau construction and oxygen anoxic event 2. Paleoceanography 20, PA3005, doi:10.1029/2004PA001093.

Skelton, P. W., Spicer, R. A., Kelley, S. P. and Gilmour, L. 2003. *The Cretaceous World*. Cambridge University Press, Cambridge, 360p.

Tarduno, J. A., Brinkman, D. B., Renne, P. R., Cottrell, R. D., Scher H., Castillo, P., 1998. Evidence for extreme climatic warmth from the Late Cretaceous Arctic vertebrates. Science 282, 2241–2244.

Wanger, T., Herrle, J. O., Sinninghe Damestè, Schouten, S., Stüsser, I., Hofmann, P., 2008. Rapid warming and salinity changes of Cretaceous surface waters in the subtropical North Atlantic. Geology, 36, 203-206.

Weissert, H. and E. Erba. 2004. Volcanism, CO_2 and palaeoclimate: a Late Jurassic–Early Cretaceous carbon and oxygen isotope record. *Journal of Geological Society, London* 161: 695-702.

Wilson, P. A. and Norris, R. D., 2001, Warm tropical ocean surface and global anoxia during the mid-Cretaceous period, Nature, 412, 425-429.

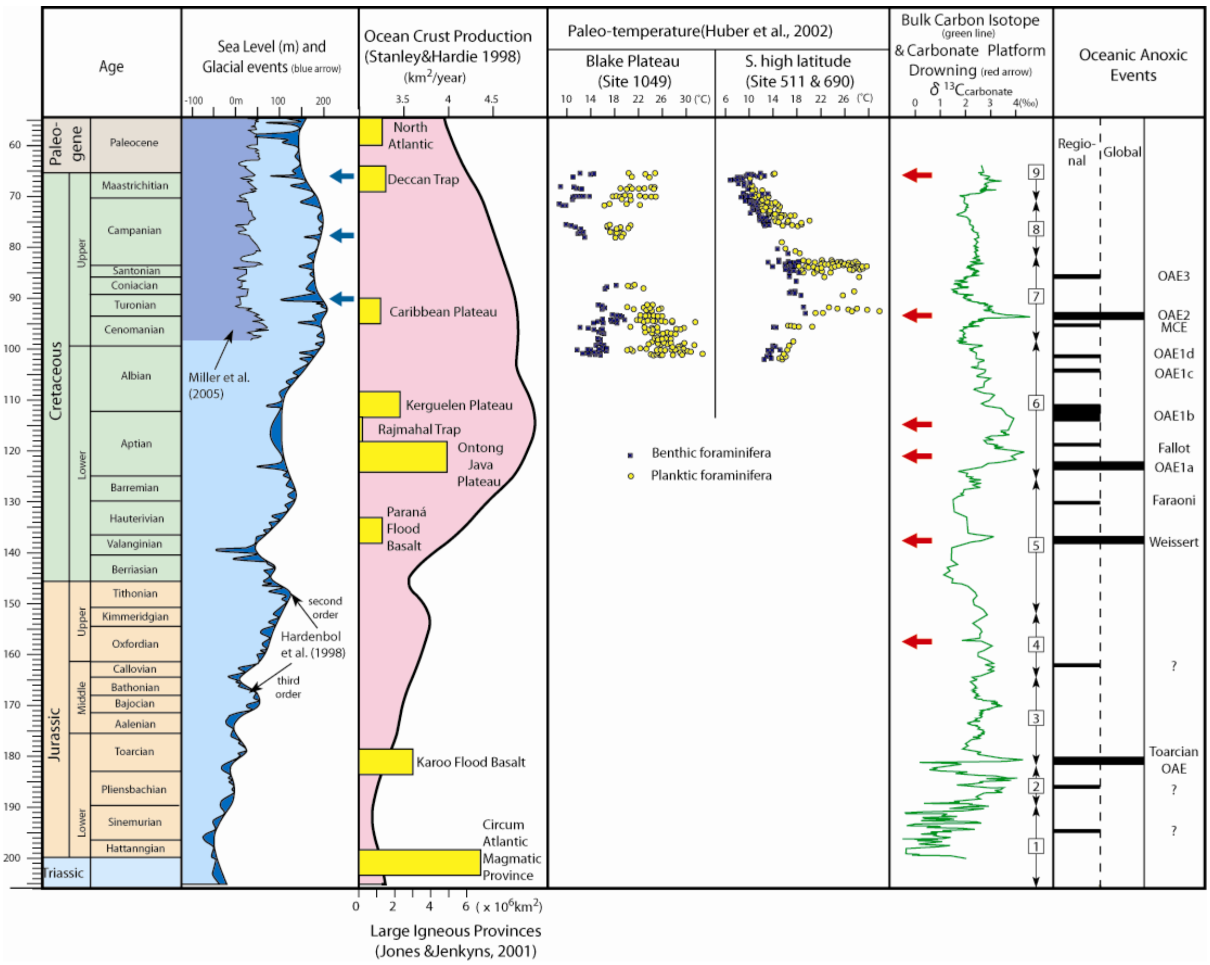

Figure 1. Compilation showing Jurassic–Cretaceous changes in sea level, ocean crust production, paleo-temperature, bulk carbon isotopes, carbonate platform drowning events and OAEs.