Marine carbon cycle during the Late Paleocene thermal maximum

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An abrupt climate warming occurred at the end of the Paleocene (55.5 Ma). This is known as the Late Paleocene thermal maximum (LPTM). At that time, temperature of deep water and high-latitude surface water increased by 4 to 8 degrees within 10,000 years, which is estimated from excursion (-2 to -3 per mill) of oxygen isotope composition of benthic foraminifera of all oceans and planktonic foraminifera of high-latitude surface oceans. Carbon isotope composition also shows an abrupt negative excursion. In addition to the excursion, carbon isotope record shows some interesting features. A difference between the carbon isotope composition of surface and deep ocean becomes smaller during the carbon isotope excursion, and, the carbon isotope composition after the excursion becomes stable at a slightly lower level than that before the excursion. These features suggest that the carbon cycle must have changed during LPTM.

To explain the climate warming and the carbon isotope excursion, the hydrate dissociation hypothesis is proposed by Dickens et al. (1995). In this hypothesis, dissociation of large quantities of methane hydrate occurred, and CH4 and/or CO2 with a carbon isotope composition of -60 per mill was released to the ocean-atmosphere system, which caused the warming and the carbon isotope excursion. This hypothesis, however, doesn't provide explanations to other features of the carbon isotope record described above.

In this study, we try to reconstruct change of the marine carbon cycle during LPTM by using a one-dimensional marine carbon cycle model and the carbon isotope record.

The productivity of organic carbon and the global mean upwelling rate rapidly increase at the carbon isotope excursion event. This is because the value of carbon isotope composition of the surface water at the carbon isotope excursion is, at most, about 0 per mill whereas the input flux of hydrate has the carbon isotope composition of -60 per mill, a large quantity of light carbon should be removed from the surface water as particulate organic matter. Therefore, the productivity of organic carbon should increase. The upwelling rate should increase in order to decrease the difference between the carbon isotope composition of the surface and the deep water as observed at the carbon isotope excursion event. These results may be interpreted as follows: the climate warming affects the ocean circulation, intensity of vertical water-mixing increases, nutrients are supplied to the surface water from the middle and the deep waters, and so the productivity increases.

The carbon isotope composition after the excursion becomes stable at a level of 1 per mill lower than that before the excursion. The lower carbon isotope composition is usually interpreted as a lower productivity of organic carbon. However, this study shows that both the productivity and the upwelling rate do not change greatly between the time before and after the carbon isotope excursion event. The lower level of the carbon isotope composition after the excursion event may reflect a large quantity of light carbon remained in the ocean because of the input of the large amount of light carbon to the ocean and the decrease of the productivity just after the excursion event.